Precision Livestock Farming '05

Edited by
S. Cox

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JTI - Swedish Institute of Agricultural and Environmental Engineering

SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES

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Editorial

My Editorial for the first ECPLF, in Berlin, 2003, emphasised the common aims of the ECPA and ECPLF meetings. It outlined their similar goals, with special reference to traceability of food sources and control of process quality in food production, as well as their common scientific principles and methodology in the context of process engineering. It also emphasised the inevitable overlap of areas of interest in the two meetings, which centre on animal food production. Indeed, it is interesting to note that of the seven joint programme themes for 5ECPA and 2ECPLF, listed in the First Newsletter and Call for papers, only horticulture and viticulture could be described as marginal to 2ECPLF. Other general points common to both Conferences were that the outlook of farmers must be considered and that Conferences should focus on practical techniques, discussed in a "cross-disciplinary atmosphere", by people with a wide range of specialisations.

Overall, it is clear that the joint ECPA/ECPLF Conferences have a distinctive and valuable role, focusing on practicable developments essential to an industry which must supply products to meet steadily increasing standards for food quality, animal welfare and environmental "friendliness".

In the above context, I have been greatly encouraged by the number, range and content of the papers accepted for publication in these Proceedings. The increased page allowance per paper has undoubtedly been beneficial, while the number of accepted papers has increased substantially, compared with 1ECPLF.

Three authoritative Keynote papers cover subjects of interest to both Conferences. Two relate to developments in sensors, while the third introduces the concept of Integrated Management Systems (IMS), based on automatic monitoring of processes.

Overall, the contents of these Proceedings provide encouraging evidence of a widening and deepening of research, development and evaluation of the underlying concepts of Precision Agriculture (defined as measurement and management of spatial and temporal variability) to the vast and diverse world of livestock production. The prospects for further developments are manifold.

Sidney Cox
Editor

Keynotes

Field effect transistors in precision agriculture

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Abstract

The development of field effect transistor (FET) based sensors for the detection of ionic species in solution is described. This development started about 35 years ago with the invention of the ion-sensitive field effect transistor (ISFET) for the detection of solution pH. Later chemically sensitive field effect transistors (CHEMFETs) have been developed for the detection of many different cations and anions. The first CHEMFETs were based on ion-selective membranes deposited physically on the gate oxide of an ISFET. More durable CHEMFETs were made by linking all membrane components covalently. Applications of field effect based sensors are discussed. The possibilities of a new generation of sensors, based on hybrid organic semiconductor field effect transistors (HOSFETs) are described.

Keywords: sensor, pH, nutrient, hybrid organic semiconductor field effect transistor, potentiometry, surface modification, organic monolayer

Introduction

Precision agriculture is a farm management strategy based on sensing, positioning and information technology, which may contribute to further optimize soil and crop quality, production levels, sustainability, food safety and farm profitability (Robert, 2002). Currently, the ability to obtain soil analysis in a rapid and cheap way is a big challenge for precision agriculture (Birrell and Hummel, 2000).

Different sensors to monitor soil properties are available. To register salinity, moisture and pH electrical conductance sensors are applied. The presence of clay particles, of organics and also of moisture can be detected using optical sensors. Mechanical sensors are able to measure soil resistance. Electrochemical sensors can measure pH and soil nutrients levels, and airflow sensors are able to detect various soil types (Adamchuk *et al*., 2004).

This contribution will focus on the use of field effect transistor based electrochemical sensors to monitor quantitatively different chemical species, especially protons (pH) and several nutrients (potassium, nitrate, ammonium, calcium, ...).

Field effect transistors

The most widely applied field effect transistor is the so called metal oxide semiconductor field effect transistor (MOSFET). In such a transistor an oxide insulator is sandwiched between the metal gate and the semiconductor. This transistor can be found in almost every micro-electronic device today, where it operates as a binary switch.

It was Piet Bergveld in 1970, who got the idea to remove the metal layer from a MOSFET and to expose the underlying silicon dioxide insulator directly to a sample solution (Bergveld, 1970). He was able to detect with this ion-sensitive field effect transistor (ISFET) changes in the pH of the solution. Later it was recognized that a reference electrode is necessary for the proper functioning of an ISFET as a pH sensor. Many publications have appeared on ISFETs and related devices like the EnzymeFETs and ImmunoFETS. Recently, two nicely written papers have appeared, one from

Bergveld (Bergveld, 2003) and the other from Janata (Janata, 2004), giving their personal views after 30 years of research on FET based sensors. In these papers it is remarked that commercialization of these ISFETs and CHEMFETs (Chemically sensitive FETs) is unfortunately not very successful. Probably the encountered problems regarding biocompatibility, which is very important for the anticipated biomedical applications, has contributed to stop further industrial developments (Bergveld, 2003). However, successful commercialization of ISFETs is foreseen in those application areas, where the vulnerability of using glass electrodes is a serious problem.

Ion-sensitive field effect transistors

An ISFET is a solid state sensor able to detect protons (pH) in a potentiometric way. A schematic representation of the set-up of a pH measurement using an ISFET is shown in Figure 1. The sensor area exposed to the sample solution is the gate oxide. Often thermally grown silicon dioxide of thickness of ca. 100 nm is used. The gate oxide covers the channel of the p-doped (boron) silicon semiconductor. The channel is located between the n-doped (phosphorus) source and drain regions. Doping of silicon influences its semi conducting properties. Since boron possesses one valency electron less than silicon the material becomes positively doped (p-doped). These 'holes' contribute to the conductivity. Similarly, the material becomes negatively doped (n-doped) by the addition of phosphorus atoms, which do possess one valency electron more than silicon. In that case 'electrons' contribute to the conductivity. By making a structure in silicon of subsequently n-doped/p-doped/n-doped (i.e. source/channel/drain), a so called diode is obtained. If the source and drain are connected to an external voltage source (V_{ds}), no current will flow (I_d=0), since the junction between p-doped silicon and n-doped silicon acts as an electron barrier. The 'holes' cannot move into the region where 'electrons' are the charge transporting species. However, this barrier is sensitive to a voltage V_{gs} applied on the reference electrode with respect to the bulk of the p-doped silicon material. If a positive voltage is applied to the reference electrode a process starts by which the channel (the region between source and drain just below the silicon dioxide insulator) becomes depleted in positive charge carriers ('holes'). At a certain voltage, the so called threshold voltage, charge inversion in the channel occurs. The 'holes' are repelled from the junction and the 'electrons' are attracted to the junction. Under these conditions, the channel behaves like n-doped silicon, the conductivity barrier is absent, and an electron current from source to drain starts to flow. Under these conditions, field effect based sensors generally operate. Further increase of V_{gs} results in an additional increase of I_d. From this picture it is easily recognized that MOSFETs act as a binary switch and/or as an electronic amplifier. If V_{gs} is below V_t no current flows and the switch

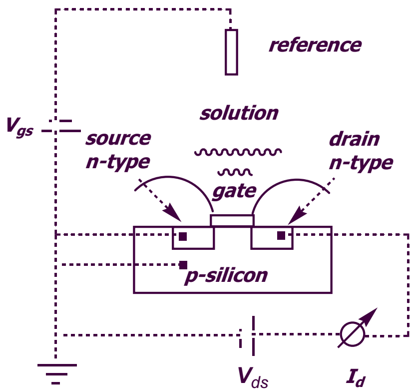

Figure 1. Schematic representation of an ISFET set-up.

is ‘off’. If V_{gs} is above V_t a current will flow and the switch is ‘on’. Since the source-drain current I_d is the result of the changing gate-source voltage, and the current flowing through the insulator will be very low, it is seen that the ratio of these two currents is the mentioned amplification.
Typical gate areas are 15 x 500 µm (width x length; width is the distance between source and drain). The drain-source current (I_d) at a certain drain-source voltage (V_{ds}) is tuned by the gate-source voltage (V_{gs}). Source and bulk are shortcut with the ground.
As said, if the voltage applied to the reference electrode V_{gs} is above the threshold voltage V_t of the semiconductor, an inversion from p to n occurs in the channel region close to the interface with the silicon dioxide insulator, and a current I_d starts to flow. This current I_d can now be modulated by chemical interactions at the silicon dioxide interface with the solution. In most experimental set-ups not the change of source-drain current I_d is measured as a function of changing sample composition, but V_{gs} is adapted in such a way that the source-drain current I_d is kept constant at a fixed V_{ds}. The change of V_{gs} is then registered. This change of V_{gs} compensates the potential change at the insulator interface with the sample solution, which is a direct consequence of the chemical interactions at the interface.
ISFETs have shown many benefits, like for instance their small dimensions (individual chips are typically 3 x 4.5 mm), their fast response time on changes in the sample solution, their robustness due to the all-solid state set-up, their high signal-to-noise ratio, and the low output impedance due to the in situ impedance transformation, which makes the electrical output signal less sensitive for external disturbances. In addition, the ISFETs have the possibilities for subsequent integration with other electronic functions. And last but not least, ISFETs can be stored under dry conditions.
The selectivity and sensitivity of ISFETs is determined by chemical interactions occurring at the insulator-solution interface. If the insulator is made of silicon dioxide we will find silanol groups (Si-OH) at the surface. The surface density of silanol groups is about 5 nm^{-2} = 5 x 10^{14} cm^{-2}. The surface silanol groups are amphoteric in character. That means that depending on the pH of the solution, the silanol groups are positively charged due to protonation ($Si\text{-}OH_2^+$; pK_{a1}=-2), neutral (Si-OH), or negatively charged due to dissociation ($Si\text{-}O^-$; pK_{a2}=6). This change in surface charge density directly modulates the field effect transistor, as described above. Theoretical models have been developed to simulate the surface charge as a function of solution pH, pK_{a1} and pK_{a2} values, and surface density of silanol groups. The calculated surface charge density σ (Coulomb/cm^2) is related to a surface potential φ (Volt) by the well known relation $\sigma/C_{eq} = \varphi$, where C_{eq} is the equivalent double layer capacity. Often a value of C_{eq} = 20 mF/cm^2 is taken in the simulations. In the ideal case the increase in surface potential with concentration of protons in solution is given by the Nernst equation and amounts 59 mV/pH unit. For silicon dioxide gate insulators a smaller value of ca 45 mV/pH unit is experimentally observed. The origin of this deviation is probably caused by the approximation of the surface of silanol groups as a simple sheet, rather than by a more realistic but also more complex hydrated gel layer (Sandifer, 1988). The best experimental results for pH sensing have been obtained using silicon(oxy)nitride as the insulator gate material. This material shows a perfect passivation of the semiconductor and has a stable and reproducible pH response.

Chemically sensitive field effect transistors

Field effect transistors sensitive for other ionic species than protons (H^+) have been made by depositing ion-selective membranes on top of the gate oxide. The ion selectivity comes from the presence of ionophores in the membrane. Generally such membranes are made from plasticized poly(vinylchloride) (PVC), often with the addition of lipophilic ions, having a charge opposite to the charge of the ion to be detected. In essence such membranes are ion-exchanging. If the lipophilic ion is an anion, for instance tetra phenyl borate, the membrane exchanges cations. The selectivity for a certain cation is determined by the partitioning of the cation between solution and membrane. Selective complex formation between cation and ionophore in the membrane finally determines the membrane selectivity. The cation that is selectively exchanged with the membrane is called potential-determining. Such membranes can be seen as buffers for the potential-determining cations. The ionophores bind a certain amount of cations, which are in equilibrium with unbound cations in the membrane. These unbound cations equilibrate to the solution phase. As long as the unbound cation concentration in the membrane is fixed, also the free cation concentration in solution near the membrane interface is fixed. An electro-chemical equilibrium now exists between the cations in solution near the membrane interface and the cations in the bulk solution. This determines the surface potential at the membrane solution interface. This membrane surface potential modulates the source-drain current I_d of the semiconductor in a way similar to the pH sensitive ISFETs. Many different ionophores have been investigated successfully and are described in literature. Therefore, a wide variety of CHEMFETs for the detection of cations and anions does exist.

In order to increase the mechanical stability of the deposited ion-selective membranes a lot of research has been performed on the covalent binding of the membrane and its components (Lugtenburg *et al*., 1998). To prevent dissolution of the plasticizer to the aqueous phase, intrinsically 'plastic' poly(siloxanes) have been used. Durable membranes for the selective detection of sodium (Na^+), potassium (K^+) and lead (Pb^{2+}) ions have been made. These ion-selective membranes are not coupled directly to the gate oxide, but are coupled to an intermediate poly(hydroxyethylmethacrylate) hydro gel layer (polyHEMA) covering the gate. This hydro gel layer contains a buffer and a certain concentration of the ion to be detected (Sudhölter *et al*., 1990; van der Wal *et al*., 1990). Such a hydro-gel layer contributes to a much better electrical tuning of the CHEMFETs, it prevents an undesired potentiometric response due to carbon dioxide (CO_2) diffusing through the membrane, and it fixes the interfacial potentials between membrane and hydro gel and between hydro gel and semiconductor in a controllable way (Sudhölter *et al*., 1990; van der Wal *et al*., 1990). The necessity of using an intermediate hydro gel layer for the fixation of electronic junctions was disputed later (Janata and Josowicz, 1998).

In contrast to the ISFETs, most membrane modified CHEMFETs are less robust. Mechanical force can disrupt the membrane and also differences in the osmolality between the sample solution and hydro gel layer, may cause drift and mechanical disruption of the membrane. Therefore, CHEMFETs have to be used preferably not in direct contact with the sample solution, but in a more controlled way. A possible way is to incorporate CHEMFETs in a flow injection system (van der Wal *et al*., 1991). The composition of the background solution flowing along the CHEMFETs can be controlled with respect to osmolality and ionic composition. By injection of small volumes of sample solution in the flow, only a plug of sample solution comes during a short time interval in contact with the membrane surface. At that moment the unknown sample solution is measured. After that contact the original solution composition is restored. Possible surface contamination is flushed away easily. Application of CHEMFETs in a flow injection system has more benefits. In situ calibration can easily be performed by application of injecting volumes of known composition. Also the problem of a reference electrode can be eliminated by performing a differential measurement using two CHEMFETs with different selectivities and a common metallic contact to the solution.

Hybrid organic semiconductor field effect transistors

In Wageningen we are working on a new type of FET-based sensors for the detection of ionic species and biomolecules. These are called hybrid organic semiconductor field effect transistors (HOSFETs). In a HOSFET both the metal and insulating oxide layer have been replaced by a functionalized organic monolayer. The organic hydrocarbon tail acts as the insulator, replacing the oxide, and the terminal functional group introduces the sensitivity and selectivity. Different functional groups can be chosen. For instance, carboxylic groups (-COOH) or amino groups (-NH_2) will introduce pH sensitivity, quaternary ammonium groups (-NR_4^+) will introduce anion sensitivity. Also more complex (bio)receptor molecules can be bound covalently to the terminal end of the monolayer. As an example are given crown ethers and calixarenes to introduce cation selectivity. So far, our research has focused primarily on the coupling of the monolayers to the silicon surface and the properties of the monolayer. A detailed electrical characterization of the bound monolayer will be described elsewhere (Faber *et al*., 2005).

The surface modification of silicon to covalently bound organic monolayers proceeds according to the next steps. First, the silicon substrate is etched to remove the present oxide layer. This results in the formation of hydrogen-terminated silicon (Si-H), which reacts subsequently with alkenes under thermal conditions to alkyl modified silicon (Sieval *et al*., 1998). A mechanism is proposed in which the Si-H bond is disrupted homolytically giving surface Si• radicals. Such a radical site reacts with the terminal double bond giving a new stable silicon-carbon bond between the surface silicon atom

and the terminal carbon atom of the alkene. The radical is now situated at the β-carbon atom and is in a position to capture a hydrogen radical from a neighboring surface Si-H site. In this way the radical process proceeds along the surface. Highly ordered and solid-like organic monolayers are formed. The organic monolayers show a very good passivation of the silicon substrate (Sieval *et al*., 2003). The method also works well in the presence of a solvent (Sieval *et al*., 1999) and with alkynes (Sieval *et al*., 2000) as the reagent. An illustration of the reaction is given in Figure 2.

Recently, the method has been applied successfully to couple carbohydrates bio receptor molecules to silicon surfaces (de Smet *et al*., 2003). The coupling of organic monolayers by using photochemical methods is also possible (Sun *et al*., 2004). This is very important not only in relation for the successful coupling of thermally labile biomolecules, but also it offers a nice possibility to pattern silicon surfaces with different bio receptor molecules. We have found that the thermal method also works on silicon(oxy)nitride (Arafat *et al*., 2004) surfaces.

We expect that HOSFETs will have a bright prospect for near future sensing applications. The method for introducing (bio)chemical functionality is rather simple and can be performed under mild conditions. The replacement of the silicon oxide insulating layer with an organic monolayer will contribute to more stable and better functioning field effect transistors.

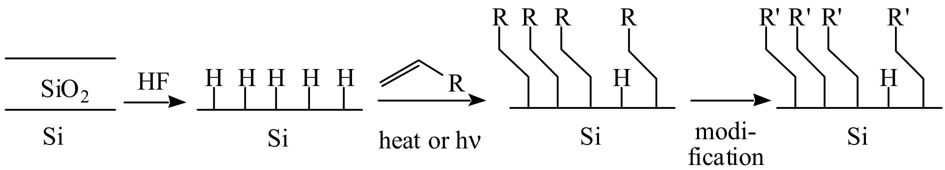

Figure 2. Covalent attachment of organic monolayers to silicon surfaces and subsequent fictionalization.

Applications of field effect transistors in precision farming

For monitoring pH values the ISFETs having a silicon(oxy)nitride gate show a sensitive, stable and reproducible response. Especially under harsh conditions, these sensors perform better than the conventional glass electrodes. These ISFETs are not only applied for the monitoring of pH in meat and milk, but are also useful for pH monitoring in soil, manure, horticulture and of drainage water. Monitoring of different nutrients (K^+, Ca^{2+}, NO_3^-,) is possible by a range of existing CHEMFETs (Artigas *et al*., 2001). These sensors are however vulnerable to mechanical damage, due to the presence of the ion-selective membrane. Use of these CHEMFETs in a flow system under well controlled conditions is therefore strongly recommended. These CHEMFETs have been applied for the monitoring of nitrate and ammonium in soil samples. Often, the soil samples are first filtered and extracted with water, and subsequently the extract in analyzed using a CHEMFET.

The HOSFETs are expected to become promising candidates for near future monitoring of nutrients and different biomolecules. Besides the mentioned benefits of ISFETs in comparison with conventional ion-selective electrodes (ISEs), HOSFETs have some additional benefits. Due to the absence of an inorganic insulating layer, drift as a result of ion migration in the insulator is also absent. In some way HOSFETs resemble ISFETs, because the different (bio)chemical receptors in HOSFETs are located at the surface of the insulating organic monolayer, like the pH sensitive silanol groups are located at the surface of the inorganic insulator. A junction between ion-selective membrane and insulator as in CHEMFETs is not present in the HOSFETs. Chemically and biochemically-sensitive layers can be introduced in a rather simple way. Using photo patterning, arrays of many different receptor molecules can be made on a single chip. Such a multi-array sensor can be integrated with micro channel devices for sample pretreatments (filtering, pre concentration) and in situ calibration and also integrated with other electronic functionalities.

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A review of spectroscopic methods and their suitability as analytical techniques for farm testing

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Abstract

This presentation describes the potential use of near- and mid-infrared sensors as analytical tools for real-time measurements on farms. The technology has been used at laboratory level for many decades and is accepted today as an official method for the determination of the composition of agricultural and dairy products. The application of infrared spectroscopy for quantitative measurements started in the agricultural and dairy industries. Since then, the technique has been used in various industrial fields (pharmaceutical, chemical etc.). The simplicity of this technology makes it well suited as a farm analytical tool. The methods are fast and little or no sample treatments or chemical reagents are required. It is outlined that on-farm sensors must be very robust, easy to operate and also rather inexpensive. Many obstacles remain to be solved before the method fulfils the most critical demands for an on-farm sensor.

Keywords: mid- and near-infrared, MIR, NIR, NIT, accuracy, on-farm

Introduction

With increasing demands on quality assurance, cost efficient and high quality production, the requirements for sensors in the production chain from “field to table” have increased tremendously. Process and production control today require sensors to be placed as closely as possible to the process and production lines such as in-line, on-line, at-line, in-field, on-farm, on-harvester, etc. Furthermore, the industry asks for process analytical tools (PAT) to improve the process quality and production speed thereby reducing the production cost. The target is to make the measurements in real-time (in-line, on-line) or in the proximity to the process (at-line).
Various technologies are already used as real-time sensors for measurements of temperature, refractive index, conductivity, pH, etc. Infrared sensors are found everywhere in the form of remote controls, motion detectors, infrared pyrometers and cameras, etc. However, the more sophisticated quantitative techniques of near-infrared and mid-infrared spectroscopy have also exhibited the potential to function as process sensors for real time measurements. These types of process analytical tools are proliferating. The development towards process spectroscopy is estimated to have an annual growth rate of 5.4% from $178 million, with near-infrared monitors expected to be the largest segment of the market according to Business Communications Company (www.bccresearch.com/editors/RG-228R.html).
The analytical methods, near-infrared (NIR) and mid-infrared (MIR) spectroscopy, have been used in the agricultural, food, dairy, and chemical industry for several decades and are today official laboratory methods. The main advantages of these methods are that they are fast, need little or no sample treatments and no chemical reagents. Furthermore, it is possible to measure multiple parameters simultaneously. The disadvantage, however, is that calibration, and particularly the stability of the calibration, needs frequent checks or recalibrations. There are differences between NIR and MIR technologies in calibration principles for quantitative measurements. For instance, the MIR milk analyzers have a less complicated calibration system. In a laboratory environment, calibration can be done relatively easily due to the availability of control and calibration samples.

Using the same technique in-field or on-farm implies that the demands are much higher regarding the instrument specification. Analytical instruments to be used on farm must be very robust, inexpensive, easy to operate, easy to check and calibrate, and the most important factor for in-field or on-farm analytical equipment is that the reproducibility over time must be very high.
So, is it worthwhile to invest in these types of instrumentation for on-farm analyses? The aim of this article is to give some background to the development of techniques, discuss the requirements on the specifications and give some examples where the spectroscopic methods have been a success.

Measurement methods

Mid-infrared

J.D.S. Goulden did the pioneer work on spectroscopic analyzers for milk in the 1960s (Goulden, 1961; Goulden, 1964). Since then, mid-infrared transmission spectroscopy has been used routinely for milk analyses. Today approximately 600 million milk samples per year are analyzed worldwide with this technology. The results of the milk analyses are used for milk payment, animal breeding and management purposes. At the speed of 600 samples per hour, 5-10 milk components can be determined simultaneously.
The first semi-automatic MIR milk analyzer, IRMA, was a scanning monochromatic instrument with a distance of nine metres between light source and detector (Grubb Parsons, Newcastle-upon-Tyne, UK). Today the distance is only a few millimetres. The introduction of interference filters stimulated the milk analyzer instrument market to expansion, and the instruments were used for the measurement of individual cow milk samples as well as milk samples for payment (Sjaunja, 1982). The dominating laboratory instruments for milk analyses in use today are either dispersive spectroscopy with transmission interference filters with liquid cells or Fourier-Transform mid-infrared transmission spectroscopy with liquid cells. The latest development is that these instruments can also analyse solid products, if the products are converted to a liquid suspension/emulsion. In a comprehensive study of cheese analyses between NIR (FoodScan, Foss-Electric, Denmark) and MIR (FT120, Foss Electric, Denmark), the overall accuracy was found to be superior for the MIR principle (Malmström, 2005).
The MIR spectroscopy milk analyzers are extremely accurate <1% (CV-coefficient of variation) over a broad compositional range. It implies that a milk component is measured with a 95% confidence level within ± 0.08 percentage units. The reproducibility over time (hour, day, and week) is also very high. The commercial mid-infrared instruments used for milk or dairy products are checked for variations in temperature, humidity, light-scattering and base-line drift by using temperature-controlled cells, vapour-sealed compartments as well as built-in homogenizers. The baseline level is automatically or manually calibrated with distilled water or chemical solutions at various time intervals. In the mid-infrared spectrum, fundamental vibrations are associated with different functional chemical groups, which are directly correlated to fat, protein and lactose etc. (Biggs *et al.,* 1987). For example, only three wavebands are needed to measure the levels of fat, protein, lactose and total solids in milk. On the market today, there are commercial food and milk analyzers with both waveband selector (interference cells) and Fourier transform infrared (FTIR) for measuring transmission in liquid cells.
Mid-infrared spectroscopy uses the 2500-50000 nm (4000-200 cm^{-1}) bands in the electromagnetic radiation region. MIR transmission spectroscopy of milk uses the 2500-10000 nm (4000-1000 cm^{-1}) bands, due to the material of the windows in the cuvette. In the MIR electromagnetic region, fundamental stretching vibrations are associated with functional groups in organic molecules. The wavebands are more intense and narrow than in the NIR region. The theory of fundamental vibrations can be found in handbooks (e.g. Shurval, 2002) and more specific theories of

components in food and dairy products in (Li-Chan *et al.*, 2002). The effect of scattering is that the radiation is reduced when the particle size is less than the wavelength. This is one of the advantages of using MIR spectroscopy for milk analysis, since the diameter of fat globules in unhomogenized milk is only in the region of 1000 to 10000 nm. Homogenization of milk will reduce the scattering in the MIR region and, therefore, the commercial laboratory milk analyzers have built-in homogenizers. In the NIR region (780 to 2500 nm), the homogenization will increase the amount of scattering centres and the diffuse reflection will increase. Variation in particle size causes more interference in the NIR region than in the MIR region. This might be one reason why NIR spectroscopy has not shown the same analytical accuracy as MIR spectroscopy for milk. In addition, MIR spectroscopy has the potential of measuring minor components in milk and other liquids, such as citric acid, urea, lactic acid etc, which has not been proven to be possible with NIR. Recently, promising results have been obtained in the analysis of silage juice for lactate, ethanol, 2-3-butanediol, sugars, ammonia, amino acids, etc. (Udén, unpublished). Also, other applications to animal nutrition research are presently under investigation at the Kungsängen Research Centre, SLU in Uppsala, Sweden.

Near-infrared

Near-infrared reflectance spectroscopy for agricultural applications was exploited for commercial purposes after Norris published two pioneering works in the early 1960s (Norris and Butler, 1961; Norris, 1964). Since then, the application of NIR spectroscopy has achieved an enormous breakthrough in different industrial fields (pharmaceutical, food, chemistry etc.). However, as early as 1957, J.D.S. Goulden published a work using diffuse reflectance of dairy products (dried milk products and butter) in the near infrared spectra (Goulden, 1957). The technique is approved as an official method for different agriculture products. The rapid developments in electronics, computers, and statistical (chemometric) methods have contributed to the development of the spectroscopic instruments. However, all these improvements have not dramatically improved the accuracy. For example, the accuracy for protein in grains is still about 2% (CV %), (www.usda.org/gipsa), which is similar to what was published in earlier studies. The USDA's accuracy validation was performed on a very comprehensive material. On average, a CV of about 2% implies that with a 95% confidence level the results are within ± 0.5 percentage units for protein contents of about 12%-units.
Near infrared spectroscopy is, primarily, more suitable for solid agricultural products (grains, forages), while the MIR instruments are most suitable for liquid products (milk, whey, fermented milk, etc.). NIR spectroscopy on milk has been evaluated by Tsenkova *et al.*, (1999), but until today, MIR spectroscopy seems to be superior for milk analyses. The only spectroscopy method approved for milk payment purposes is mid-infrared transmission spectroscopy by the AOAC (Association of Official Analytical Chemistry). Earlier, all solid samples needed to be ground or freeze dried, but the introduction of the near-infrared transmission spectroscopy instruments meant that, for example, whole grains could be analyzed directly. The easy sample handling system for the NIR technique is probably the most important reason for its popularity.
Near-infrared spectroscopy is performed between 780-2500 nm (12800-4000 cm^{-1}) in the electromagnetic radiation region. The absorption wavebands are overtones and combinations of fundamental stretching vibrational bands. These overtones are associated with C-H, N-H, O-H and S-H chemical bindings. The bands are more or less overlapped, so different statistical methods are used for quantitative analysis. The bands are broad and the intensity of absorption peaks is weak, compared to fundamental bands in the MIR region. The higher frequency (energy) and lower intensity of absorption in the NIR region results in a deeper sample penetration. That also means that the distance between the windows of the sample device (path length) can be longer <30 mm.

NIR spectroscopy can either be performed as reflectance or transmission spectroscopy. Near-infrared transmission spectroscopy, abbreviated NIT, NITS and also NIRT, usually uses wavebands below 1000 nm (above 10000 cm^{-1}), where the absorption peaks are coming from 2^{nd} and 3^{rd} overtones. Near-infrared reflectance spectroscopy, abbreviated NIR or NIRS, uses wavebands between 1000-2500 nm (below 10000 cm^{-1}). More comprehensive reviews of NIRS theory can be found in Williams and Norris (1987), Osborne *et al.*, (1993), Givens *et al.*, (1997) and Weyer and Lo (2002).
From a technical point of view, the production of NIR instruments is simpler and less expensive than that of MIR instruments because the vital components such as emitters, cell windows and detectors are cheaper. This can also be seen in the market, since there are many more companies producing and selling NIR instruments, while for example, there are only two or three companies producing MIR instruments for milk and food analyses. In the scientific world, the general belief is that mid-infrared spectroscopy is more suitable for identification (structure-correlation spectra) and less for quantification than near-infrared spectroscopy due to, among other things, a low signal-to-noise ratio (Skoog and Leary, 1992). This notion must be seriously questioned, as evaluation studies indicate that quantitative measurements have relative accuracies of about 1% (CV) for MIR spectroscopy compared to about 2% (CV) for near-infrared spectroscopy.

Statistical evaluation

Several organizations such as the International Dairy Federation (IDF), International Organization for Standardization (ISO), Food and Drug Administration (FDA), the European Agency for the Evaluation of Medical Products (EMEA), have their own guidelines for validating and calibrating analytical spectroscopy methods, in which they give definitions and protocols for evaluating different methods. In the US, AOAC (Association of Official Analytical Chemistry) approve which methods fulfil the demands for an official method for different products. In addition, different countries can have their own rules for certification. The definitions differ slightly, depending on analytical methods. For example, in the dairy sector, two standards, the ISO 5725 and IDF 128:1985 standards, define precision (repeatability, reproducibility) and accuracy for determination of milk with mid-infrared spectroscopy.
Repeatability means that the same samples are determined at least in duplicate on the same instrument within a short time interval, while *reproducibility* implies that replicates of the same samples are determined under different conditions (days, laboratories, etc.). *Accuracy* describes how well the evaluated methods perform in relation to “true” or reference values. The accuracy is given as standard deviations between the evaluated method and reference, either as the standard deviation for the difference between the methods or as the standard deviation of the estimated regression line between reference and the tested method. The standard deviations can be given as STD, RMSE (root mean square error), RMSEP (root mean square error of prediction), SEP (standard error of prediction), SEC (standard error of calibration) or SECV (standard error of cross validation). RMSEP and SEP are used as accuracy parameters for validation of the method. These parameters can also be given as relative standard error, namely standard deviation divided by the mean of reference values, and named as CV (coefficient of variation).
It is important to pay attention to the fact that estimates of accuracy include both systematic and random errors. The standard deviation of the regression model is corrected for deviations in the slope parameter not equal to 1. Calibration models estimated by multivariate methods using many (>5) wavebands can easily give an overestimation of the accuracy due to over fitting. Therefore, it is very important that validation of these calibration models is performed on a new, independent set of samples. It is also important to note that standard errors as well as slope and bias parameters can be different depending on which variable is chosen as the dependent or the independent variable.

A method with a relative standard error of prediction CV<1% may be inferior compared to a method with a CV<10%. A judgement of whether or not accuracy is sufficiently good for a specific analytical purpose must be compared to:

- The total variation within the population to be tested.
- Biological variation (day-to-day within cows, within fields, etc.).

The standard error of prediction (SEP) for an analytical method must be less than the standard error of the material to be analyzed, otherwise the accuracy will be higher by guessing that all the single measurements are equal to the mean value of the samples. The estimated accuracy between the guessed results and reference values will be equal to the standard error of the tested samples. Therefore, a method validation must be performed on a similar population for which the method is targeted. In many publications, the validation data is based on samples with a very broad range. For example, by including samples with very high or low concentrations, the coefficient of correlation (r) or determination (R^2) will automatically be higher than for a narrow range. The SEP parameter must therefore always be compared with the total variation within a product, field, herd etc., when judging the suitability of a method for process control, payment purposes, ranking ability etc. In the cheese industry, the controls are often performed within classes of fat in dry matter (30+, 45+, etc.). The variations of fat content within each class are very small and therefore there is a need for a method with very high accuracy to be able to rank the fat content of different types of cheese production within each class of fat in the dry matter.

Calibration methods

Calibration of spectroscopy methods can be achieved by different statistical methods, such as multiple linear regression (MLR), principal component regression (PCR), partial least squares (PLS), non linear models (NLIN) and artificial neural networks (ANN). NLIN and ANN are similar methods predicting non linear relationships. In the world of spectroscopy there are still different opinions about the best statistical method. All statistical models estimate partial coefficients (B_0-B_n) according to:

$$Y_i = B_0 + B_1X_{1i} + B_2X_{2i} + ... + B_nX_{ni}$$

where, Y_i is the reference value of the ith sample, X is the spectral value for each combination of one or more spectral values. The spectral values X can also be of second or higher orders. The near-infrared instruments mainly use PLS or PCR statistical models due to the need for using many spectral wavebands. The PLS and PCR methods give the possibility of predicting a calibration with fewer observations than spectral wavebands. The general belief in the scientific world has been that the chemometric methods (PLS and PCR) are the best methods to be used in all spectroscopy methods. However, the linear equations used in the pioneer work by J.D.S Goulden (Goulden, 1964) are still valid calibration equations for analyzing fat, protein and lactose in milk by mid-infrared transmission spectroscopy. Here, only three wavebands are used, compared to using PLS or PCR models which employ an almost infinite number of wavebands. The only modification of Goulden´s original models has been that the spectral wavebands are now pre-linearized or estimated by non linear models, where spectral transmission wavebands have a logarithmic transformation:

$$Y=B_0+B_1 \log((1-b_2)((\exp(-X)-b2))+...+B_n \log((1-B_{n+1})/(\exp(-X)-B_{n-1}))$$

NIR spectroscopy is very calibration intensive and requires many wavebands and separate calibrations for different classes within , e.g., each grain type as well as between countries. This is perhaps the greatest obstacle for using the method. The USDA grain inspection, packers and stockyards administration (GIPSA) have decided to implement an ANN (artificial neural network) wheat protein calibration on all official near-infrared instruments in May 2005 (www.usda.org). The ANN calibration, as discussed earlier, uses non-linear models, which may be one reason why only one calibration is needed for all classes of wheat. The calibration of MIR milk analyzers is relatively simple, since the original calibration models are usually not changed. The operators only fine-tune the calibration with a bias or a slope factor for best agreement to chemical reference methods. This simplicity is due to temperature-controlled cells, vapour-sealed optical parts and baseline checks with special liquids.

On-farm/in-field instruments

On-farm/in-field instruments demand a totally different level of performance and other specifications compared to instruments used in laboratory environments. Firstly, the instruments are intended to be used by people not trained in laboratory work. The instruments must therefore be uncomplicated and easy to handle. Secondly, the instruments must in some way be self-controlling of, for example, the electronics and the calibrations. The instruments must be very robust and capable of withstanding internal and external interference. In other words, the instruments must have very high reproducibility over time. This is a tremendous challenge for the developers of on-farm, in-field, and on-harvester spectroscopy methods. The on-farm/in-field instruments are more or less miniature laboratory instruments and modified to be more robust against internal and external interference. This has been possible due to technical developments of computers, emitters and detectors.
Today, however, there are only a few companies marketing and selling near/mid- infrared spectroscopy instruments for applications in the agricultural and dairy industry (Analytical Spectral Devices, Inc., USA; NIR Technology Australia, Australia; Zeltec Inc., USA) and mid-infrared spectroscopy on-farm milk analyzers, Farm Milk Analyzer, FMA2001 (MIRIS AB, Sweden).

Near-infrared

The NIT sensor from Zeltec Inc. (Zeltec AccuHarvest) is an example of using a specially designed near-infrared transmission spectroscopy is integrated into a combine harvester. The NIT sensor is small in size and is developed to be resistant against vibrations and other interferences. The agreement between the on-harvester sensor and a laboratory NIR, given as coefficient of variation, was below 3% for protein and moisture content in wheat. The sample variation within a transect was about 8% and 1.5% for protein and moisture, respectively (Taylor *et al*., 2005). The small variation in moisture content of the wheat samples should at least require a method with better accuracy to be able to rank the content within a transect of a field. This method is still undergoing trials and improvements of the sample procedures are expected to increase the long-term stability.

Mid-infrared

The MIR sensor from MIRIS AB (FMA 2001) is a small, robust and simple stand-alone instrument for measurements of milk composition. The FMA 2001 measures fat, protein, lactose, dry matter and energy content in unhomogenized milk. The method has been evaluated in a field test which has given good performance and accuracy results (Svennersten-Sjaunja *et al.*, 2005). The instrument does not need to be calibrated since the calibration is tested with a check solution and adjustments are performed automatically. Each measurement takes 40-60 seconds, depending on the software version. The instrument has been on the market for about one and a half years, mainly on small dairies and milk collecting centres, and has met with very positive response. The same company has also developed an on-line (MIRIS *Onlyzer*) instrument, which measures multiple components in a pipeline every 0.5 seconds. This instrument is not yet commercially available, but preliminary data seem very promising.

Future prospects

The principle of spectroscopy methods with an emitter sending electromagnetic radiation through a sample compartment to a detector without any sample treatment ought, in theory, to be a very suitable technology for on-farm sensors. Sensors within the near- and mid-infrared spectra have the potential to measure the composition and quality of many different products produced on the farms. However, there are several obstacles to overcome. New innovations in telecom, IT, computers, nanotechnology and electronic sciences will, of course be found in future sensors. We can expect that different types of simple and inexpensive sensors will be found on farm. The trend will be towards a decentralization of different types of measurements and the results will be captured by wireless devices into local, as well as, central computers. The two spectroscopy methods (near-infrared and mid-infrared) presented have great potentials to be found in on-farm/in-field sensors, because the analytical principle is suited for in- or on-line systems.

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Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall?

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Abstract

This paper reviews the development of precision livestock farming, PLF, from the view point of the engineer, farm animal and the farmer. It considers the technological principles upon which PLF is based, gives several examples of PLF, considers which livestock processes are suitable for the PLF approach particularly those affecting animal welfare, addresses whether PLF constitutes technology push or market pull, and stresses the need for a prospective bioethical analysis of PLF. We conclude that PLF is an embryonic technology with great promise but one that requires considerable research and development before uptake.

Keywords: animals, welfare, bioethics, health, production, environment

Introduction

Precision livestock farming, PLF, can be defined as the management of livestock farming using the principles and technology of process engineering. It is otherwise known as Integrated Management Systems, IMS, and relies upon automatic monitoring of livestock and related physical processes. PLF treats livestock production as a set of interlinked processes, which act together in a complex network. Processes suitable for the PLF approach include animal growth, the output of milk and eggs, possibly animal health, behaviour and welfare, and the physical environment of a livestock building, such as its thermal micro-environment. To date, attention has focussed upon management of individual processes but it is their interaction that are of such importance and which have not been studied previously.

Figure 1 shows the basis of PLF for biological processes: the same concepts apply to physical processes (Clarke, 1988; Aerts *et al.,* 1998a; 2003c). PLF requires (i) continuous sensing of the process responses (or outputs in the terminology of the process engineer) at an appropriate frequency and scale with information fed back to the process controller; (ii) a compact, mathematical model, which predicts the dynamic responses of each process output to variation of the inputs and can be - and is best - estimated on-line in real time; (iii) a target value or trajectory for each process output, e.g. a behavioural pattern or growth rate; and (iv) actuators and a model-based predictive controller for the process inputs.

The initial application of PLF has been the growth of housed pigs and poultry though, in principle, the PLF approach could be applied to any farmed species, including animals farmed extensively (Frost, 2001). Our strategic premise is that sustainable livestock production requires tight product specifications to be met profitably while adverse environmental impacts are minimised and animal health and welfare promoted. These requirements may conflict and current compromises avoid a

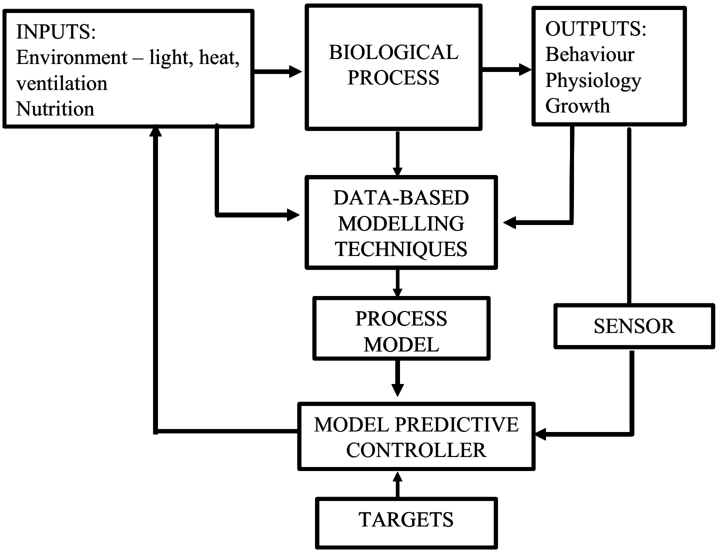


Figure 1. Schematic overview of the key components of PLF to control biological processes, such as animal behaviour, physiology and growth (after Aerts *et al.*, 1998a; 2003c).

long-term solution. What is needed is an integrated system that manages the interlinked biological and physical processes of livestock production. At present, integration of the necessary information and coordinated actions is carried out manually by stockmen. However, within Europe, the supply of stockmen with the necessary management skills is limited and the profit margins of livestock farming are slim. We propose that livestock farming, like manufacturing industries, will have to adopt computer-based methods of process management to overcome these constraints. This, then, is the background against which the developments of precision livestock farming will take place. The opportunities afforded by the introduction of PLF are many but there are historical lessons to be learnt if the promise of PLF is to be realised by the pioneers and not thwarted by technological, ethical or economic barriers. Our paper's title reflects the three groups with interests in PLF and indicates alternative perspectives on the desirability or attractiveness of PLF. For the engineer, application of process engineering principles to livestock production is not necessarily straightforward because of the complex interactions between the component processes, the need for low-cost technology such as sensors, and interpretation of biological responses and their translation into meaningful control inputs. From the animal's perspective, there are questions concerning the instrumental use of animals by overt, active control of the animal's environment or its behaviour, for example. Arguably, such control is no different in principle from passive management as currently practised since the same production goals are met, albeit by a different means. Certainly, control of physiological and behavioural processes poses significant challenges because of our limited understanding of the underlying causal mechanisms. Finally, the socio-economic factors considered by livestock farmers in the adoption of new technology are complex and require careful analysis before - or at least in parallel with - engineering research and development on PLF: the livestock engineer's workshop is littered with inventions that failed at one of the many steps needed for successful commercialisation. Fortunately, there are engineering successes too: mechanical handling of feedstuffs, bedding and excreta and ventilation systems are two examples to guide the PLF pioneers.

The principles of PLF

The inclusion of live animals in the system distinguishes PLF from other applications of modern control theory. From the engineer's perspective, the animal generates the most important process signals, which need to be measured directly and continuously. One way to realise the PLF scheme shown in Figure 1 is by using model predictive control. This does not designate a specific control strategy, but rather a range of control methods which have in common that they use continuous feedback of the process output, as in other control strategies, make an explicit use of a dynamic model of the process to predict the process response, and use this model to calculate the control signal by minimizing an objective function (Clarke, 1988; Soeterboek, 1992; Camacho and Bordons, 1999).

Feedback of animal responses using sensors

Stockmen routinely gather auditory, olfactory and visual information from their animals to evaluate health, welfare and productivity. New technology can aid this task, even with large flocks or herds, thanks to the (r)evolution in sensors and sensing techniques, e.g. developments in micro- and nano-electronics (Frost *et al.,* 1997; Berckmans, 2004).

Low cost cameras, in combination with image analysis techniques, can be used to quantify animal behaviour (De Wet *et al.*, 2003; Leroy *et al.*, 2004) or to estimate the size, shape and weight of farm animals (e.g. pigs: Schofield, 1990; Whittemore and Schofield, 2000; White *et al.*, 2004; broilers: Chedad *et al.,* 2003; De Wet *et al.*, 2003). Sounds produced by animals can be monitored and frequency analysed to assess health status (Van Hirtum and Berckmans, 2004). The advantage of these monitoring systems is that much information can be collected without the stress of animal disturbance or handling (Scott and Moran, 1993; Hamilton *et al.*, 2004).

Sensors can also be used directly on the animal, such as pedometers for monitoring oestrus behaviour in dairy cows (Brehme *et al.*, 2004). Automatic weighing systems for broilers, laying hens and turkeys have been used for a number of years to estimate the average weight of a flock (e.g. Turner *et al.*, 1984; Lokhorst, 1996; Vranken *et al.*, 2004). Telemetry sensors for measuring heart rate, body temperature and activity have been developed, e.g. Mitchell *et al.*, 2004; Laureyn, 2004. Sensors for quantifying milk conductivity and yield of individual cows are available and may be used to optimise production and provide early detection of poor welfare in individuals (de Mol and Ouweltjes, 2001; Kohler and Kaufmann, 2003). The above examples are not exhaustive, but demonstrate the present and future possibilities in feeding back signals from animals as part of integrated livestock management. Recently, these developments have been summarised during the Third Workshop on Smart Sensors in Livestock Monitoring (SMART2004).

Assessment of livestock can be either on an individual or a group basis. For example, the automatic broiler weighing perch, developed by Turner *et al*. (1984) and utilised in the Flockman system (Filmer, 2001), relies on information from individuals. In practical use, a self-selected group of broilers use the perch, biasing the data; a manual correction has to be applied. This can be a general problem in monitoring large herds or flocks and its consequence needs to be assessed statistically where individual measures form the basis for group-level control.

In the future, we predict that the sensors and sensing techniques for monitoring livestock will become readily available, thereby placing the animal at the heart of PLF. However, the availability of low cost, reliable and robust sensors remains the main problem to be solved if PLF is to be applied in the field. More research and development are needed, taking advantage of technologies from other applications where the scale of demand has forced down manufacturing costs, e.g. web cams. The agricultural engineer will still have to develop application-specific algorithms to interpret sensor data.

Predicting animal responses

The next critical element that should be fulfilled to realize the PLF scheme is prediction of the animal's response(s) to its process environment. Not every mathematical model can be used as a basis for control purposes, and certainly not for complex dynamic processes such as livestock production, which often require an adaptive approach because farm animals constitute complex, individual, time-varying dynamic (CITD) systems (Berckmans, 2004). The process model should allow the process response to be predicted accurately under both steady state and dynamic conditions and should be compact enough to be implemented in a control design (Bridges *et al.*, 1995).

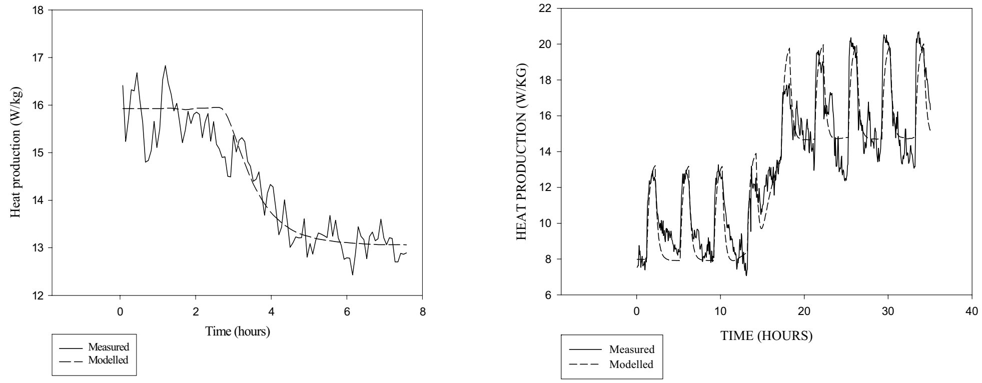
Mechanistic models of the physiological and behavioural responses of animals to their physical micro-environment are often complex with many parameters, relying upon many assumptions (e.g. Bruce and Clark, 1979; Oltjen *et al.*, 1986; Kettlewell and Moran, 1992; Turnpenny *et al*., 2000). For control purposes, these models are often over-complex and inaccurate since parameter values may change over time and space (Oltjen *et al.*, 1986; Bridges *et al.*, 1995), although the parameters do have biological meaning. Empirical models have the advantage of a simple model structure with few parameters, but the majority are static and time-invariant. For control purposes, they suffer from the important drawback that they do not describe the dynamic behaviour of the process response that is needed for a model-based control algorithm (Golten and Verwer, 1991).

Recent developments in modern information technology hardware (e.g. price, computational power, reliability and size) and software have enabled the use of advanced on-line mathematical identification techniques in PLF (Young, 1984; Ljung, 1987). These modelling techniques estimate the unknown model parameters of an abstract mathematical model structure, based on on-line measurements of process inputs and outputs. The model parameters can be estimated on-line during the process, resulting in an adaptive model that can cope with the CITD characteristics of most biological processes (Goodwin and Sin, 1984; Ljung, 1987, Aerts *et al*., 2003a, b). However, the model parameters and structure do not provide biological insight into the causal mechanisms.

The complexity of the mathematical models depends on the PLF process. In the simplest case, a PLF process may only have one system input and one system output (SISO). In most practical applications, however, PLF systems have several process inputs and outputs with complex interactions, resulting in complex multiple-input, multiple-output systems (MIMO) where the component processes may act in series, in parallel or with feedback. Examples of modelling results for SISO, MISO (multiple input, single output) and MIMO bioprocesses are shown in Figures 2 and 3. The model predictions were all generated by means of compact, dynamic mathematical model structures.

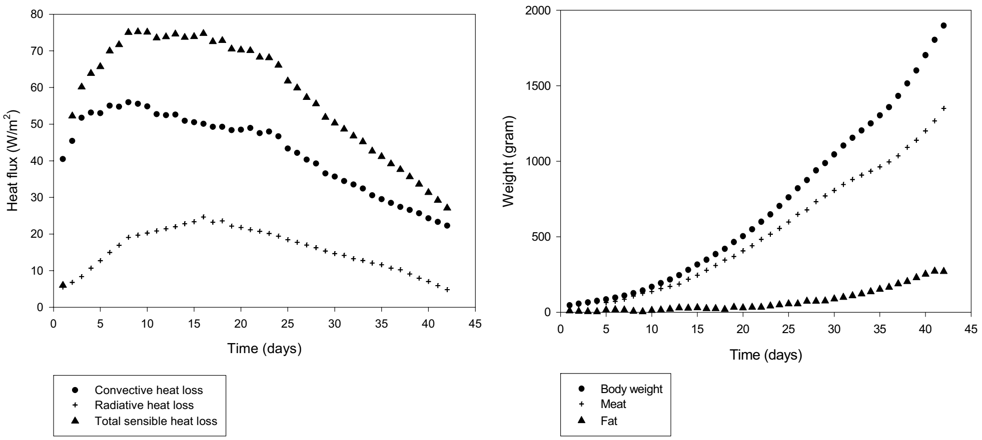
Black box models can provide efficient control of PLF processes though no understanding of the model structure and its parameters is required. In PLF applications, however we foresee difficulties in acceptance of these controllers because of this lack of biological understanding. This disadvantage can be overcome in the intermediate approach of grey box models in which the parameters can be interpreted on the basis of the underlying biological or physical processes. The challenge is to develop tools to determine the biological meaning of model structure, order and parameters.

An example of this intermediate approach is modelling the activity of broiler chickens following step-wise variation in light intensity (Kristensen *et al*., submitted). Activity, measured as total movement on a group basis, was modelled initially using a data-based approach. The model selection procedure employed biological insight of the system to produce a final model structure with a set number of parameters, though their biological interpretation requires further work. However, the approach was suitable for determining the system order.



(a) (b)

Figure 2. Examples of measured and modelled responses of heat production of broilers to stepwise changes in (a) temperature (SISO system; Aerts *et al.*, 2000); and (b) temperature and light intensity (MISO; Aerts *et al.*, 1998b).



(a) (b)

Figure 3. Example of modelled responses of broiler chickens (a) total sensible, convective and radiative heat loss, and (b) body weight, meat growth and fat growth to air temperature, air velocity and feed supply (MIMO system; Aerts and Berckmans, 2004).

Target and trajectory

The above elements enable the engineer to take efficient control of animal processes but the final element is the overall target for the process and the trajectory by which it is reached. The trajectory defines the minute-by-minute or day-by-day adjustments needed to the process inputs. Definition of the overall target is not a control problem as such because it depends on external and internal factors, e.g. animal welfare, work efficiency, environmental impact, feed cost, product price etc.

We also need to consider the relative interests of the farmer and the animal; this can be solved partially by a bioethical analysis *vide infra*. Should we focus on production efficiency, profitability, animal health or welfare? Optimising the process to meet one overall target can have implications for another, e.g. farmers' income vs. animal welfare. In many PLF applications, however, the optimal target needs research and farm trials prior to implementation. For example, it may be possible to control broiler activity by dynamic varying light intensity though the appropriate target of activity is unknown (Kristensen *et al*., *submitted*). The unique advantage of PLF is that the targets can be farm-specific and modified 'on-the-fly' if circumstances change, e.g. because of a disease outbreak or change in product specification.

Growth control of broiler chickens as a research exemplar of PLF

In this example of PLF, the objective was to control the growth trajectory of broiler chickens using an adaptive, compact, dynamic process model (Aerts *et al. 2003b*). Daily food supply was calculated to allow the birds to follow a defined target growth trajectory. Parameters of the growth model, which predicted the response to the control input (food supply), were estimated on-line. This adapted the model to the actual response of weight to feed intake and was the basis for efficient control. The control algorithm developed enabled the broilers to follow different target trajectories with a mean relative error ranging between 3.7 and 6.0%. With a few exceptions, the numerical values of feed conversion ratio and mortality after week 1 were lower and the values of uniformity index were higher in the controlled groups compared with *ad libitum* fed animals (Figure 4).

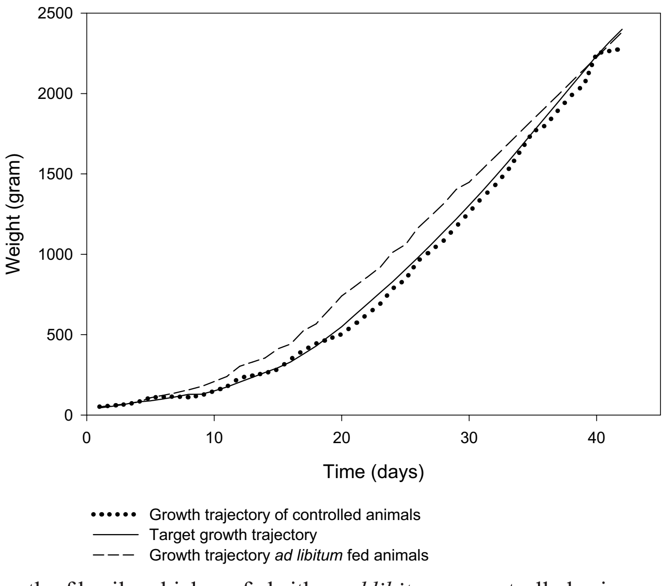


Figure 4. Growth of broiler chickens fed either *ad libitum* or controlled using a model-based control algorithm with a target trajectory of pronounced compensatory growth and a final body weight of 2400 g (Aerts *et al. 2003b*).

Livestock processes which are suitable for PLF

Compared with traditional livestock management, PLF has the potential to monitor, manage and control many aspects of livestock production, both simultaneously and automatically. Physical and biological processes are equally suitable for the PLF approach. One benefit for animal welfare is that stockmen are provided with detailed information on animal processes, such as behaviour and physiology, and are allowed more time for inspection rather than more laborious tasks (Frost *et al*., 1997). Examples of livestock processes, which may be particularly suitable for PLF, include animal growth and production, disease detection and behavioural surveillance (Table 1).

Is PLF an example of technology push or market pull?

Is the development of PLF likely to be valuable to the livestock farmer? A moment's thought reveals the potential reasons why farmers may either adopt or reject PLF including:

Adoption of PLF

- Diminishing supply of skilled stockmen encourages technological aids to livestock management.
- Greater ability to satisfy market demand for livestock products of tight specifications.
- Ability to reconcile potentially conflicting demands on livestock production, e.g. aerial pollutant emissions *vs.* optimal growth rates.
- Electronic record keeping forms a part of quality assurance and product traceability.

Rejection of PLF

- Uncertain payback period for capital investment.
- Lack of confidence in technology-based production systems, e.g. poor public perception of "active animal control".
- Incomplete development of technology with poor equipment reliability, leading to rejection by early adopters.

PLF is a new technology that is in its early stages of research and development with only a few PLF products available commercially. Several recent conferences highlight the attractions of PLF for agricultural engineers in the research phase (Wathes *et al.,* 2001; Cox, 2003), though few researchers have tackled PLF *in toto*, i.e. the fully engineered system of sensors, models, controllers and process targets working automatically. Commercially, the only PLF product that has been sold on a significant scale is the Flockman system for meat poultry (Filmer, 2001). The first embodiment of Flockman required significant manual interpretation of a vast stream of environmental and production data in order to set the nutrient supply to the broilers. This early system incorporated all the essential features of PLF. It was refined after research to include semi-automatic control of diet according to on-line measurement of broiler weight and predicted growth (from an empirical model; Parsons *et al*., 2004; Frost *et al.*, 2003). Flockman provides evidence of market pull in one sector of livestock farming.

Another example of market pull for PLF is provided by the British Pig Executive (BPEX, the U.K. industry trade organisations), which is reviewing the needs of the pig industry for applied R&D (www.bpex.org). These are driven (or pulled) by BPEX's strategic goals for the British pig industry over the next 10-15 years that include a doubling of the annual gain in growth efficiency and a reduction in feed cost of 25%, alongside other goals relating to the consumer, policy and meat processing. BPEX believes that these goals will be achieved by applied R&D in which the skills of the bioengineer in the form of PLF technology will be in the vanguard, alongside those of the veterinarian and nutritionist.

In its strategic review, BPEX identifies the main reasons for failure of knowledge and technology transfer from the (engineering) researcher to the end user. Faults are apparent at many points along

Table 1. Potential advantages and disadvantages of controlling livestock processes in PLF systems from an animal welfare perspective.

Process	Potential advantage	Potential disadvantage
Growth	Optimises nutrient supply, based upon real-time measurement of demand and response. Ensures chosen growth trajectory is followed.	Control is likely to act at a group level, although data may be collected from individuals, potentially introducing bias. PLF may not accommodate variation between individuals, leading to inadequate nutrition.
Milk production	Optimises milk yield for individual dairy cows. Automatic milking tailors milking frequency to individual cows. PLF technology encourages disease monitoring, e.g. milk conductivity.	Automatic milking may not promote beneficial behaviour, e.g. social relationships between animals.
Disease monitoring and detection	PLF allows early detection of disease e.g. mastitis, coughing. Less need to handle individual animals during inspections	Stockmen must remain vigilant for signs of other diseases and must not rely too heavily on automatic detection. PLF may require individual identification in the flock or herd.
Behavioural repertoire	Controlling repertoire, e.g. exercise or activity in broiler chickens, may improve leg health. May enhance the level of synchronisation between individual animals.	Active control of behavioural repertoire may be stressful. Ethical issue of active control of animal behaviour may be significant.
Maladaptive behaviours	Early detection of maladaptive behaviours, e.g. feather pecking or tail-biting. Monitoring provides early treatment and prevention of spread of maladaptive behaviours.	Much research required to identify individuals performing maladaptive behaviours. Behavioural causation and potential prevention techniques need to be understood prior to implementation.

the transfer chain from applied research via product development, demonstration and extension to on-farm use. There are too many examples of good applied research that never reaches the farmer. BPEX's solution is to accept the need for, and co-fund where necessary, the large-scale

development work that irons out the wrinkles in a new product before it is demonstrated under contrasting farm conditions. This model has been operated successfully for many years in Denmark by the National Committee for Pig production, though the cooperative structure of the Danish pig industry may explain its success: livestock industries in other countries in a more competitive market economy may find it less useful.
Just as the engineering principles of PLF have been borrowed from manufacturing industry, so the pioneers of PLF should recognise that successful design engineers in other industries employ a variety of tools in new product development. Baxter (1995) shows how successful product innovation requires management of risk by targeting customer needs and killing off unsuccessful products early in the design process. As a rule of thumb, for every ten ideas, three are developed into products, of which 1.3 is launched and only one makes a profit (Baxter, 1995). The early stages of product design have the highest risks with the greatest uncertainty but are also the most cost-effective in terms of investment. The crucial question for engineers concerned with PLF research is whether sufficient market research has been done amongst the end-users to establish clear priorities for the uses of PLF. Our view is that such an analysis has not been conducted, but is sorely needed.

Bioethical analysis of PLF

Our analysis of PLF so far has focused upon the science and technology of PLF and its potential applications to housed livestock. PLF is a new biotechnology that, in our opinion, has great potential to transform livestock farming by introducing a degree of control over the component processes that was previously impossible. The basis of this control is the detailed knowledge of individual animals or herds that a 21st Century farmer will possess, akin to the intimate relationship that existed between a medieval shepherd and his small flock of sheep or husbandman and his house cow or sow. The essential difference is the scale of the modern livestock farm. However, new farming technologies may have a much wider impact on society than the immediate consequences for farmers and their livestock; this impact may be evaluated objectively using the new technique of bioethical analysis.
Bioethical analysis is a form of a technology assessment that identifies ethical issues in a transparent, objective and systematic manner. Its application to farming and food biotechnologies has been pioneered by Ben Mepham at the University of Nottingham (see Mepham, 1996, for a full description). In practice, bioethical analysis requires assessment of a technology by a committee of competent moral judges using an accepted ethical framework. Amongst other characteristics, the judges should be knowledgeable, reasonable, empathetic and without vested interests. For the ethical framework, Mepham devised a bioethical matrix that is soundly based in ethical theory and employs respect for three widely-accepted ethical principles, i.e. wellbeing, autonomy and justice (see Table 2). These principles are applied to affected groups (stakeholders) with an interest in the technology. Once the matrix and interest groups have been identified, then evidence is collated for each of the matrix's cells. This is then analysed by the moral judges to provide an overall, ethical assessment.
Only a few biotechnologies have been analysed by Mepham and his co-workers but their bioethical analysis of automatic milking systems, AMS, for dairy cows is highly pertinent to PLF (Millar, 2000; Millar and Mepham, 2001). Robotic milking is an essential feature of AMS; machines incorporating the principal robotic features were developed in the laboratory in the 80's (Frost, 1990) and AMS has been exploited commercially since 1992 (Lind *et al*., 2000). Millar and Mepham identified improvements in dairy production efficiency, human and cow welfare as positive impacts, but there were concerns over the adverse impact of AMS on rural employment, milk quality and instrumental use of animals. A comprehensive bioethical analysis could be undertaken because there was substantial evidence in the scientific literature about various aspects

Table 2. Bioethical matrix (Mepham, 1996).

Respect for:	Wellbeing	Autonomy	Justice
Livestock	Animal welfare	Behavioural freedom	Animal 'telos'
Producers	Adequate income and working conditions	Freedom to adopt or not adopt	Fair treatment in law and trade
Consumers	Availability of safe food, acceptability	Consumer choice	Universal affordability
Biota	Protection of the biota	Maintenance of biodiversity	Sustainability of biotic populations

of AMS, which complemented surveys of the attitudes of consumers, farmers and retailers to AMS (Millar and Mepham, 2001). AMS was largely accepted with caveats by consumers and with caution by farmers while retailers were cautious. The ethical principle of autonomy was translated by Millar for the dairy cow as respect for behavioural freedom, which reflects the U.K.'s Farm Animal Welfare Council's freedom to express normal behaviour (www.fawc.org.uk): this freedom has been the subject of much critical debate amongst welfare scientists. Given the wealth of published evidence, Millar (2000) was able to assess the effects of AMS on various types of behaviour including motivation to be milked, grazing and dominance, evaluating the ethical impact of each. A similar bioethical analysis was conducted on the other cells of the matrix (Table 2).

Millar's bioethical analysis of AMS is pioneering but not without its limitations. The procedure is consistent, coherent and transparent in that the data sources are reliable and the analytical logic is sound. However, some questions about the impact of AMS on cow health or the biota were difficult to answer due to lack of scientific information and practical experience on farms. While a tentative conclusion could be drawn (at the time) about AMS, more evidence was clearly needed before a definitive judgement could be made. Nevertheless, no grave ethical concerns were identified by Millar such that the commercialisation of AMS should be subject to special legislation or restrictions: this is not always the case with novel food biotechnologies (Mepham, 1996).

PLF is a new technology that is in the very early stages of R&D; it is akin to the milking robots of the mid 80's and PLF shares many features with AMS. These features were a cause for concern for Millar and Mepham (2001) because AMS was a technology that (i) does not fit readily into current assessment procedures; (ii) may have a long-term revolutionary impact on farming; and (iii) has many potential positive and negative impacts on different interest groups. With today's knowledge of PLF, it would be premature to undertake a bioethical analysis of its various applications but an example may shed some light on ethical issues.

Assume that the behavioural repertoire of a broiler chicken is to be actively controlled by manipulation of light intensity using the PLF approach. Indeed, parts of this application have already been developed (Kristensen *et al.*, submitted), *viz* a mathematical model of the dynamic relationship between intensity and activity (as a surrogate for exercise), and a monitoring system based upon image analysis. Lack of exercise in broiler chickens, especially when young, has been identified regularly as an important causal factor in musculoskeletal disorders (Bradshaw *et al.*, 2002) that represents poor welfare. Considering only the interests of the broiler chicken, what evidence would be needed for a bioethical analysis of this particular PLF application? Table 3 shows the outcome of a hypothetical, though plausible, prospective analysis.

We propose that a bioethical analysis of PLF should be undertaken to identify any substantial cause for concern by the various interest groups. Assuming that any advance concerns can be addressed then commercial development of PLF will have a greater chance of success, secure in the

Table 3. Prospective, partial bioethical analysis of PLF to control exercise in broiler chickens.

Respect for Wellbeing - translated as animal welfare
+ Reduction of the incidence and prevalence of leg disorders improves health
+ Monitoring system for diagnosis of lameness
- Disturbance to sleep
- Loss of human-chicken interaction
Respect for Wellbeing - translated as animal welfare
+ Reduction of the incidence and prevalence of leg disorders improves health
+ Monitoring system for diagnosis of lameness
- Disturbance to sleep
- Loss of human-chicken interaction
Respect for Justice - translated as telos
N Selection of chickens amenable to active control
- Instrumental use of animals.

+ Respect for principle; N neutral impact; - Infringement of principle

knowledge that the technology has a sound ethical basis. At present the body of scientific evidence needed for the bioethical analysis is not available.

Is PLF an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall?

The provocative title of our paper indicates our concern that there are significant scientific, technical, bioethical and marketing issues to be resolved if PLF is to live up to its promise of transforming the management of livestock. Other industries have successfully applied modern control theory but livestock farming imposes additional technical constraints on the control engineer. Firstly, the size of the potential market implies that sensors and sensing systems are unlikely to be developed specifically for livestock; instead, effort should be concentrated on adapting sensing systems to the harsh environments of livestock farming and to signal analysis. Secondly, while data-based models of single livestock processes have been developed (e.g. Aerts *et al*., 2003c), there are no examples of process models that predict the behaviour of two or more interacting processes. Considerable research effort will be required to develop modelling techniques to describe, interpret and control MIMO systems. Thirdly, PLF provides an unprecedented accuracy of management of livestock production that will enable various strategies to be adopted, specified by farm-specific targets. These targets will need to be evaluated in terms of their effects on animal performance, health and welfare and other criteria: different producers may adopt radically different strategies to serve commodity or niche markets. Finally, the slim profit margins of livestock farming, the unrealistic expectations of researchers and the low uptake of other 'revolutionary' biotechnologies emphasize the importance of product design in developing PLF applications.

We envisage two scenarios for the development of PLF by agricultural engineers. Lack of affordable sensing system, inappropriate process models, an inability to control MIMO systems, conflicting targets, unreliable first products evaluated at the farmer's expense and/or poor publicity will militate against PLF. Alternatively, a planned approach for PLF development, which is based upon careful selection of initial applications, close co-operation between researchers and manufacturers and a prospective bioethical analysis, should maximise the chances of success. We believe that PLF is too promising a technology for sustainable livestock production to be wasted by insufficient consideration of all the phases of the research funnel. If PLF researchers abide by these proven 'rules', then PLF will satisfy the aspirations of the agricultural engineer, promote farm animal health and welfare and provide the livestock farmer with the technology he will need in the 21st Century to farm sustainably and successfully.

Conclusions

PLF is an embryonic technology with great potential to transform intensive livestock production by efficient utilisation of nutrients, early warning of ill health, reduction in pollutant emissions and provision of useful information to skilled stockmen. However, in our opinion a cautious approach is needed to PLF research and development if the promise of the technology is not to be dashed against the rocks of poor product design and marketing. We foresee four significant hurdles to be overcome by the pioneers of PLF in the next 5 to 7 years.

1. Technology The most pressing technological needs are: robust, low cost sensing systems; data-based models of the key biological and physical processes with meaningful parameters, and control systems that can govern two or more interacting physical and/or biological processes.
2. Livestock applications Targets and trajectories are required for the main candidate processes, principally animal growth, health and behaviour, based upon sound biological principles.
3. Marketing PLF must be demonstrated at a commercial scale if livestock farmers are to have confidence in the manufacturers.
4. Bioethics PLF may be viewed unfavourably by consumers as a technology that encourages instrumental use of animals, potentially compromising welfare. A bioethical analysis of PLF is needed but cannot be undertaken until the underpinning research has been carried out. This will demonstrate the value of PLF to the major interest groups, thereby allowing an informed decision to be taken about its utility to society at large.

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Evironmental effects of precision livestock farming

Reduced nitrate leaching from livestock in a large lake catchment in New Zealand

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Abstract

Lake Taupo, a major New Zealand tourist attraction, has declining water clarity due to increased phytoplankton levels. Increased phytoplankton levels are a response to increasing nitrate levels in groundwater and groundwater-fed streams entering the lake. Urine from grazing animals is the largest, manageable, contributor to ground water nitrates. As means of reducing nitrate emissions, changed management on, and changed use of, farmland are options explored in two trials reported here. Production and nitrogen (N) leaching from annual and perennial crops have been measured over 2 years. Similar measurements were made in a cattle grazing trial comparing all year grazing (AYG), no winter grazing (NWG) and no grazing (NG - baleage). Lucerne, pasture, triticale+annual ryegrass and forage maize+annual ryegrass yields were variable between years and lower than expected. Nitrate leaching from perennial crops was lower than from annual crops (11-28 v 50-223 kg $N0_3$-N ha^{-1}). N utilisation was similar in NWG and AYG (177 kg N ha^{-1} yr^{-1}) but $N0_3$-N leaching losses in AYG were significantly greater than those in NWG and NG (16.6, 5.6, 2.4 kg $N0_3$-N ha^{-1} yr^{-1} respectively). Management options incorporating the low nitrate emission systems are being evaluated for agricultural and economic feasibility and, using selected scenarios, will be extrapolated across the farmed landscape in the Taupo Catchment to predict potential nitrate leaching reductions.

Keywords: nitrate leaching; livestock farming; cropping; catchments

Introduction

Declining water clarity in Lake Taupo, New Zealand, is a serious threat to this important tourist attraction. The decline results from increased phytoplankton levels in response to nitrates entering the lake from groundwater and groundwater-fed streams (Morgenstern 2004). Development of rural land from the 1960's, and urban expansion within the 279,875 ha catchment land area, are seen as the two land uses from which nitrate losses can feasibly be managed (Vant and Smith 2002). In New Zealand non-dairy grazing systems, the greatest inputs of nitrogen (N) arise from clover N_2 fixation (100 to 200 kg N ha^{-1} yr^{-1}) and mineralization of soil organic N (70 to 300 kg N ha^{-1} yr^{-1}, Ruz-Jerez *et al.,* 1995; Fillery 2001). Significant direct nitrate loss from fertiliser N occurs only where application rates are high, with nitrate leaching losses coming predominantly from urine patches (Ruz-Jerez *et al.,* 1995; Ledgard *et al.,* 1999). Where similar inputs of N are used, nitrate leaching losses are higher from grazed land than from cropped land, and losses during the winter drainage period are greater if the preceding summer was hot and dry rather than cool and wet (Scholefield *et al.,* 1993). They also found that the volume of winter drainage is less of a determinant of nitrate leaching than the amount of potentially leachable nitrate in the soil. Cuttle *et al.* (1998) reported that nitrate leaching is strongly influenced by the number of stock grazing days late in the growing season, the level of dry matter (DM) utilised and the amount of N input, but is largely unaffected by the form of N input (fertiliser N v N_2 fixation). de Klein and Ledgard (2001) found, through modelling, potential benefits of a 35-50% reduction in nitrate leaching by moving cattle to a feedpad during autumn and winter, although nitrous gas losses from the feedpad increased. High $N0_3$-N leaching of mineralised plant-residue-N in pasture and cropping rotations can be expected, especially in soils with a high hydraulic conductivity (Fillery 2001), as have pumice soils.

In 2004, Environment Waikato, the regional authority responsible for this catchment, announced that by 2015 nitrate leaching from farmland must fall to 20% below current levels. This seems likely to be achieved by converting 20% of grazed farmland to other uses and limiting nitrate leaching from remaining farms within the catchment to current levels. To maintain economic viability within 'capped' nitrate emission levels, land uses that include heavily fertilised, high yielding, cut and carry forage crops that can be sold outside the catchment, or used in feeding systems within the catchment (provided that nitrate leaching is prevented), may be useful substitutes to current grazing practices. This paper reports research activities undertaken to provide quantitative data from grazed farmland and cropping systems to assist land managers to develop sustainable farming enterprises that meet the allowable nitrate emissions to groundwater.

Materials and methods

Two trials, 1 km apart, each with 3 replications of 0.7-1.0 ha plots, were established on rolling, very deep, free-draining, pumice soil. The available water holding capacity in the 0-10 cm horizon is 19.2% (v/v). Winter pasture growth in the district is < 5 kg DM ha^{-1} d^{-1} for up to 6 weeks in winter (R. Webby, pers comm.).

Cropping trial

Four treatments were established in glyphosate-sprayed pasture that was power-harrowed and rolled in 2002. Perennial crops of *lucerne (Medicago sativa)* (12 kg ha^{-1}) and *pasture* (*Lolium* spp., 25 kg ha^{-1}; legumes, *Trifolium* spp. 6 kg ha^{-1}) were established in spring (October) 2001. The annual crop, *triticale* (*Triticosecale* spp Wittm.)(180 kg ha^{-1}), was sown at the same time in both years, but was direct drilled into glyphosate-sprayed annual ryegrass in 2003. Green feed *maize* (*Zea mays*) was sown (115,000 seed ha^{-1}) into cultivated soil only in October 2003 under a UV-degradable plastic film with pre-emergent herbicides and insecticides through which the plants broke-out after 4-5 weeks. This technology is necessary in this region with its short growing season. Following harvest of annual crops in mid or late summer, annual ryegrass (28 kg ha^{-1}) was sown as a cover crop.

Except for lucerne which received 20 kg ha^{-1} in spring, Year 2, crops were fertilised with N (Table 1), P, K, S, Co, Se at a rate to provide for potential yields from lucerne, pasture, triticale+annual ryegrass and maize+annual ryegrass (Year 2 only) of about 12, 14, 16, and 22 tonne DM ha^{-1} yr^{-1} respectively. Soil pH was > 6.0. Pasture, lucerne, triticale and annual ryegrass were cut, wilted and made into wrapped, round bales which were weighed and sampled for dry matter (DM) content and quality. Maize yield was assessed in the standing crop, and quality sampled from the silage stack. Concentration of leached N was determined from 10 porous ceramic cup samplers (Lord and Shepherd 1993) at 60 cm depth, within each plot. Cups were sampled after accumulated drainage was estimated to be 40 mm since the previous sampling. Nitrate-N and ammonium-N concentrations were measured to ISO standards using flow injection analyses. Drainage volume was estimated by daily water balance using as inputs: temperature, wind run, solar radiation and rainfall, from an on-site meteorological station. Leached $N0_3$-N per plot was the product of mean $N0_3$-N concentration within the plot and estimated drainage volume for the trial site. As cups were not established in the maize plots until November 2003, these mean data were excluded from statistical analyses. Ammonium-N yield ranged between only 1 to 3 kg ha^{-1} yr^{-1} and was independent of treatment effects, therefore these data are not presented in this report.

Grazing trial

All-year-grazing (AYG) was compared with *No-winter-grazing* (NWG), as most nitrate leaching was assumed to occur over winter months. Mixed-age cattle grazing simulated rotational grazing systems typically used in the region. The same class of female cattle was used at each grazing but sometimes differed between grazings. In the first 5 months of this trial sheep and cattle were alternated between successive grazings, but this changed to cattle-only grazings for easier interpretation of data. A 10-year-old temperate, grass-legume pasture, with annual maintenance applications of P, K and S nutrients, but without fertiliser N, was used. A third, *No-grazing* (NG) treatment, from which pasture was cut and baled, was the control. This treatment received N (Table 2) and potassium after each second cut to replace that estimated to have been removed in baleage. Pasture utilisation was estimated by 'difference' between rising plate meter readings taken before and after grazing, and N utilisation was calculated using the 'difference' and the total N content of pre-grazing hand-plucked pasture. Nitrate leaching was determined as in the cropping trial, except that 20 ceramic cups were used in the approximately 1 ha plots, and weather data were collected on-site.

Statistical analyses

For harvested DM yield, N harvested, and mean $N0_3$-N leached per plot, split-plot analyses of variance were used to test the effect of Treatment, Year and Treatment.Year, with Years nested within Plots. Block main effects were removed. Where ceramic cups failed in the cropping trial only, missing value estimates of $N0_3$-N concentration were made by fitting stationary smoothing splines using Flexi (Upstell 1999) before calculating plot mean concentrations.

Results

Cropping trial

The establishment year had little rain between January and May (Figure 1), thereby contributing to the low yields of all treatments in Year 1. The 1-in-100 year 440 mm rainfall event over several days in February 2004 resulted in unusually high summer leaching in Year 2. In both years about 50% of annual rainfall drained to ground water (Figure 1). Month to month variation in rainfall and drainage was also high in both years. In the cropping trial, except for lucerne which received a small N boost in Spring Year 2, high rates of N fertiliser for this region of New Zealand, were applied. Higher N rates in Year 2 were used to try and improve on the poor growth measured in Year 1 (Table 1). Triticale failed to establish at the first sowing in Year 2 and was resown 3 weeks later. Inadvertently, the establishment application of di-ammonium phosphate was re-applied at the second sowing thereby accounting for much of the substantially higher fertiliser N application to triticale in
Year 2 compared with Year 1. Year 2 DM yields were greater than in Year 1, but except for maize, were well below expectation (Table 1). Annual crops leached substantially more $N0_3$-N than perennial crops in each year (Table 1). Lower $N0_3$-N losses in Year 1 reflect the shorter (7-month) sampling period and the lower drainage volume compared to Year 2. However, the very dry period (January to May, 2003) would have resulted in no nitrate leaching, had the ceramic cups been in place earlier. Cumulative $N0_3$-N losses (Figure 2a) indicate higher loss from triticale+ryegrass than from the perennial crops in winter (June to September) 2003. Losses resulting from the high

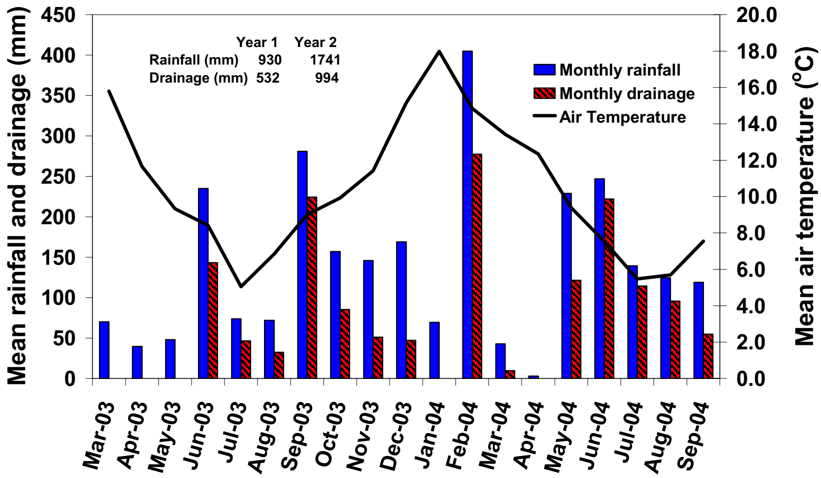


Figure 1. Mean monthly air temperature, rainfall and apparent drainage volume determined by daily water balance at the cropping trial. These data were similar to those in the grazing trial (data not presented).

Table 1. Mean total fertiliser-N applied, DM and N harvested, and $N0_3$-N leached in 2002-2003 (Year 1, Oct-Sep) and 2003-2004 (Year 2) for perennial crops sown in Year 1, and annual crops followed by annual ryegrass in one or both years. Leached nitrate-N (kg ha^{-1}) in Year 1 refers only to the March-September period.

	Fertiliser N (kg ha^{-1})		DM Yield (kg ha^{-1})		N harvested (kg ha^{-1})		$N0_3$-N leached (kg ha^{-1})	
Treatment	Yr1	Yr2	Yr1	Yr2	Yr1	Yr2	Yr1	Yr2
Lucerne	0	20	1332	3724	46	174	10.8	27.5
Pasture	130	158	2524	7645	63	179	8.9	12.1
Triticale+ryegrass	145	324[a]	7427	8963	117	172	50.2	149.5
SED			706.2		21.5		5.9	
Maize+ryegrass[b]		210		22000		246		223

[a]Triticale re-sown and two applications of N applied in error
[b]Not included in analyses (see text)

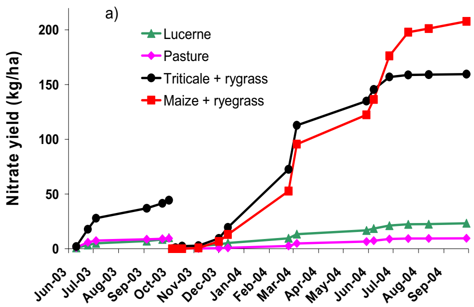
February rainfall and the following wet winter resulted in an average 2.7 times more $N0_3$-N loss in Year 2 than in Year 1. The higher loss from triticale+ryegrass in the second year also reflects the very high input of fertiliser N in the second year. The fertiliser N input to maize+ryegrass was only 65% of that used on triticale+ryegrass, yet $N0_3$-N loss was 50% greater from the maize treatment in spite of its 22 t DM ha^{-1} yield (Table 2).

Grazing trial

Table 2. Mean total fertiliser-N, DM yield, N-harvested and leached $N0_3$-N in 2002-2003 (Year 1, Dec-Sep) and 2003-2004 (Year 2, Oct-Sep) in the grazing trial.

	Fertiliser N (kg ha^{-1})		N harvested (kg ha^{-1})		Log $N0_3$-N leached (kg ha^{-1})		Back-transformed $N0_3$-N leached (kg ha^{-1})	
Treatment	Yr1	Yr2	Yr1	Yr2	Yr1	Yr2	Yr1	Yr2
All Year Grazing	0	0	208	195	2.88	2.74	17.8	15.5
No Winter Grazing	0	0	148	159	0.76	2.22	2.1	9.2
No Grazing	97	130	65	129	0.01	1.33	1.0	3.8
SED			13.0		0.49		Not applicable	

Rainfall and drainage at the grazing trial site was 838 mm and 460 mm in Year 1 and 1621 mm and 968 mm in Year 2, respectively. While about 100 kg N ha^{-1} was applied to NG, significantly less N was harvested from NG than from the two grazing treatments which had no fertiliser N applied (Table 2). More N was harvested in AYG than in NWG, which in turn had more harvested than that harvested as baled forage in NG. $N0_3$-N leached from AYG was 5.6 times greater than from NWG in Year 1, whereas the difference was not significant in Year 2 since both grazing treatments leached large quantities of $N0_3$-N during February and early March (Figure 2b). Loss of $N0_3$-N from NG was consistently low in both years. In Year 1, the percentage of N-harvested that was leached as $N0_3$-N was higher in AYG (8.6%) where there were 2 winter grazing events during which NWG (1.5%) was fallowed (Table 2). In Year 2 the NWG loss was higher than in Year 1 due to the high $N0_3$-N loss in both treatments in summer. There was no significant difference in leached $N0_3$-N between NWG and NG in either year.
During both winters (June-September), more $N0_3$-N was leached from AYG than from NWG, but during the February 2004 storm, when both pastures were being grazed, losses were similar (Figure 2b).



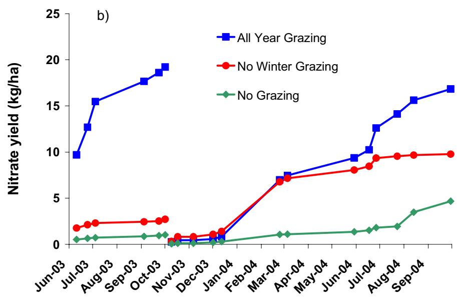


Figure 2. Mean cumulative $N0_3$-N in leachate at a) the cropping trial and b) the grazing trial sites from March 2003 to September 2004. Note the different y axis scales. Raw data, that differ slightly from data in Tables 1and2, have been plotted.

Discussion

Nitrate leaching losses were substantially higher under annual than under perennial crops or grazing. This is somewhat surprising given that N fertiliser inputs were applied to provide for realistic, but high, crop yields. That these yields were not achieved, and that no allowance was made for the contribution of mineralised N to plant nutrition, meant that surplus N was available for leaching. Spraying of annual ryegrass before sowing triticale or maize in spring, and the decay of stubble following harvest of these crops in late-summer and early-autumn will have contributed large amounts of available N to the soil N pool (Fillery 2001). The high rainfall and drainage in the region, especially over autumn and winter, appears to have created N deficient conditions that restricted the growth of the annual ryegrass cover crop during this period in spite of fertiliser N having been applied in autumn when growth conditions were good (data not presented). The risk of nitrate leaching from well fertilised summer annual crops or N-fertilised perennial pasture is also high where summer storms (and drainage) occur, especially if this occurs soon after the application of N fertiliser. In a near-by, unpublished, lysimeter study using pumice soil, we estimate that ~130 mm drainage is required to move urinary-N (and dissolved fertiliser N) to the depth of the ceramic cups. This drainage volume was first experienced in June 2003 (Year 1), in February and then May 2004 (Year 2). Thus, leaching of nitrate to below the root zone of winter-active grasses, can occur early in the cool season, thereby limiting later cool-season pasture growth.

By placing ceramic cups at 60 cm depth, we may have over-estimated $N0_3$-N loss and drainage volume under the deep rooting lucerne and maize crops which are likely to have extracted water and nitrates from a greater depth than the sampling cups. During winter, as maize was dead and lucerne was dormant, leaching loss during the growing season would have been more accurately determined.

Optimum yield and quality of triticale can be achieved only when the crop is harvested within a 5-10 day ‘window of opportunity’. In both years, this was very difficult to achieve, due to limitations of wet weather and availability of the harvester. While maize production was up to expectation in Year 2, the high cost of establishing this crop ‘under-plastic’, the risk of plastic blowing away before the crop established, the risk of late frost damage and high nitrate losses, all contributed to the local farmers being unprepared to grow maize as an alternative to livestock farming. Only lucerne and perennial pasture provided minimal risk of nitrate leaching due to zero/low use of fertiliser N. However, higher productivity is required, before these cut and carry pastures become a realistic alternative land-use to livestock grazing.

Removing cattle from pastures over the late-autumn winter period (NWG) was very effective at reducing nitrate leaching at that time of year. DeKlein *et al.* (2001) also showed with modelling that restricting cattle to feed pads over winter will reduce nitrate leaching compared to conventional year-round grazing. Compared to high yielding, heavily N-fertilised and highly stocked dairy-grazed pastures in a drier region of New Zealand, that can lose up to 204 kg $N0_3$-N ha^{-1} (Ledgard *et al.,* 1999), nitrate loss from our less intensively stocked beef cattle system on our free draining pumice, was low. While the two grazing systems utilised similar amounts of pasture N, most growth and N utilisation was over the spring to mid-autumn period when both treatments were being grazed by cattle. But, the difference in nitrate loss between treatments occurred almost totally during late-autumn and winter. The lack of difference in nitrate leaching between the grazing treatments during the heavy February rainfall event, shows that even where a Best Management Practice of no-winter-cattle grazing is used, summer storms can result in significant movement of nitrate to below the root zone. The twenty-year weather records from Taupo show only 3 years when January to March drainage totalled between 50 and 120 mm - volumes that might result in significant warm-season movement of nitrate through and, perhaps beyond, the root zone of typical forage species other than lucerne and maize. Ten of those years had no drainage over that time.

With no winter grazing in NWG, there was some reduction in harvested N but this did not result in more nitrate leaching, since such losses in grazed pastures come mainly from urine patches (Ruz-Jerez *et al.,* 1995). While nitrate leaching from NG was less than in the two grazed treatments, the level of pasture production, where only the amounts of added N and potassium equalled the estimated loss of these minerals in baled forage, this management option would not be economically viable.

The presence of large pasture growth responses within urine patches at the end of winter, in both grazing treatments indicated that much of the readily available soil N had been leached from the root zone. Without input of fertiliser N, spring growth of these pastures depends upon mineralization of organic N and on N_2 fixation by legumes once soils warm in spring.

In nearby, concurrent work (Betteridge *et al.,* 2005), nitrate loss from yearling heifers was nearly double that from yearling hinds and yearling ewes, between May and October 2004. This finding provides further scope for land managers to manipulate farming systems to reduce nitrate leaching within the allowable nitrate emission level determined for the farm.

These data provide the foundation upon which farmers in the Taupo catchment are designing modified farming systems that will permit them to continue a sustainable farming enterprise within the constraint of their capped nitrate emission from the farm. Modified systems are being evaluated in decision support models for feasibility and financial soundness.

Impacts of changed management across the whole, 100-farm Taupo Catchment, will then be assessed using GIS datasets of soil type, contour, aspect, livestock enterprises including stock type and numbers, and weather records. A framework model to incorporate nitrate sub-models of: plant/animal/soil interactions, vadose zone and groundwater movement, wetland movement and N transformations, and a landscape hydrology model is being developed to enable extrapolation of our plot-scale data to the whole catchment.

Whatever progress is made in reducing nitrate emissions, the lag between water, and therefore nitrates, entering the soil, and draining as ground water into streams and the lake has been estimated to be between 40 and 70 years. Therefore lake water quality will deteriorate before it can improve (Morgenstern, 2004).

Conclusions

Highly fertilised, annual, cut and carry cropping systems can contribute very high nitrate losses to ground water on free-draining pumice soils in a high rainfall environment. Losses from perennial crops lucerne and pasture are substantially less due to their lower requirement for fertiliser N. De-stocking cattle over winter can greatly reduce annual nitrate leaching losses, except when there is substantial summer drainage from storms. The impact of manipulating farming systems on lake water quality can only be assessed by using a combination of models that span across scales.

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Environmental effects of pig house ventilation controlled by animal activity and CO_2 indoor concentration

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Abstract

The environment in and around livestock houses is influenced to a large extent by its ventilation and ventilation control. Additional control parameters (animal activity and CO_2 indoor concentration) as well as adiabatic air cooling were integrated into newly-developed ventilation control concepts and randomly investigated during four fattening periods. Measurements included temperature, humidity, ventilation rate, CO_2, NH_3, airborne particles (different size fractions), and bioaerosols. A high correlation between the animal activity and the indoor particulate matter concentration of PM_{10} (aerosols with an upper particle size limit of 10µm) was especially found at the ad libitum feeding system. Using the CO_2 controlled ventilation strategy, a reduction of the ventilation rate of 20 % at low outside temperatures was measured, with only minor effects on the indoor air quality. The main influences on indoor air quality as well as on emission of NH_3 and aerosol particles were due to season and water fogging.

Keywords: ammonia emission, dust, bioaerosols, indoor air quality, adiabatic cooling

Introduction

Requirements for the ventilation of livestock buildings are in general to ensure a good indoor air quality as well as environmental control, in order to avoid health and environmental hazards. The complex environmental system of a livestock building is influenced by the indoor temperature, indoor humidity, wet areas, as well as the volatilisation of ammonia, carbon dioxide, and aerosols. Commonly, only the temperature is used to control the ventilation rate in mechanically ventilated livestock buildings. Although high air exchange rates are common in summer, main problems are caused by hot indoor temperatures, combined with heat stress and a decrease in animal performance. Adiabatic air cooling, e.g. by evaporation of fine water droplets, fogged under high pressure, can be an effective measure to lower the indoor air temperature in agricultural buildings (Arbel *et al.*, 2003; ASHRAE 2003). Additional humidity sensors are used to control the indoor humidity and to counteract injurious conditions.
During winter and cold outside conditions, buildings are in general heated and the ventilation rate is kept on minimum, causing high indoor gas concentrations, dust, and microbial hazards, which can cause health problems for farmers and animals (Hartung and Seedorf, 2002). Livestock management, the arrangement of functional areas, animal activity, and pen fouling by the animals can deteriorate the indoor air quality additionally and increase emission rates due to their influence on the release of NH_3, dust, and bioaerosols from animals, faeces, straw, and fouled surfaces (Aarnink, 1997, Gallmann, 2003, Rieger, 2004). Further, the kind of ventilation control influences the level and dynamics of the indoor concentration and emission of gases and airborne particles, and determines the environmental impact of a livestock building (Aerts *et al.*, 2004; Hartung *et al.*, 2004). Beside environmental relevant gaseous emissions, the emission of dust and bioaerosols from livestock housings gain in relevance due to their potential hazard for public health (Wathes *et al.*, 2004). The objective of the research project is the development of innovative ventilation control

concepts, which include adiabatic indoor air cooling by fogging of water particles at high pressure. The main focus is how to manage the different and partly contrary demands on the indoor air quality, emission reduction, and energy consumption in an intelligent way by integrating additional sensors and control parameters, like animal activity, indoor gas concentrations, and humidity into newly-developed ventilation control strategies.

Materials and methods

The newly-developed ventilation control strategies were processed by a commercial control software. The digital ventilation controllers used (Lon-R-Bus) were networked via a two-wire-data bus and directly connected to the PC-controlled measuring and data acquisition system. A randomly distributed testing of the ventilation control strategies was accomplished during four fattening periods (FP 1 to FP 4) from February 2003 until July 2004 in the Hohenheim research pig facility. Regarding the investigations on indoor air, NH_3, and dust, approximately 50 % of the measurements were carried out below and above mean daily outside temperatures of 14°C. For the analysis, the measurements for each of the two outside temperature ranges were regarded separately, as both have different demands towards the ventilation of a pig house, according to cold and warm outside conditions.

The two compartments of the research facility (Hartung, 2001) are dimensioned for 54 pigs each (27 pigs per pen; 0.9 m^2 / pig). The pens feature a blank and slotted concrete floor; straw was supplied weekly via an occupation equipment, type "Porky Play" (straw capacity: approx. 3-4 kg). Each compartment is equipped with a separately controllable ventilation system (negative pressure), designed as underfloor extraction. Fresh air is supplied via two air inlet pore channels per compartment, which are arranged centrally above the animal area. The climatisation of each compartment was supported by two separately controllable water fogging lines to cool down and humidify the air. The fogging lines were placed in front of the air inlets (2 nozzles per inlet) and centrally inside the compartments (3 nozzles per pen) respectively. A fog creating high pressure pump (7 MPa) was connected to the ventilation controller. The pump was activated either when the indoor temperature raised to more than 1.5 K above the set temperature (T_{set}), the indoor humidity dropped below 50 % (Strat. A, Strat. B, Strat. C, Table 1) or by the signal of the animal activity (Strat. A, Table 1). Maximum indoor humidity was set on 80%.

CO_2 and NH_3 concentrations (NDIR spectroscopy, MAIHAK / ROSEMOUNT), ventilation rate (measuring fan, MULTIFAN), temperature and humidity (ROTRONIC), as well as fogging events, water consumption and the signal transduction to the climate controllers, were logged continuously. The measured NH_3 concentration values were corrected afterwards, according to the water vapour cross sensitivity of the gas analyser. The calculation of the NH_3 emission rate took into account the difference in the gas concentration at the exhaust and incoming air, as well as the ventilation rate. The average animal activity of the animal group was measured by one passive infrared sensor per pen (Petersen and Pedersen, 1995).

Table 1.Overview on ventilation control strategies and parameters.

ventilation control strategy	strat. A animal activity humidifying	strat. B temperature humidifying	strat. C CO_2 humidifying	strat. R reference no humidifying
control parameters	temperature, humidity and animal activity	temperature and humidity	CO_2 indoor concentration, temperature and humidity	temperature

For all ventilation control strategies, the temperature sensor was used as a main control parameter for the ventilation rate as well as for the start of the humidifying, supported by the additional input parameters (Table 1). Using Strat. C, however, the ventilation rate was controlled solely by the CO_2 indoor concentration for temperatures lower than the maximum temperature (T_{set} + 3 K). At Strat. A, the ventilation rate was increased additionally at times when the animals were more active. The experimental approach and the control strategies are described in more detail in Häussermann *et al.* (2004).
Airborne particles and biological hazards were investigated discontinuously during the experiments by the regional occupational health service. Per fattening period, the airborne particles and bioaerosols were measured twice per ventilation control strategy per compartment. Sampling of respirable, thoracic, and inhalable dust particles, with regard to labour protection, took place indoors at a height of 170 cm, for a time span of two to three hours (measuring frequency: 1 minute) - either in the morning or in the afternoon. Thoracic dust emissions were calculated based on indoor concentration and ventilation rate. The particles were measured by virtual impaction, sampling on filters and scatter light photometry (Respicon™), according to EN 481 (1993), with a 50 % sampling selective cut off at an aerodynamic diameter d_{ae}^{50} of 4µm, 10µm and 100µm, respectively. The average value of the optical measured course was corrected afterwards with the gravimetric weight of the filter samples. For the dust sampling, hydrophobic glass fibre filters were used, which were changed, dried and weighed after each measurement. Parallel to the dust measurements, endotoxins, moulds, and bacteria were sampled using a personal total dust sampling system (PGP/GSP, flow rate 1.0 l/min, measuring time: 30 minutes and SAS 90, sampling volume 10 l, respectively).
During the last two fattening periods, additionally the indoor particulate mass concentrations and emissions of aerosols with an upper particle size limit of 10µm (PM_{10}), were determined with scatter light photometers (TSI, Model DustTrak 8520). Measurements were done indoors in the control corridor and in the exhaust shaft, parallel to the dust measurements mentioned above, but over whole day periods (24 hours).

Results and discussion

Relation between animal activity and indoor dust concentration

Based on a mean diurnal course at days with reference ventilation, a correlation between the signal of the animal activity and the indoor PM_{10} concentration R^2_{adj} of 0.70 for the ad libitum and 0.47 for the sensor feeding system was found (Figure 1). The calculated mean diurnal course considers that variations on the absolute value of the indoor dust concentration, due to influences of the age and weight of the animals and the seasonal level of the ventilation rate, cannot be detected by the signal of the animal activity. With regard to the correlation, the measured animal activity can be suitable to predetermine diurnal dynamics of the indoor dust concentration, but did fail in describing the absolute value or the increase of the indoor dust concentration. Differences might be caused by varying distances of the dust source, measured as animal activity, and the measuring instrument. The dynamics of a processed signal of animal activity, however, are suitable for an effective control of short-term-focused timely and spatial distribution of additional ventilation strategies to counteract an increase of airborne particles. These can be targeted mitigation measures, like an increase of the ventilation rate or sprinkling of oil (Takai *et al.*, 1998).

Indoor air quality for mean daily outside temperatures below 14°C

The main influence on the indoor air quality at mean daily outside temperatures below 14°C was due to the reduction of the ventilation rate of approximately 20 %, when using the CO_2 controlled

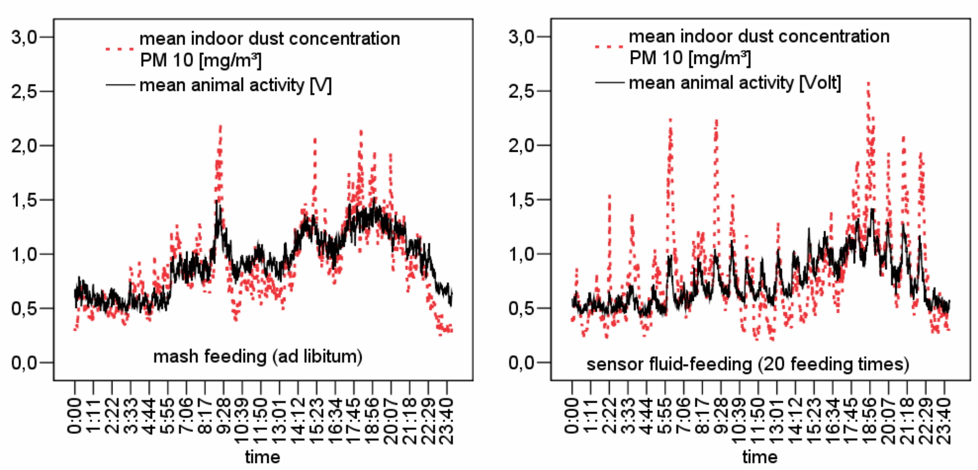

Figure 1. Mean diurnal course of animal activity and indoor PM_{10} concentration at two different feeding systems (n = 4 and 5.5 days for ad libitum and sensor feeding, respectively).

ventilation strategy (Strat. C). The reduction of the ventilation rate was combined with a slightly higher indoor temperature. However, an increase of the mean indoor concentration of CO_2 and NH_3, due to the reduced CO_2 controlled ventilation rate, occurred mainly at times when the CO_2 and NH_3 indoor concentration was rather low. For all ventilation control strategies, the threshold for the CO_2 indoor concentration (3000 ppm) was exceeded equally, at approximately 2 % of all cases, showing the effectiveness of the used control parameter. Although the threshold for the NH_3 indoor concentration was exceeded more often: the indoor concentration was found between 20 ppm and 25 ppm for approximately 11 % of the measuring days in this temperature range. Only slight differences between the ventilation control strategies occurred for thoracic and inhalable dust particles with an average indoor concentration of approximately 1 mg m^{-3} and 2 mg m^{-3} respectively. An increased respirable dust concentration can be remarked for Strat. A, Strat. B and Strat. C, which might be caused by the additional humidifying. High pressure water fogging was mainly used to avoid dry indoor conditions for the respective ventilation control strategies (Strat. A, Strat. B and Strat. C, Table 2).

The indoor endotoxin concentration featured a clear seasonal dynamic with minimum concentrations of 40 to 600 EU m^{-3} during spring, summer and autumn and maximum concentrations up to 4000 EU m^{-3} in winter. Mean concentrations of 739 EU m^{-3} were measured. The concentration of moulds averaged at 924 CFU m^{-3} (incubation at 22°C) and 239 CFU m^{-3} (incubation at 37°C) and of bacteria at 0.14 Mio CFU m^{-3} (incubation at 35°C). Neither for moulds, nor for bacteria, a seasonal influence occurred. Compared to literature (Rieger, 2004), rather low bioaerosol concentrations were measured during these investigations, which underlines the generally effective ventilation in the research stable. Differences between the control strategies, regarding bioaerosol levels, were rather low, compared to further influences like individual organisation and management in pig husbandry, hygiene, and dimensioning of the ventilation, which are more important aspects regarding the absolute concentration of airborne biological hazards (Hartung, *et al.*, 2004). Therefore, no influence of the ventilation control strategies, a reduced ventilation rate, or the humidifying on the level of the bioaerosol concentration was found.

Table 2. Mean ventilation rate and indoor air quality regarding different ventilation control strategies (mean daily outside temperatures below 14°C).

	Strat. A	Strat. B	Strat. C	Reference
Mean outside temperature [°C]	7.8	7.3	7.3	5.7
Mean indoor temperature [°C]	18.9	18.8	19.9	19.2
Mean indoor humidity [%]	58	57	64	48
Mean ventilation rate [m^3 h^{-1} pig^{-1}]	46	46	36	45
Mean CO_2 concentration [ppm]	2003	2039	2364	2056
(value >3000ppm)	(2.4 %)	(1.2 %)	(1.8 %)	(2.3 %)
Mean NH_3 concentration [ppm]	11.6	11.5	14.4	10.9
(value > 20 ppm)	(2.1 %)	(0.5 %)	(11.1 %)[a]	(1.2 %)
Mean respirable dust particles [mg/m^3]	0.34	0.36	0.32	0.21
Mean thoracic dust particles [mg/m^3]	1.0	1.1	1.1	0.9
Mean inhalable dust particles [mg/m^3]	1.8	2.0	2.2	1.9

[a]0.4 % above 25 ppm

Ammonia and dust emission rates

For mean daily outside temperatures below 14°C, only slight influences of the ventilation control strategies on temperature and ventilation occurred. Nevertheless, the NH_3 emission rate for Strat. A, Strat. B and Strat. C was approximately 10 to 14 % higher than for the reference ventilation (Table 3). The increase of NH_3 emission might be due to an increased indoor humidity, wet areas and floor surfaces with respect to the solubility of NH_3 in water.
Regarding mean daily outside temperatures above 14°C, temperature peaks and ventilation rates were clearly lowered by adiabatic air cooling (Table 4). Maximum temperature differences between the two parallel investigated compartments ranged up to 7°C, comparing ventilation strategies with and without humidifying. The CO_2 controlled ventilation rate was damped furthermore, compared to the temperature controlled ventilation rates. For this outside temperature range, similar NH_3 emission rates of approximately 112 g d^{-1} LU^{-1} occurred for all ventilation control strategies (Table 4). Although the ventilation rate, as well as the indoor temperature, has been lowered significantly by Strat. A, Strat. B and Strat. C, no clearly lowered NH_3 emission rate occurred in comparison to the reference ventilation. However, the effect of the reduced temperature and ventilation rate was able to counteract an increase of the emission rate due to an increased indoor humidity.

Table 3. NH_3 and dust emission rate (mean daily outside temperatures below 14°C).

	Strat. A	Strat. B	Strat. C	Reference
Mean NH_3 emission rate [g d^{-1} LU^{-1}]	113	113	109	99
Mean PM_{10} emission rate [g d^{-1} pig^{-1}][a]	0.8	1.0	0.7	0.8
Mean thoracic emission rate [g d^{-1} pig^{-1}][b]	1.3	1.2	1.0	1.1

[a]exhaust concentration*ventilation rate (dust and water particles); FP 3 (Nov 03 until Feb 04)
[b]indoor concentration*ventilation rate (four fattening periods, Feb 03 until Jul 04)

The PM_{10} emission rate differed between ventilation with and without humidifying mainly for warm outside conditions (FP 4, Table 4). For the summer period, the measured PM_{10} emission rate for the ventilation strategies with humidifying averaged at 1.5 g d^{-1} pig^{-1}. Compared to the reference ventilation, or to colder outside temperatures in FP 3, it was nearly doubled (Table 3). However, no differences between the ventilation control strategies occurred for the weight-corrected thoracic dust emissions, although a seasonal influence can also be remarked here, comparing the two temperature ranges (Table 3, Table 4). In contrast to the measured PM_{10} concentration, the measurement of thoracic aerosols did only consider dust particles, due to the gravimetric correction of the mean value. Differences between PM_{10} emission rates seemed to be mainly caused by water aerosols, which were measured and calculated according to dust particles. The calculation of the thoracic dust emission did assume a relation between the indoor and exhaust concentration similar to the relation for PM_{10}: regarding measuring days with reference ventilation, a correlation R^2_{adj} of 0.82 was found between the indoor and the exhaust PM_{10} concentration. Similarly, a correlation R^2_{adj} of 0.80 occurred between the indoor thoracic dust concentration and the PM_{10} exhaust concentration. The PM_{10} concentration, measured in the exhaust shaft, was in average 88 % of the PM_{10} indoor concentration for mean daily outside temperatures below 14°C. However, at higher mean daily outside temperatures, with higher ventilation rates, similar indoor and exhaust concentrations occurred. For low outside temperatures or moderate ventilation rates, the calculation of the thoracic dust emission rate therefore might overestimate the real values about approx. 10 % to 15 %.

Table 4. Indoor climate, NH_3 and dust emission (mean daily outside temperatures above 14°C).

	Strat. A	Strat. B	Strat. C	Reference
Mean outside temperature [°C]	19.1	18.8	20.1	21.2
Mean indoor temperature [°C]	20.4	20.4	21.8	24.5
Mean indoor humidity [%]	74	70	74	46
Mean ventilation rate [m^3 h^{-1} pig^{-1}]	92	93	80	119
Mean NH_3 emission rate [g d^{-1} LU^{-1}]	110	110	113	114
Mean PM_{10} emission rate [g d^{-1} pig^{-1}] [a]	1.2	1.7	1.6	0.9
Mean thoracic emission rate [g d^{-1} pig^{-1}] [b]	1.4	1.5	1.6	1.7

[a]exhaust concentration$_*$ventilation rate (dust and water particles); FP 4 (Apr 04 until Jul 04)
[b]indoor concentration$_*$ventilation rate (four fattening periods, Feb 03 until Jul 04)

Conclusions

Additional input and control parameters are suitable for an effective and advanced ventilation control of livestock houses. Due to its relation to dust peaks, the signal of the animal activity can be used effectively as an input signal for short-termed mitigation measures, in order to counteract peaks in dust or bioaerosols.

The reduction of the ventilation rate, at the tested CO_2 controlled ventilation strategy, did increase the indoor concentrations of gases, but without exceeding the threshold for the CO_2 indoor concentration more often than a higher, temperature controlled ventilation rate. In this context, the signal of the CO_2 indoor concentration was appropriate to control the indoor air quality. No increase in thoracic or inhalable dust indoor concentration was measured due to the reduction of the ventilation rate, although respirable dust concentration was increased in combination with

humidifying. No influence of the ventilation control strategies, a reduced ventilation rate or the humidifying on the level of the bioaerosol concentration was measured.
NH_3 emissions were increased for ventilation strategies with humidifying at mean daily outside temperatures below 14°C. For warmer outside temperatures, however, this increase was counteracted by the reduction of the indoor temperature and ventilation rate.

Acknowledgement

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Impact of protein feeding on odour emissions

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Abstract

Two pig fattening trials were conducted to determine the effects of standard vs. protein reduced diets on slurry odour generation. Measurements of odour concentration and quality of odour perception were performed with a dynamic dilution olfactometer. At two-week intervals gas samples were taken from the headspace of representative slurry samples (30 l barrel) and measured. Results of the odour measurements show only little impact of diet protein level on odour concentrations. But there is some clear evidence for changes in the quality of odour perception. When feeding protein reduced diets, slurry odours were perceived less intensive and less unpleasant by the human nose, compared to standard diets.

Keywords: odour, -concentration, -intensity, -unpleasantness

Introduction

Pork production units are substantial contributors to air pollution such as ammonia and odours. In contrast to noxious gases, odours exhibit only little harmful effects to the environment. However, they have the potential to become very annoying for adjoining residents. Resulting problems are long known. They have prompted extensive research, resulting in numerous methods to reduce gaseous emissions. Some of those methods have been adopted in practical pig keeping, as well as in the regulatory rule-work, e.g. considering protein-adjusted multi-phase feeding as "state of the art" to reduce ammonia emissions. Regarding the problem of odour emissions, it proved practicable to establish minimum distances to neighbouring residential areas to avoid conflicts caused by manure smells (German legislation). Yet, it is not always possible to keep up the required distances. Conflicts can arise, especially when animal numbers are to be stocked up or when new pig keeping locations are planned on farms close to residential areas. In such special cases it is possible to reduce the required minimum distances, if measures can be proved that are suited to minimize odour emissions or odour offensiveness. It has been investigated in this project whether protein adapted feeding is not only a measure to reduce ammonia emissions, but also odours in concentration and offensiveness.
Odour emissions from pig keeping units originate mainly from the slurry. Feeding determines to a high extent volume and properties of the slurry. Nutritional demands of fattening pigs are changing with ongoing growth of the animals. The demand for crude protein increases in smaller terms than the demand for energy. Even when applying multi-phase feeding, the animals are supplied over long periods with a surplus of protein. After passing the digestive tract of the pig, unutilized feed protein ends partially undigested and partially after decomposition as ammonia and intermediates in the slurry. Besides ammonium, slurry contains a large number of other volatile odorous compounds. They are mostly organic metabolic intermediates with osmophorous groups. Except for the volatile fatty acids, most of those substances originate from the amino acid breakdown. They can be grouped in phenolic compounds, indoles, sulphides and amines (O'Neill and Phillips, 1992; Mackie *et al.,* 1998; Zhu *et al.,* 1999). Thus, strong indication is given that feed protein might be a central component in the formation of slurry bound odours and their characteristics perceived by the human nose. It can be assumed, that by reducing protein surpluses in pig diets, the concentration of odorous compounds in the slurry might be reduced as well. In conclusion, odour emissions would be lowered as well as the nuisance caused by them.

On the other hand, it has been shown that protein reduced diets lead to similar faeces but to lower urine volumes, compared to high level protein diets (Pfeiffer, 1991). Thus, urine volume as a solvent for odorous compounds is smaller, leading to higher concentration levels of odorants in the slurry. According to the law of Henry and Dalton higher concentrations of odorants in the slurry lead to an increased partial pressure. This might cause higher emission rates. In this case it could be assumed that odour emissions would be higher.

Not only the diet is linked to manure composition and will likely affect odours, but also the microbial mechanisms responsible for manure decomposition. Complex effects of biological, chemical and physical processes in the slurry are caused by diet modifications. Consequently, alterations in the emission processes might occur, resulting in changes of the odorant compound complex (Bridges *et al*., 1995; Hobbs *et al*., 1998). Accordingly, interactions between individual odorants might lead to changes in the smell that is perceived by humans. It is known that individual odours can eliminate, mask and reinforce each other, or they might even lead in varying combinations to totally new smells.

Above all, the impact of odour on the human nose cannot yet be predicted with technical-physical sensors (Boeker, 2001; Garlapp *et al*., 2001). Even an accurate quantification of each substance in a compound gas is not suited to describe the semantic interpretation of odours by the limbic system of the human brain. The effects on the sense of smell can vary enormously, depending of the pattern and concentration of complex odorants and of individual perception by humans. Due to the large number of different substances in slurry odours - over 300 substances have been identified so far (O'Neill and Phillips, 1992), it is almost impossible to analyze all odorants and make predictions of the resulting smell. Reliable guide components have not yet been identified. Since technical sensors are not the solution to measure complex odours such as slurry smells, the human nose is still essential for odour measurements. Olfactometry is a measurement method that uses the human nose as a sensor. It allows the detection of odour thresholds by dynamic dilution of gaseous samples and evaluation of the smell with a set of panellists. Besides detecting the odour threshold, the panellists can also evaluate odour intensity and the offensiveness of a smell at predefined dilution levels.

Materials and methods

Instrumentation

The base for olfactometric measurement methods used in this experiment corresponds to the German VDI Standard 3881/3882 (Figure 1). Odour concentration measurements were made by using a dynamic dilution olfactometer (Mannebeck TO 7) with a forced-choice type presentation of gas samples to a panel of 4 persons and 3 repeated measuring rows, totalling 12 answers per sample. Dilutions were made using odour-free air (reference air) supplied by a compressor fitted with filters and an air dryer. The olfactometer has 4 sniffing ports, one for each panellist. Starting with a dilution level below the expected threshold, the panellists receive in alternating mode either sample air or reference air. After each presentation the panellist has to decide, whether the actual presentation is different from the one before, which can be either reference air or diluted sample air. In case of detecting a difference in smell the panellist has to indicate a positive answer via keypad. From the starting point with a dilution level below odour threshold, the dilution levels are decreased stepwise on a logarithmic scale. A measuring row is finished at the point of 50 % positive answers, indicating a sensation of smell. The point of 50 % odour detection by the panellists is defined as the odour threshold. By definition the odour concentration at the threshold is 1 odour unit/m^3 (OU/m^3). Odorant concentration of a sample is calculated using the dilution level at the odour threshold and is expressed in OU/m^3.

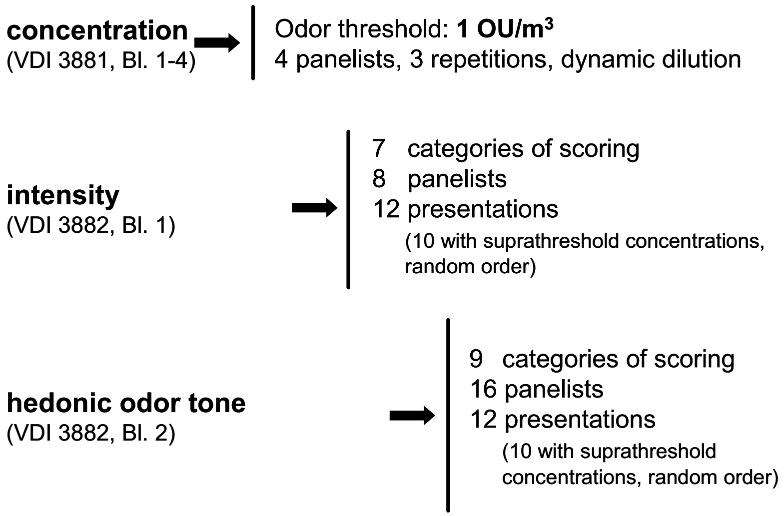

Figure 1. Olfactometric measurement methods for the quantification of odour concentration and odour quality according German VDI Guidelines 3881/3882.

Odour intensity and hedonic odour tone measurements are performed using the same equipment as for odour concentration. It requires the panellists to score their perception of odour intensity in a range of concentrations according to a category scale from 0 (no odour) to 7 (extremely strong odour). Similar for the hedonic odour tone, ranging from +4 (extremely pleasant) via 0 (neither/nor) to -4 (extremely unpleasant). In the case of slurry only the negative scale for the perception of unpleasantness is relevant. Intensity and hedonic odour tone are related linearly to the logarithm of concentrations. The samples at defined dilution steps are presented to the panellists in random order. Each sample presentation has to be evaluated on an independent scale. After a measurement row is completed, the scores are sorted in ascending order, according to the logarithmically scaled concentration levels.

Odour sampling

For this study data have been taken from two pig fattening trials. Representative slurry samples with a volume of 30 l have been collected after thorough homogenization from the slurry storage cellar below the slatted floors. The slurry sampling was carried out at two-week intervals. After sampling, the slurry has been frozen to eliminate effects of changing ambient conditions while sampling, transport and storing. After controlled thawing in a tempered water bath, gas samples have been taken in 20 l Teflon bags at the point where the slurry temperature reached 20 °C. The olfactometric measurements were carried out immediately after gas sampling.

Fattening trial

In two consecutive fattening trials a total of 184 fattening/finishing pigs were allotted to a control diet (CD) and two experimental low protein diets (LP1 and LP2). All diets were based on cereal and soybean meal and were formulated to fully meet the nutritional demands for all groups. It was aimed to over-provide the control groups with crude protein (CP) in the finishing phase, to test the effect of CP surpluses against demand meeting CP supply on odour emissions.

The animals were stalled up in two parallel compartments with slatted floors and separate manure pit units for each group. In the growing phase up to 65 kg bodyweight (BW), all animals had access to CD (19.5% CP). In the finishing phase > 65 kg BW one control group per compartment continued with the CD diet up to 120 kg BW and one of each test groups received either the LP1 (15.5% CP) diet or the LP2 (13.5% CP) diet, respectively. Access to feed has been offered ad libitum. Experimental setup and feeding strategy is listed in Table 1.

Statistics were performed as a paired Student's *t*-test, comparing CD vs. LP1/2 in each compartment.

Table 1. Experimental setup of two consecutive fattening trials, testing the effect of dietetic crude protein surpluses (control diet CD vs. low protein diet LP1 or LP2) on odour concentration and characteristics.

Fattening Trial	Compartment	Group	Feeding strategy
1	1	A	CD
		B	CD/ LP1
	2	C	CD
		D	CD/LP2
2	1	E	CD/LP1
		F	CD
	2	G	CD/LP2
		H	CD

Results and discussion

Odour concentration

The results of the measured odour concentrations are listed in Table 2. Averaged values vary considerably between all groups, ranging for the total fattening period from 3400 to 6464 OU/m^3, for the growing period from 2733 to 5200 OU/m^3 and for the finishing period from 3420 to 7638 OU/m^3.

Differences in odour concentrations between the tested trial groups (A vs. B, C vs. D, F vs. E and H vs. G) are not significant and seem to be smaller than between the two compartments and the two consecutive fattening trials.

There is a general trend to increased odour concentrations with ongoing growth of the animals. Odour concentrations are significant higher in the finishing period, compared to the growing period. Increasing maturity of the animals leads to endocrinologic and metabolic changes causing an enhanced production of odorant compounds that end in the slurry and affect slurry odour.

Besides seasonal effects on slurry odour concentrations from trial 1 to trial 2, further effects arise from the compartment, respectively from the characteristics of the slurry storage unit. This is obvious particularly for the growing period, where all animals received the same diet. The groups within a compartment produce slurries of different odour generation potential.

As the results indicate, differences in odour concentrations are not only caused by dietary treatment and error of measurement, but also by changes in the animals and environmental factors that lead to alterations in anaerobic decomposition processes in the slurry.

Table 2. Odour concentrations (OU/m^3) for control groups (CG) and low protein groups (LP1 and LP2) averaged for total fattening period, growing and finishing period with A, B, C, D in fattening trial 1 and E, F,G, H in fattening trial 2.

trial	compartment			Total 35-120 kg BW				Growing 35-65 kg BW				Finishing >64-120 kg BW			
				CG	LP1	LP2		CG	LP1	LP2		CG	LP1	LP2	
		Diet:		CP	CP	CP		CP	CP	CP		CP			
		Growing		19.5%	19.5%	19.5%	t-test	19.5%	19.5%	19.5%	t-test		CP	CP	t-test
		finishing		19.5%	15.5%	13.5%	p>0,05				p>0,05	19.5%	15.5%	13.5%	p>0,05
		Groups		[OU/m^3]				[OU/m^3]				[OU/m^3]			
1	1	A	B	3873	5196		ns	3067	4100		ns	4477	6018		ns
			sd	2017	3355			115	2138			2680	4197		
	2	C	D	3400		3514	ns	3367		3067	ns	3425		3850	ns
			sd	1314		1826		1563		757		13503		2437	
2	1	F	E	6464	6379		ns	5200	4700		Ns	7413	7638		ns
			sd	1957	1703			2685	866			239	610		
	2	H	G	4136		3700	ns	2733		3433	ns	5188		3900	ns
			sd	1979		1143		1626		1328		1621		1146	

Odour quality

Results of odour intensity and unpleasantness of odour were similar in the growing period, but there are trends indicating changes in the odour perception after diet change in the finishing period. Data relating odour concentration to odour intensity for the finishing period is depicted in Figure 1 and similar for unpleasantness of odour perception in Figure 2.

Starting at the odour threshold with 1 OU/m^3 there is an initial lag phase, where an increase in odour concentration not necessarily leads to changes in the quality of odour perception. After the lag phase, further increases in concentrations (in logarithmic scale) lead to a more intensive, and in the case of slurry to a more unpleasant odour perception. As can be seen in Figure 1 there are distinct differences between CD and LP1/LP2. For both fattening trials it can be shown that the lag phase for CD is slightly shorter compared to the low protein groups LP1 and LP2. Vice versa, a higher concentration is needed for LP1 and LP2 to detect the odour with similar intensity. After the lag phase, the slope in the raise of intensity is almost similar.

The unpleasantness of odour perception tends to result in a similar picture as odour intensity, yet the differences are not so distinct (Figure 2). In both fattening trials it can be seen that the lag phase, until the odour becomes more unpleasant with increasing concentrations, is shorter for CD. At

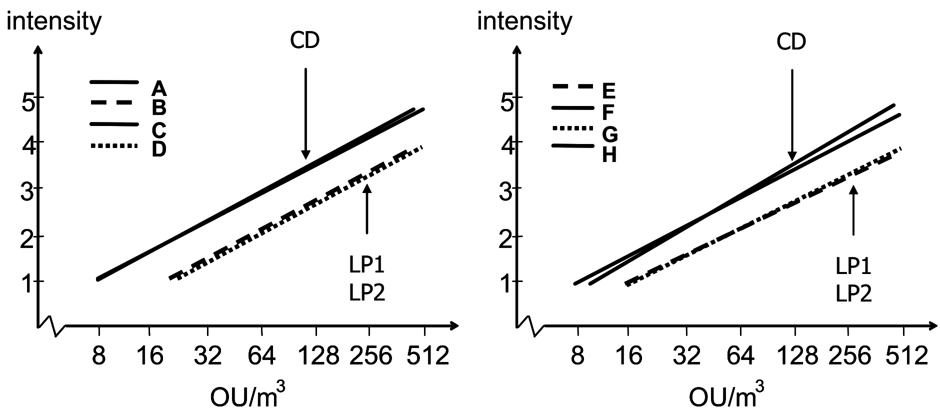

Figure 2. Odour intensity related to supra-threshold odour concentrations.

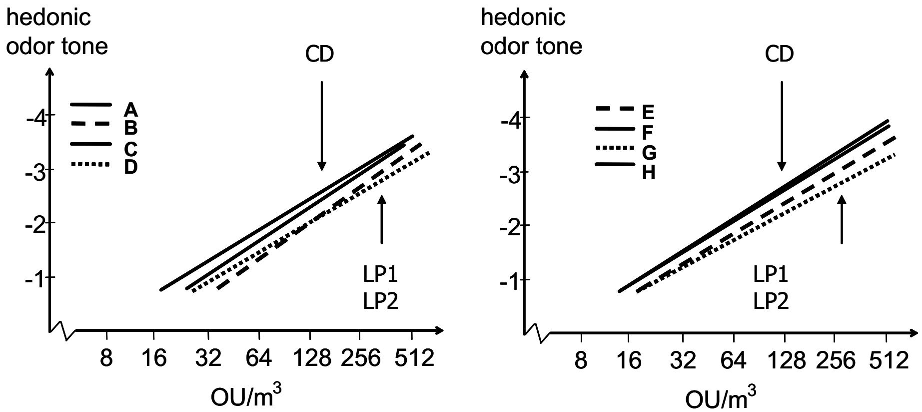

Figure 3. Hedonic odour tone related to supra-threshold odour concentrations.

similar concentrations slurry odours from protein reduced diets (LP1 and LP2) lead to less unpleasant odour perceptions.

The problem of odour nuisance can be tackled by reducing either the concentration or the offensiveness. The first assumption that reduced levels of protein surpluses in the diet would lead to reduced odour concentrations from the slurry cannot be stated within the results of this study.

On the other hand, this might be due to a misinterpretation of the olfactometric measurement results. Odour units are calculated from the dilution level at the measured odour threshold. Slurry odours contain some substances, such as H_2S, with a very low odour threshold. Panellists have to detect in the measuring procedure whether they notice a change of smell of the presented sample. They do not have to recognize the odour. Especially the prolonged lag phase for LP1 and LP2 shows that a higher concentration level is needed, before the odour starts to become more intensive and more offensive. Just taking the odour concentration derived from the threshold level caused by a few substances with very low detection level could easily lead to over- estimations of the concentrations.

The incidence for changing odour qualities in dependence of dietary protein level is clear. Measurements of odour intensity and hedonic odour tone of the odorant complex has shown a less offensive and less annoying odour perception by the human nose.

Conclusions

The following conclusions can be drawn from this experiment:

1. Just taking odour concentration as a measure to analyze nuisance from slurry odours can easily lead to misinterpretations, since there is a clear lag phase between odour threshold and changes in perceived odour characteristics with increasing concentrations.
2. Low protein diets lead to differences in quality of odour in terms of odour intensity and unpleasantness of odour perception.
3. Those effects have to be considered when minimal distances are to be set up to residential neighbours.
4. Further research on odour quality in relation to pig diets is needed.

Acknowledgements

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Flushing litterless fattening houses with biologically treated slurry (SBR plant) - effects of flushing rate, percentage of treated slurry and seasons on gaseous emissions (methane, ammonia, nitrous oxide, carbon dioxide and odour)

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Abstract

Two identical compartments of one fattening pig house with fully slatted floor (120 animals per compartment) were studied comparatively with regard to their emission behaviour. One compartment - the experimental compartment - was equipped with flushing gutters. The second compartment with conventional slurry storage in the stall, was used as the reference compartment. The slurry of the experimental compartment was flushed out daily, separated and treated biologically using a Sequence Batch Reactor (SBR). The liquid phase obtained with this process was used for flushing without additional water supply. Thereafter, 40 % of the thin fraction underwent a biological treatment in the SBR reactor. In all fattening periods, significant differences ($P < 0.001$) of methane mass flows were registered between the experimental and the reference compartment. Independent from the daily flushing rate, methane emissions and emission reduction rates by flushing were very similar (81-89 %) in the winter half year. In the summer trial, the average reduction rate between the two compartments arrived up to 76 %. Flushing intensity did not have any significant influence on the reduction of methane formation. In all fattening periods, significant differences ($P < 0.001$) of ammonia mass flows between the flushing gutter and the reference compartment were registered. The ammonia reduction (24 - 42 %) depends on flushing intensity, season, air flow rate and percentage of treated slurry. In the flushing compartment odour emission was reduced by 30 % to 60 %. In general, nitrous oxide emissions were not significantly influenced. Carbon dioxide emission was reduced generally by 10 %.

Keywords: gaseous emissions, biological slurry treatment, fattening pig housing

Introduction

In conventional litterless pig fattening houses gaseous emissions (ammonia, methane, odour, carbon dioxide and nitrous oxide) are registered. Considerable methane emissions are released via fermentation of carbon into organic matter. Similarly, nitrogenous substances cause emissions of ammonia, nitrous oxide and carbon dioxide. Behind carbon dioxide, methane is considered the most important anthropogenic greenhouse gas. Even though rice paddies and anaerobic digestion processes of ruminants are the most significant anthropogenic methane sources, methane emissions from animal excrements should not be underestimated (Ahlgrimm and Breford, 1998; Husted, 1994). During slurry storage in the stall area, carbonaceous organic substances and anaerobic conditions combined with the prevalent temperatures cause unavoidably methane emissions. The question arises to what extent ammonia and methane emissions from litterless fattening pig housing can be reduced in the stall area by flushing out the daily produced excrements. In view of precision livestock farming the question poses which process parameters on slurry management are available at stable level to reduce gaseous emissions from fattening pig houses.

Animals, materials and methods

Two identical compartments of a fattening pig house with fully slatted floor (120 animals per compartment) were studied comparatively with regard to their gaseous emission behaviour. One compartment was equipped with flushing gutters (Figure 1).

The second compartment which was characterized by an intermediate slurry storage in the stable, was considered as the reference compartment. In order to guarantee the comparability of both compartments, the stalled-up animals were identical with regard to age and genetic origin. Season and technical treatment in both compartments were also identical. For the determination of gaseous emissions, concentrations of ammonia, carbon dioxide, methane and nitrous oxide in the exhaust air were measured continuously with a calibrated photo-acoustic system (multi-gas monitor 1302/multiplexer 1303, company Innova, DK). The air volume flows in both compartments were determined continuously on-line using calibrated measuring fans (FMS 45, company Fancom, NL). In each compartment two sampling points (S_1, S_2 at the reference and S_3, S_4 at the experimental compartment) were installed. Each measurement cycle for detecting gas concentrations at the sampling points took thirty minutes. The measurement sequence of each cycle was S_1, S_1, S_1, S_1, S_2, S_3, S_3, S_3, S_3, S_4. After changing the compartment, only the fourth measurement was used statistically. For all gases 48 data set were collected daily at each sampling point. Background level of ammonia was measured weekly. Regularly, the odour intensity of the exhaust air was determined by olfactometry (VDI 3881). Samples of slurry were taken at regular intervals from the different tanks. Several nitrogen fractions, dry matter, total carbon and chemical oxygen demand in the slurry were analysed in the laboratory (Meissner, 2004). The slurry flushed out daily was treated mechanically and biologically using a treatment plant described by Kiuntke (2002). In the first process step (Figure 2), the flushed-out slurry was mechanically separated in a funnel-shaped sedimentation tank using flocculation agent. Thus, the liquid phase gained was used for other flushing processes without additional water supply. Thereafter, 40 % of the thin fraction produced underwent a discontinuous biological treatment in a gassed stirring tank. In the bioreactor, primarily the nitrification of ammonium nitrogen as well as the breakdown of carbon and odour-intensive organic compounds took place.

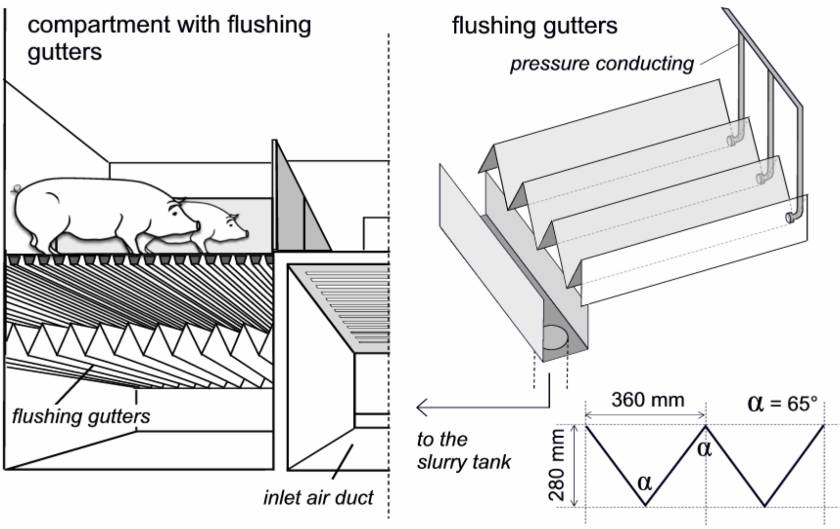

Figure 1. Cross section of the compartment with flushing gutters.

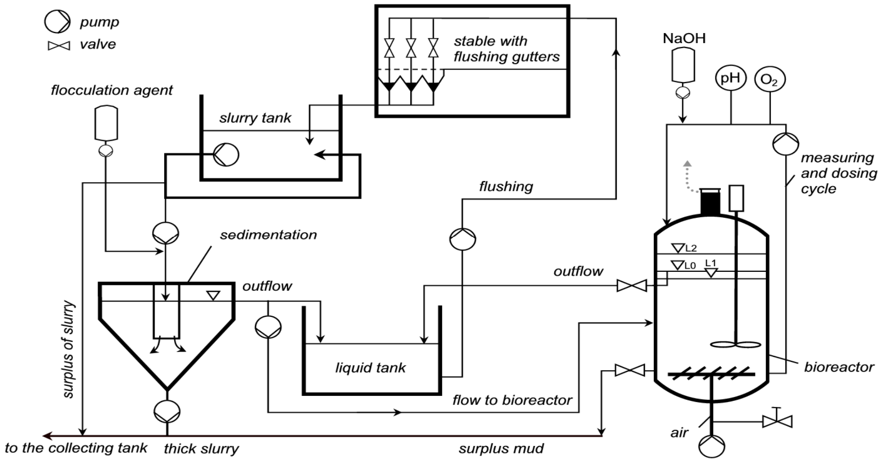

Figure 2. Flow chart of the experimental facility with a Sequence Batch Reactor (SBR).

After biological treatment, the effluent was mixed with the untreated thin fraction in a liquid tank. This mixture was used for the daily flushing (once or twice) of the flushing gutters. The treatment plant as well as the operation of the flushing demanuring system in the stall were controlled automatically. The study was divided into four experimental trials which differed in experimental set-up and season. Excrements were flushed out once per day in trial 1 and twice in the trials 2, 3 and 4. The fraction of biologically treated flushing liquid was set to 40 % for the first three experimental trials and to nil for the last trial. Except for trial 2 which was in summer, all other experiments were conducted under autumn/winter and winter/spring conditions (Table 1).
Statistical analysis of the collected data was carried out with the program package SAS 8.02 using the procedure "glm" (t-Test). First of all weekly averages of emission data were formed. For variance analytical calculations of emission data the effect of compartment, fattening week and trial were taken into consideration (LS Mean Procedure).

Results and discussion

Methane emissions

In the reference compartment methane emissions were strongly correlated to the fattening day (Figure 3). In all fattening periods, significant differences in the methane mass flows manifested themselves between the flushing gutter and the reference compartment (Figure 4).

Table 1. Experimental set-up (the measuring period lasted 12 weeks in all four trials).

Trial	Time (month/year)	Season	Daily flushing rate	Flushing liquid
V 1	01/02-05/02	winter/spring	1	40 % of flushing biologically treated
V 2	06/02-09/02	Summer/autumn	2	40 % of flushing liquid biologically treated
V 3	10/02-01/03	autumn/winter	2	40 % of flushing liquid biologically treated
V 4	02/03-05/03	winter/spring	2	liquid fraction untreated

The average CH_4 emissions as pooled over periods 1, 3 and 4 (Figure 4) amounted to 3.22-5.38 g CH_4 pig^{-1} d^{-1} for the flushing gutter compartment and to 20.49-29.62 g pig^{-1} d^{-1} for the reference. In trial V 1 and V 3 the flushing system reduced CH_4 emissions significantly by a reduction rate of 81 and 89 %. During summer (trial V 2) CH_4 emissions were much higher with 16.45 g CH_4 pig^{-1} d^{-1} for the flushing gutter compartment and 60.22 g CH_4 pig^{-1} d^{-1} for the control. The reduction rate by flushing was 76.24 %.

Ammonia emissions

In all fattening periods, significant differences of ammonia mass flows between the flushing gutter and the reference compartment were registered (Figure 5). The mean NH_3 emissions from the flushing gutter compartment were 5.02 to 9.63 g NH_3 pig^{-1} d^{-1}, compared to 8.09 to 13.99 g NH_3 pig^{-1} d^{-1} from the reference compartment.

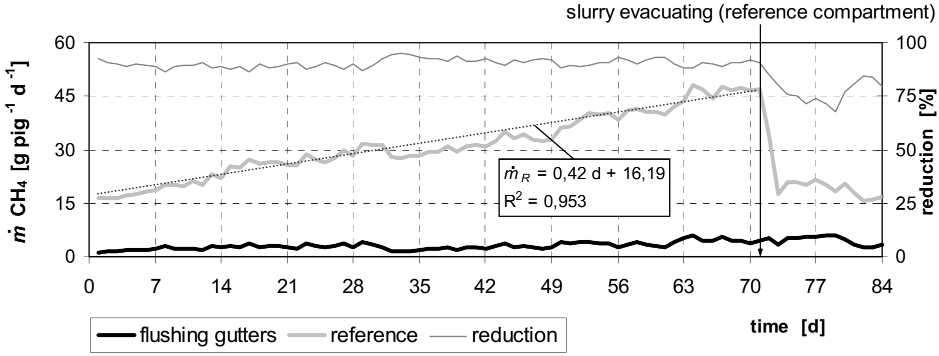

Figure 3. Daily course of daily methane emission rate depending on the treatment as well as the rate of reduction - Trial V 1, 1 flushing daily, 40 % of liquid fraction treated; ṁ mass flow.

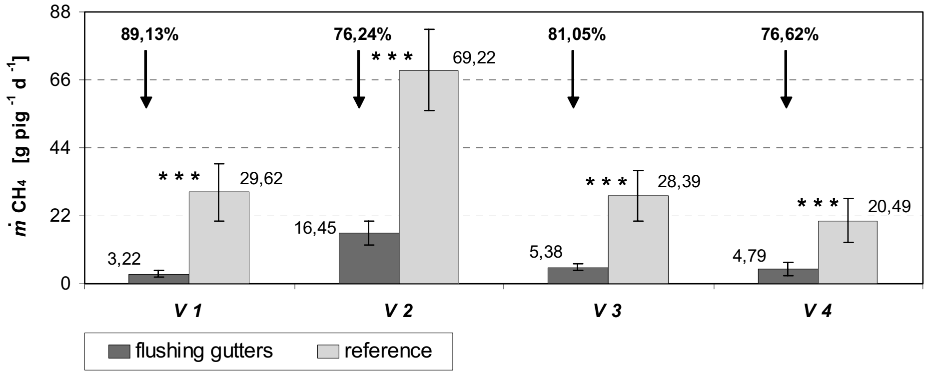

Figure 4. Least Square Means (LSM) and standard deviation (SD) of methane emission rates and the rates of reduction by the flushing system in trials V 1 - V 4
V 1, 1 flushing daily, 40 % of liquid fraction treated; V 2, 2 flushings daily, 40 % of liquid fraction treated; V 3, 2 flushings daily, 40 % of liquid fraction treated; V 4, 2 flushings daily, liquid fraction untreated; ṁ mass flow; *** P < 0.001.

Via flushing, NH_3 reduction rates of 23.91 % with one flushing event per day and up to 37.95 % with two flushing events per day were achieved (Figure 6). The combination of using biologically untreated flushing liquid and two flushings per day resulted in a reduction rate of 23.48 %. Generally, the reduction rates for NH_3 in this study were relatively small. In all trials, a high correlation between air flow rate and ammonia emission was registered (Figure 7). The ammonia reduction rate in the compartment with flushing gutters was highly correlated with the ammonia emission rate and the air flow rate (Figure 8).

Nitrous oxide emissions

Nitrous oxide emissions were rather small: a range of 0.30 to 0.48 g N_2O pig^{-1} d^{-1} for both compartments (Figure 9). Only in trial V 2, the nitrous oxide emissions were reduced significantly in the compartment with flushing gutters.

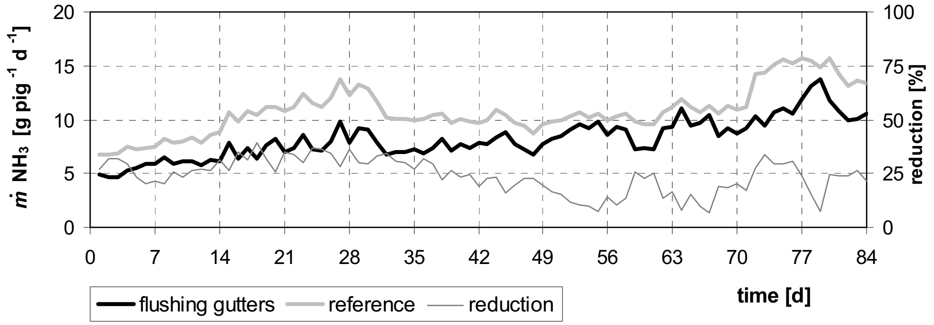

Figure 5. Daily course of ammonia emission rate depending on the treatment as well as the rate of reduction - Trial V 1, 1 flushing daily, 40 % of liquid fraction treated; ṁ mass flow.

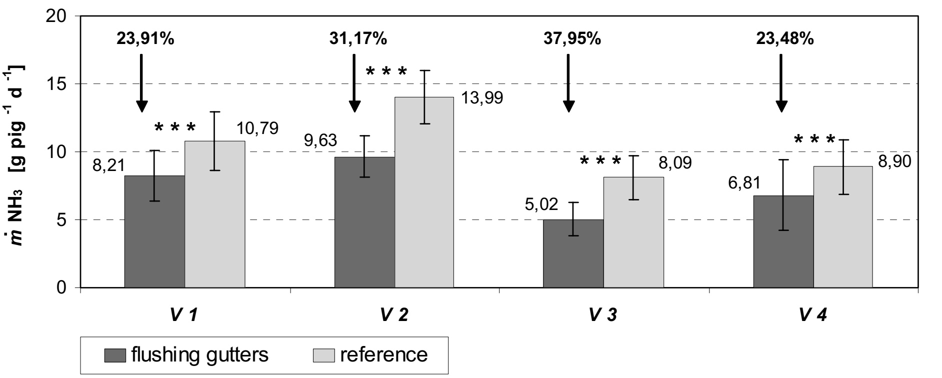

Figure 6. Least Square Means (LSM) and standard deviation (SD) of ammonia emission rates and the rates of reduction by the flushing system in trials V 1 - V 4
V 1, 1 flushing daily, 40 % of liquid fraction treated; V 2, 2 flushings daily, 40 % of liquid fraction treated; V 3, 2 flushings daily, 40 % of liquid fraction treated; V 4, 2 flushings daily, liquid fraction untreated; ṁ mass flow; *** P < 0.001.

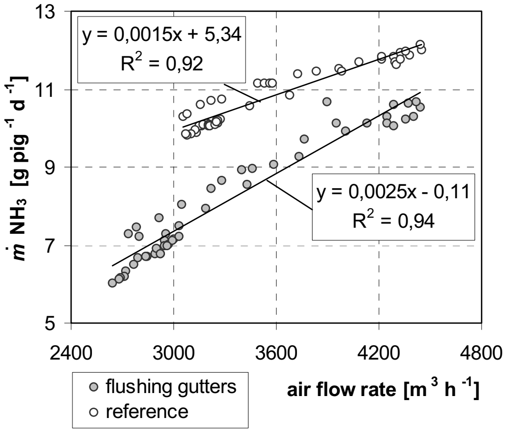

Figure 7. Relation between air flow rate and ammonia emission rate - Trial V 1, 1 flushing daily, 40 % of liquid fraction treated; $\dot{m}$ mass flow.

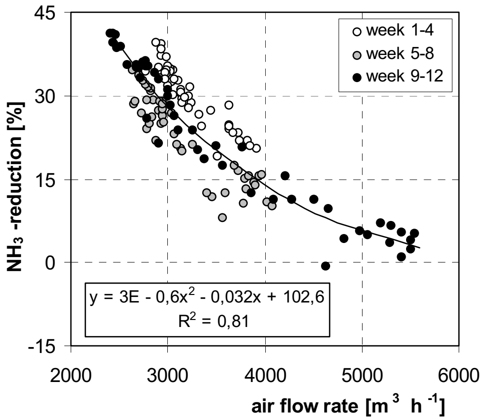

Figure 8: Relation between the ammonia emission reduction rate and the air flow rate in the compartment with flushing gutters - Trial V 1.

Carbon dioxide emissions

The mean CO_2 emissions were 1.8 and 2.2 kg CO_2 pig^{-1} d^{-1} for the flushing gutter and control compartment respectively, and resulted in a reduction rate of 10 % in the compartment with flushing gutters (Figure 10). The relationship between the emissions of CO_2 and NH_3 was found to be highly correlated in both compartments. In Figure 11 this relation for the compartment with flushing gutters is shown.

Odour emissions

Odour emissions were reduced by 30-61 % via flushing system. In the compartment with flushing gutters, the odour emissions amounted to 26-51 odour units (OU) s^{-1} LU^{-1} (livestock unit) whereas the odour emissions of the reference compartment scored 43-124 OU s^{-1} LU^{-1} (Figure 12). Soon after a flushing event, the odour concentrations reached very high values. If biologically treated

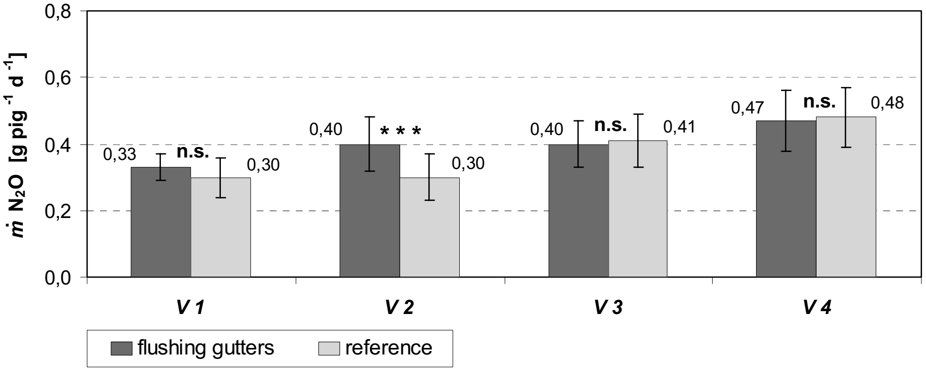

Figure 9: Least Square Means (LSM) and standard deviation (SD) of nitrous oxide emission rates in trials V 1 - V 4; ṁ mass flow; *** $P < 0.001$; n. s., not significant.

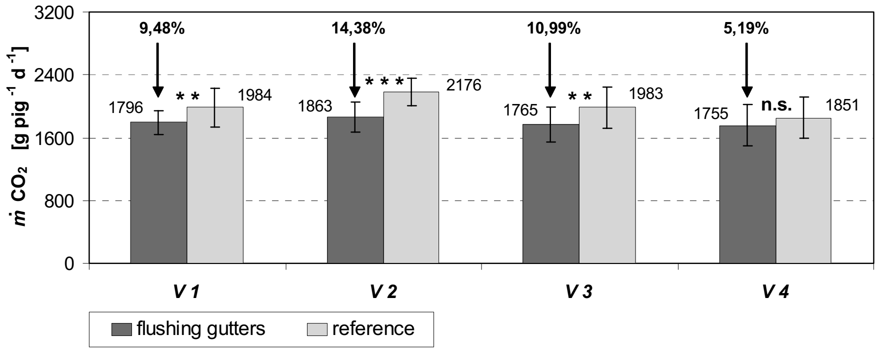

Figure 10. Least Square Means (LSM) and standard deviation (SD) of carbon dioxide emission rates and the rates of reduction by the flushing system in trials V 1 - V 4; ṁ mass flow; *** $P < 0.001$; ** $P < 0.01$; n. s., not significant.

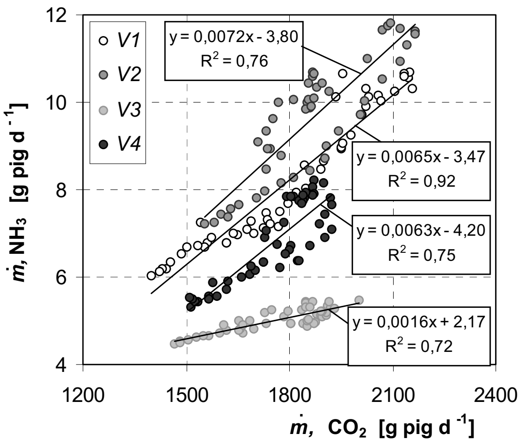

Figure 11. Relation between carbon dioxide and ammonia emission in the compartment with flushing gutters in trials V 1 - V 4; ṁ mass flow.

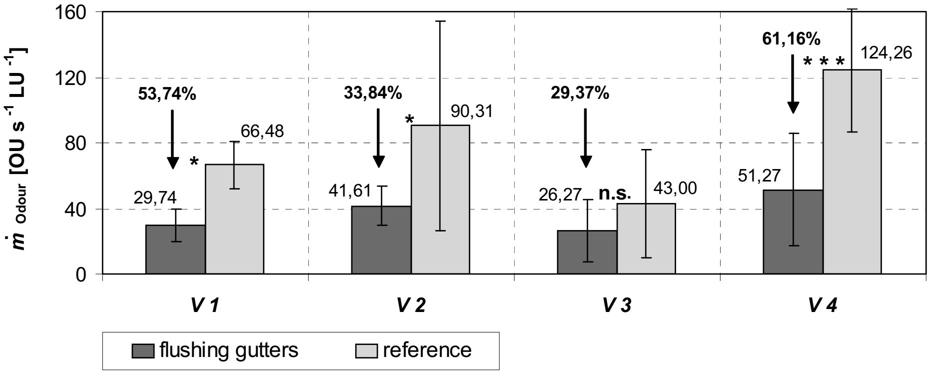

Figure 12. Least Square Means (LSM) and standard deviation (SD) of odour emission rates in the exhaust air and the rates of odour reduction by the flushing system in trials V_1 - V_4. OU, odour unit; LU, livestock unit; ṁ mass flow; *** $P < 0.001$; * $P < 0.05$; n. s., not significant.

liquid was used, peak values were 5 times higher than the overall level before the flushing event, with the usage of untreated flushing liquid peak values were 10 times higher than the overall level before the flushing event. Just like N_2O, these short-lived peak values hardly affected the overall odour emissions.

Conclusions

Methane emissions from a pig stall were reduced on a large scale with the use of the flushing gutter system. Biological slurry treatment had no influence on the methane reduction via flushing. The flushing gutter system also enabled a reduction of ammonia emissions in fattening pig houses. The level of reduction was influenced by the season (influence of outside air temperature and ventilation rate) and the daily flushing rate (once or twice a day). The effect of biological treatment on the reduction of ammonia emission could be compensated by the flushing rate. The relationship between the emissions of carbon dioxide and ammonia was highly correlated. Odour emissions were reduced by 30 - 60 % via flushing system. Nitrous oxide emissions for both compartments were rather small.

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Effect of low crude protein level in different phase feeding strategies on ammonia emission rates of finishing pig facilities

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Abstract

Ammonia volatilisation in houses for growing and finishing pigs should be reduced to protect the environment and to improve indoor air quality. The objective of the investigation was to examine the effect of various feeding strategies with decreased crude protein levels on the ammonia volatilisation in a fully slatted housing system for fattening pigs. In an insulated building with four identical mechanically ventilated compartments for fattening pigs, four feeding strategies with decreased crude protein (CP) levels were investigated. The following treatments were studied: Treatment 1, two phase feeding with two diets; treatment 2, two phase feeding with a reduced crude protein level in the finishing stage; treatment 3, multiphase feeding with a reduced crude protein level and weekly adaptation; treatment 4, multiphase feeding with a reduced crude protein level and daily adaptation.

Between the four treatments no significant differences were found for fattening performance parameters. Compared to treatment 1 multiphase feeding with daily adaptation of the mixing ratio reduced the amount of ammonia emission rate by 43 %. Multiphase feeding with decreased crude protein level results in a clearly improved indoor air quality.

Keywords: ammonia emission, indoor air quality, fattening pigs

Introduction

Research was conducted to examine the effect of low protein diets in combination with common fully slatted floor housing system for fattening pigs on ammonia emission rate, indoor air quality and performance of growing and finishing pigs. The experiment was carried out to study the possibility to reduce the ammonia volatilisation by feeding different multiphase strategies with decreased protein levels. Feeding low protein diets appears to be an efficient way for reducing the volatilisation of ammonia. Latimier and Dourmad (1993), Van der Peet-Schwering *et al.* (1996) and Portejoie *et al.* (2004) observed a similar reduction in nitrogen excretion. A reduction of nitrogen in the liquid manure of fattening pigs can be reached in practice using different diets during the growing and the finishing periods compared to a feeding strategy with one diet (17.5% CP) over the whole fattening period. Another step forward is to provide an adapted protein supply to the requirements of the pigs by mixing two diets with different protein levels each day or at least each week. The commonly so-called multiphase feeding allows a further reduction in nitrogen excretion (Bourbon *et al.*, 1997). Ammonia volatilisation from pig facilities are also strongly affected by housing conditions (Ni, 1998). This paper reports current research to establish the specific effects of several feeding strategies on ammonia volatilisation and ammonia emission rate.

Animals, materials and methods

Experimental design

Comparative investigations were carried out in four identical compartments of a thermally insulated stable with mechanical ventilation (Figures 1 and 2). In each compartment fattening pigs were reared in twelve pens on fully slatted floor (10 pigs·pen^{-1}, 0.7 m^{2}·pig^{-1}). In all compartments castrated male and female pigs of one swine nursery (German Landrace x Duroc x Piétrain) were reared at a balanced gender ratio. Within the pens of each compartment, male and female pigs were kept separately). The pigs were stalled in into the compartments with an average starting weight of 35.5 kg (±2,6 kg). In total, two fattening periods were analysed.

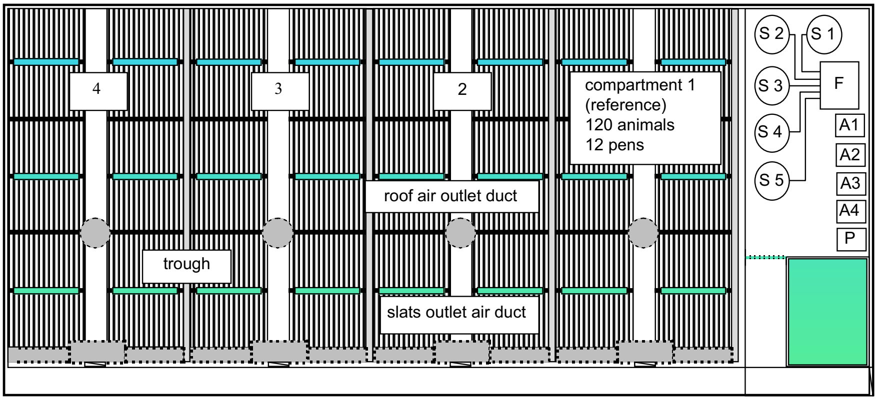


Figure 1. Outline of the experimental housing system for growing and finishing pigs.
S, silos; F, feed mixer; A, air sampling boxes; P, pump box; 2, compartment 2; 3 compartment 3; 4, compartment 4.

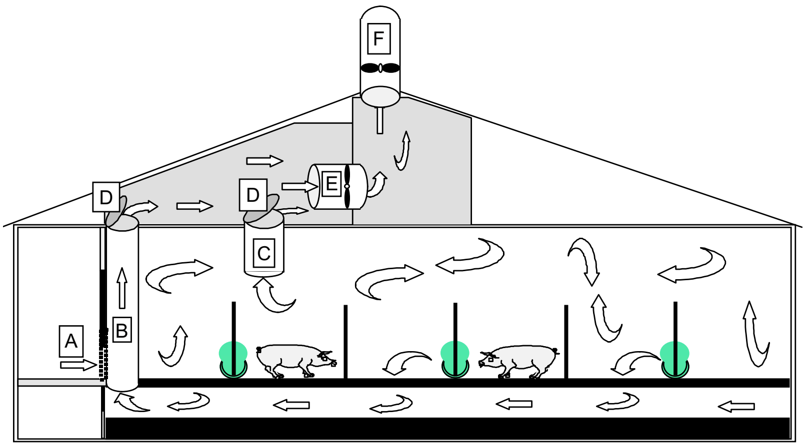


Figure 2. Ventilation system - inlet and outlet air streams.
A, air inlet; B, under slats air outlet; C, roof air outlet; D, baffle; E, sensor impeller and measuring point; F, outlet fan.

To avoid the effect of different ventilation rates (Aarnink and Wagemans, 1995; Aarnink, 1997) on ammonia emission rate, design and control of ventilation was identical in all compartments.

Composition of diets and feeding strategies

In this study, four feeding strategies with decreased crude protein levels were investigated (Table 1). Pigs of each compartment were fed different feeding strategies (treatments). In total, four different feed compositions (FC) were used in this study depending on the feeding strategy and the fatting stage (I: Live Weight (LW) < 60 kg; II: LW < 80 kg and III: > 80 kg, Table 1).

Table 1. Feeding strategies. CP, crude protein; ME, metabolic energy; FC1, FC2, FC3, FC4, feed composition 1,2,3,4

Fattening stage	Treatment	Feed
Stage I:	All treatments	18.25% CP; ME: 13MJ/kg (FC1)
Stage II	Treatment 1	16.5% CP; 0.9% Lysine; ME: 13 $MJ \cdot kg^{-1}$ (FC2)
	Treatment 2	13.8% CP; 0.8% Lysine; ME: 13 $MJ \cdot kg^{-1}$ (FC3)
	Treatment 3	FC2 and FC3 mixed in different ratios varying each week
	Treatment 4	FC2 and FC3 mixed in different ratios varying each day (20 steps)
Stage III	Treatment 1	FC2
	Treatment 2	FC3
	Treatment 3	13.5% CP; 0.72% Lysine; ME: 12.6 $MJ \cdot kg^{-1}$ (FC4) mixed with FC3 in different ratios varying each week
	Treatment 4	FC 3 and FC4 mixed in different ratios varying each day (20 steps)

Measurements

All pigs were weighed at the beginning and the end of the whole fattening period. The amount of used feed was registered in each fattening stage and in each treatment. Diets and feeding mixtures were analysed weekly. During each fattening period, the liquid manure of each compartment was stored separately. At the end of each fattening period, the liquid manure level was measured at four measuring points in each compartment. The quantity of liquid manure was calculated by multiplication of the mean of liquid manure levels and a floor space of the liquid manure canal. After each fattening period, the liquid manure of each compartment was pumped out of the canals separately. During pumping, 50 spot samples were drawn and mixed to obtain a representative liquid manure sample. The nitrogen concentration (Autoanalyser Macro N", Hereaus, Germany) as well as the dry matter content of these liquid manure sample were analysed for each compartment.

Air temperature and air humidity (indoor and outdoor) were measured continuously (Intec corp., Germany) and registered on-line with data loggers (Technetics corp., Germany). Ventilation rate was measured continuously and registered on-line with a sensor-impeller (Multifan corp., The Netherlands).

During the whole fattening period, ammonia concentrations of the indoor air were measured once daily. Therefore, every hour 1 $l \cdot min^{-1}$ outlet air of each compartment separately was drawn in by a vacuum pump and flushed through an impinger with diluted sulphuric acid (conc. 0,005 M). The impingers were changed every 24 hours (Figure 3). Ammonia and sulphuric acid reacted to ammonium sulphate. Analytical processing was done in the laboratory via the Indophenol-Blue-Reaction (modified Berthelot Reaction). The measurement of ammonium-N was carried out photometrically (EPOS-Analyser, Eppendorf corp., Germany). The concentration of ammonia was calculated by means of equation 1. The daily ammonia emission rate was calculated by multiplication of the daily ventilation rate and daily ammonia concentration.

$$NH_3\ [mg \cdot m^{-3}] = 100 \cdot NH_4^+\text{-}N\ [mg \cdot m^{-3}] \div 82.32^* \quad (1)$$

*N-ratio of the molar mass of ammonia

Statistical calculations of the collected data were carried out with the program package SAS 8.01 using the procedure "glm" (t-Test). For analytical evaluation of the variance of nitrogen related data, the effects of treatment and repetition were taken into consideration. Analytical calculations of the variance of performance data were done in relation to the effects of treatment and repetition as well as the covariable starting weight and the covariable duration of the fatting period. For calculation of lean meat percentage the effects of treatment and repetition as well as the covariable carcass weight were taken into account.

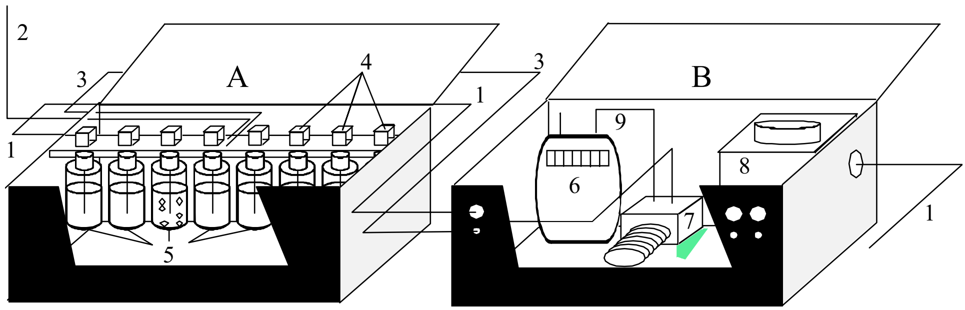
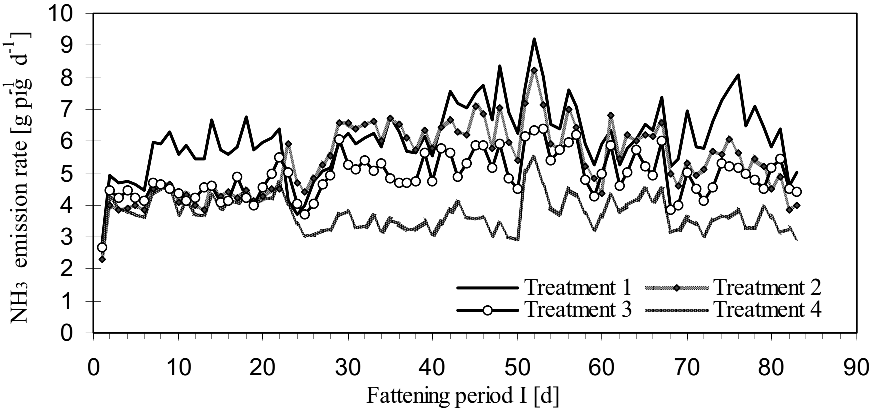


Figure 3. Air sampling and ammonia measurement.
A: air collecting box; 1, power cable; 2, PTFE-tube with dust filter; 3, PTFE-tube with critical capillary; 4, valves; 5, impinger (0.005 M sulphuric acid)
B: pump box; 6, air rate counter; 7, vacuum pump; 8, timer switch; 9, PTFE-tube

Results and discussion

Ammonia

The daily courses of the ammonia emission rate are shown in Figure 4. The courses of the different treatments reflect the content of crude protein in the feed. In fattening period I as well as in fattening period II the lowest emission rates were detected in treatment 4 with the multiphase strategy (daily adaptation), whereas in both fattening periods the highest ammonia emissions were found with treatment 1 (two phase feeding).
Least Square Means and Standard Error of ammonia concentrations and of emission rates depending on the four feeding strategies (four treatments) are shown in Table 2. Multiphase feeding with a decreased crude protein level reduced ammonia emission rates and indoor ammonia concentrations compared to treatment 1 and 2. The ammonia emission rate was reduced by 42.6



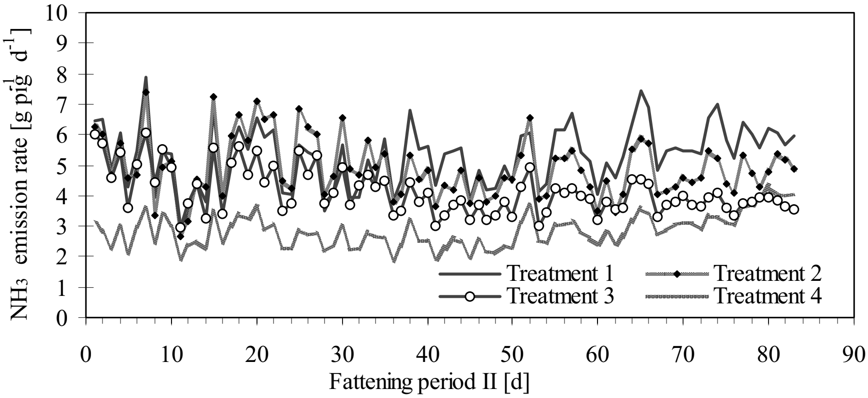


Figure 4. Daily courses of the ammonia emission rates depending on the treatment and the fattening period.

% with multiphase feeding in treatment 4 and by 21.1 % in treatment 3 compared to treatment 1. Concerning the ammonia concentration a reduction of 45.5% in treatment 4 could be established compared to treatment 1. A close connection exits between the protein level of the feed and urea excretion (Pfeiffer, 1991). It can be assumed that reducing the urea excretion led to a decrease of ammonia emission rate and ammonia concentration in pig houses.

Table 2. Least Square Means (LSM) and Standard Error (SE) of ammonia concentration and ammonia emission rate depending on the treatment.

	Treatment 1 LSM (SE)	Treatment 2 LSM (SE)	Treatment 3 LSM (SE)	Treatment 4 LSM (SE)
NH_3- concentration [$mg \cdot m^{-3}$]	14.5^a (0.4)	13.6^a (0.4)	11.1^b (0.4)	7.9^c (0.4)
NH_3-emission rate [$g \cdot pig^{-1} \cdot d^{-1}$]	5.7^a (0.1)	5.2^b (0.1)	4.5^c (0.1)	3.3^d (0.1)

d; day; LSMs with different superscripts are significantly different, P < 0.05 (t-Test).

Liquid manure

The concentration of total nitrogen in the liquid manure differed significantly between the treatments (Table 3). Liquid manure of pigs fed with the multiphase strategy (daily adaptation) contained 12.5% less total nitrogen per kilogram dry matter compared to the reference treatment 1 (two phase feeding).
By means of registered amount of liquid manure as well as analysed concentration of nitrogen and dry matter content, the amount of nitrogen in the liquid manure for each treatment was calculated. A significant reduction of nitrogen in the liquid manure of treatment 2, 3 and 4 had been determined (Table 4). Overall, 25 % (treatments 2,3,4) less nitrogen accumulated in the liquid manure compared to the reference (treatment 1).

Table 3. Least Square Means (LSM) and Standard Error (SE) of nitrogen concentrations of the liquid manure at the end of the fattening period depending on the treatment.

	Treatment 1 LSM (SE)	Treatment 2 LSM (SE)	Treatment 3 LSM (SE)	Treatment 4 LSM (SE)
Nitrogen conc. [$g \cdot kg^{-1}$ DM]	71.5^{a} (0.6)	69.7^{ab} (0.6)	68.0^{b} (0.6)	62.5^{c} (0.6)
Dry matter [%]	9.2^{a} (0.5)	8.4^{a} (0.5)	8.0^{a} (0.5)	8.5^{a} (0.5)

DM, dry matter; LSMs with different superscripts are significantly different, $P < 0.05$ (t-Test).

Table 4. Least Square Means (LSM) and Standard Error (SE) of the quantity of liquid manure and nitrogen amount in the liquid manure per pig and day depending on the treatment.

	Treatment 1 LSM (SE)	Treatment 2 LSM (SE)	Treatment 3 LSM (SE)	Treatment 4 LSM (SE)
Liquid manure [$l \cdot pig^{-1} \cdot d^{-1}$]	4.2^{a} (0.1)	4.0^{a} (0.1)	3.8^{a} (0.1)	3.8^{a} (0.1)
Nitrogen [$g \cdot pig^{-1} \cdot d^{-1}$]	27.3^{a} (1.3)	20.4^{b} (1.3)	20.9^{b} (1.3)	20.4^{b} (1.3)

d, day; LSMs with different superscripts are significantly different, $P < 0.05$ (t-Test).

Performance

Performance parameters depending on the feeding strategy are shown in Table 5. The length of the fattening period was different in all treatments, which seems to be due to the different average starting weights of the pigs in each treatment. Therefore, Least Square Means of finishing weight and carcass weight as well as weight gain are corrected on starting weight and length of fattening period. The finishing weight, carcass weight and the weight gain of piglets varied between the treatments over a small range; no significant differences could be established between the treatments. Furthermore, no significant differences were found between the treatments for daily feed intake and feed conversion. Although the percentage of lean meat was higher in Treatments 1 and 2, again no significant differences could be established between the treatments.

Table 5. Least Square Means (LSM) and Standard Error (SE) of performance parameter depending on the feeding strategy.

		Treatment 1 LSM (SE)	Treatment 2 LSM (SE)	Treatment 3 LSM (SE)	Treatment 4 LSM (SE)
Finishing weight	[$kg \cdot pig^{-1}$]	119.9^a (0.9)	119.4^a (0.6)	122.0^a (0.5)	124.7^a (0.9)
Weight gain	[$kg \cdot pig^{-1}$]	84.3^a (0.9)	83.9^a (0.5)	86.5^a (0.5)	89.1^a (0.9)
Daily weight gain	[$g \cdot d^{-1}$]	759.5^a (6.6)	752.6^a (3.3)	773.8^a (3.8)	798.5^a (6.4)
Daily feed intake	[$kg \cdot day^{-1}$]	2.46^a (0.03)	2.42^a (0.03)	2.36^a (0.03)	2.40^a (0.03)
Feed conversion	[1:]	3.11^a (0.03)	3.16^a (0.03)	3.10^a (0.03)	3.15^a (0.03)
Carcass weight	[$kg \cdot pig^{-1}$]	92.4^a (3.7)	95.7^a (1.8)	98.4^a (2.1)	103.2^a (3.5)
Lean meat	[%]	56.7^a (0.5)	56.7^a (0.3)	55.6^a (0.3)	54.6^a (0.5)

LSMs with different superscripts are significantly different, $P < 0.05$ (t-Test).

Conclusions

Comparing the four feeding strategies with different crude protein and lysine levels, the following conclusions can be drawn: No significant differences were found between the treatments for performance parameters. Compared to treatment 1, multiphase feeding with daily adaptation (treatment 4) reduced the ammonia emission rate by 43 %. Nitrogen concentration in the liquid manure was reduced in all treatments with a low crude protein feeding (treatment 2-4). The quantity of liquid manure was reduced by 10 % in treatment 3 and 4 compared to the reference treatment 1. Multiphase feeding with decreased crude protein level results in a clearly improved indoor air quality.

Acknowledgements

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Precise manure handling

Origins of blockages during the spreading of liquid manure

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Abstract

Application of animal liquid manure with trailing hoses or injectors decreases ammonia emissions, optimises agronomic efficiency and enables precision fertilising. The major drawback of this technique is its cost, but reluctance is also increasing due to frequent blockages during spreading of cattle slurry. A survey has been conducted in 20 farms where liquid manure is spread with trailing hoses. It was stated that the most frequent blockages were due to straw pieces. From examination of slurry samples, a relationship could be established between blockage frequency and two characteristics of the slurry : dry matter content and total length of straw pieces. The risk of blockage could also be assessed by means of a "clogging meter" which appeared to be a reliable tool for predicting whether a particular type of manure will be easily spread or not, and then giving the farmer information on the possibility of using trailing hoses or injectors.

Keywords: manure, spreader, blockage

Introduction

Background

Cattle housing is continuously evolving. Experts in animal housing are permanently confronted with cost reduction as well as the latest technical requirements. When building new projects, they will have to consider manure production for assessment of the required storage volumes. However, manure spreading will generally not be included within the project and its cost estimate. Therefore, unexpected expenses or consequences may arise when livestock are settled in the new shed. Specific problems arose recently in France with increasing quantities of semi liquid manure. This intermediate consistency creates large problems for spreading operations because vacuum tankers or solid manure spreaders are not suitable for semi-liquid materials. To solve this issue, housing schemes should clearly reject intermediate solutions between liquid and solid manure production. To avoid comparable difficulties, it was decided to examine the consequences of new housing designs on spreading conditions of liquid manures. Two main problems were identified : Increasing volumes of dirty water are due to rainfall on uncovered areas. Constructing large storage facilities is usually preferred rather than building roofs over walkways and yards. Spreading costs are then highly increased by these dirty waters, which necessitate the same compulsory precautions as those required for liquid manure. For correct cost estimates, it is therefore necessary to consider spreading costs in the global cost calculation.
The second issue was the risk of blockage during liquid manure spreading. No reference or solution was available on this particular difficulty and no clear relationship with housing design could be defined. Therefore an analysis of this problem was initiated and constitutes the topic of the present research work.

Purpose of the research

Application of animal liquid manure with trailing hoses or injectors decreases ammonia emissions, optimises agronomic efficiency and enables precision fertilising. The major drawback of this technique is its cost, but reluctance is also increasing due to frequent blockages during spreading of cattle slurry. This risk may discourage farmers directly involved in an environmental approach. It is also often of concern to the different users of these spreaders which are usually owned by a group of farmers. Consequently, the choice of trailing hoses or injectors can be compromised by one single member of the group facing this particular difficulty. Different explanations are usually given for these blockages. According to manufacturers, these problems are created by waste or undesirable objects within the slurry. For most farmers, blockages are linked with straw content or inefficient equipment. Understanding of the origin of blockages was thus necessary.

Objectives

The first objective was to determine the influence of housing design on the risk of blockages in order to optimize new housing schemes. The second objective was to establish the main parameters which are the causes of these phenomena, so that technological solutions could be proposed. The last objective was to set up some test to inform farmers on the possibility of using trailing hoses or injectors with a given type of slurry. This test could also be used to evaluate the efficiency of different pieces of equipment with regard to risk of blockages.

Materials and methods

Initial survey

In order to relate housing design with risks of blockages, a farm survey was conducted. Twenty cattle farms were visited in Brittany where intensive livestock farming is developed. Among this sample, 18 farms are using trailing hoses and two are using injectors. The cattle slurry may be mixed with pig manure or dirty waters. At each farm, a questionnaire was filled in order to determine, on one hand, the real observed risk and, on the other, the estimated latent risk corresponding to the particular housing scheme.

Actual blockage occurrences were assessed by blockage frequency as stated by the farmers. The average number of blockages per day is subsequently the selected indicator for the real risk. To assess the potential risk of each cattle house, two categories were considered, mainly in relation with manure handling principles. These categories were based on the possibility of incorporating bedding material inside the slurry. In this way, a plan of the housing was drawn and the contacts between liquid manure and solid manure while scraping were identified. For example, housings with slatted floor were considered as not generating risk. For cubicle houses, the potential risk was estimated as being dependant on the predictable quantities of straw in the slurry. Figure 1 shows an example of cubicle housing being considered as moderately hazardous. Two passageways, with solid concrete floor, are scraped separately. The amount of straw used for bedding is quite significant : 3 kg per cow and per day. The manure issued from cubicles is scraped in the passageway and pushed into the solid manure store. Liquid manure scraped on the other passageway is directly discharged into the tank. No real possibility of mixing both elements can be observed.

An example of hazardous design is shown in Figure 2. In this case, four passageways with concrete solid floors have common parts. One part of the shed is utilized as a loose pen. Solid manure will be scraped from the neighbouring passageway. For cubicles bedding, straw bales are set down in a central corridor. Straw is extracted and spread out in cubicles by the cows themselves. Straw quantity is not really controlled. Therefore, the manure issued from cubicles may have a

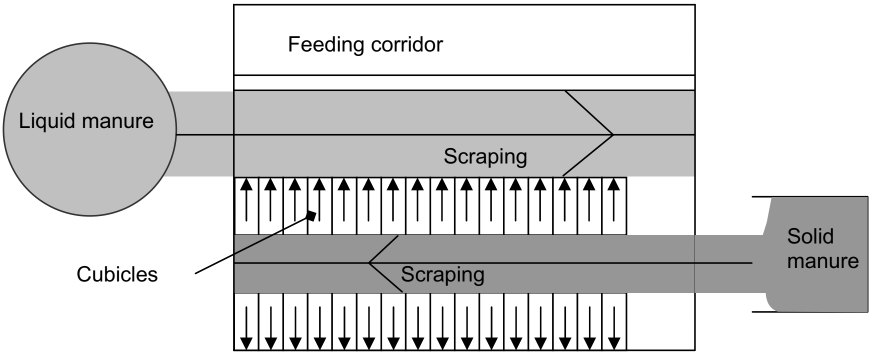

Figure 1. Example of housing design considered as moderately hazardous for risk of blockages (arrows represent cows positions in the cubicles).

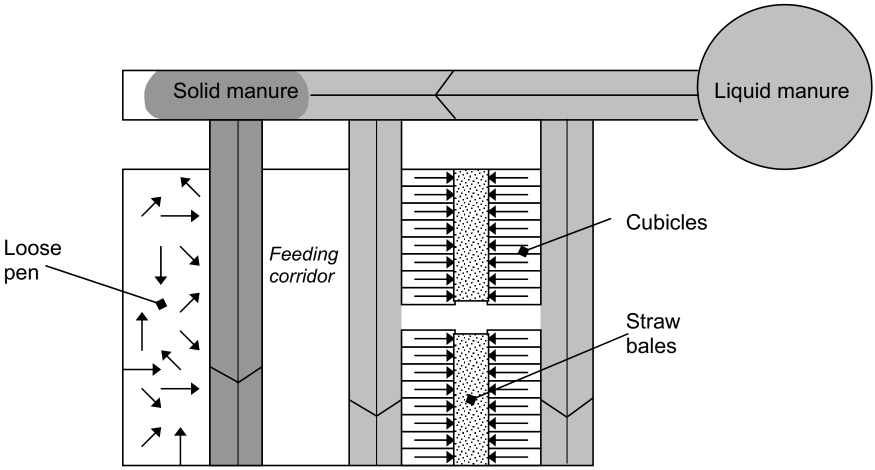

Figure 2. Example of housing design considered as highly hazardous for risk of blockages (arrows represent cows positions).

significant straw content. Furthermore, additional straw may be mixed with liquid manure when the terminal scraper works at the edge of the solid manure store.

Samples analysis

During the survey, slurry samples were taken from manure tanks. This was done only on tanks which had been recently agitated. In the end, 13 samples were collected and examined. Dry matter content, density and settling rapidity were measured. The main operation was separation of the various constituting elements issued from one litre of slurry sample. Figure 3 shows the principle of this separation in four different components:

- Screened liquid effluent
- Straw pieces
- Grains, silage bits, various particles
- Fibres of undigested hay or silage

Straw pieces were measured and counted.

Figure 3. Separation of 1 litre of slurry into 4 different components.

Testing equipment

Two different types of apparatus have been used to determine their efficiency in evaluating risks of blockages. Both equipments have been designed by JTI (Malgery and Wetterberg, 1996).
The "fluidimeter" is shown in Figure 4. When the valve is opened, the operator measures the time to empty, using a stop watch or a light cell. This time to empty determines the slurry fluidity.

The "clogging meter" has a volume of approximately 80 litres and is divided in four sections. In the bottom of each section, there are holes with diameters of 15, 25, 35 and 45 mm, respectively. The total hole area is the same in all four sections. When the meter is filled with slurry, the bottom is opened and slurry flows through the holes. A "clogging index" i_{cl} is then determined according to the number of the clogged holes n_{cl} and the depth d_{ret} of retained slurry in corresponding sections.

$$i_{cl} = 25\left(\frac{n_{cl1}}{64} + \frac{n_{cl2}}{24} + \frac{n_{cl3}}{12} + \frac{n_{cl4}}{7} + \frac{d_{ret1} + d_{ret2} + d_{ret3} + d_{ret4}}{d_0}\right) \quad (1)$$

Figure 5 shows the design of the "clogging meter" used during the research.
Large quantities of slurry are necessary to fill these two apparatus. Specific equipment was designed for pumping from the manure store without disturbing the slurry structure. The liquid is sucked by vacuum into a 1000 litres capacity tank. An adjustable pole allows control of pumping

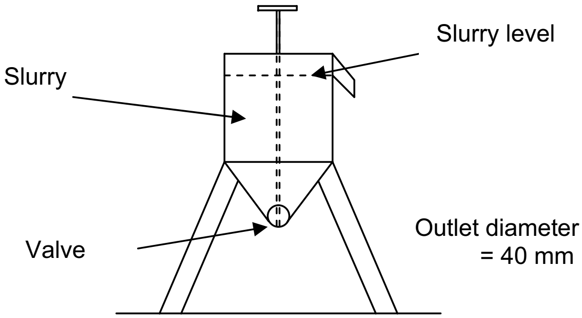

Figure 4. Diagram of the fluidimeter.

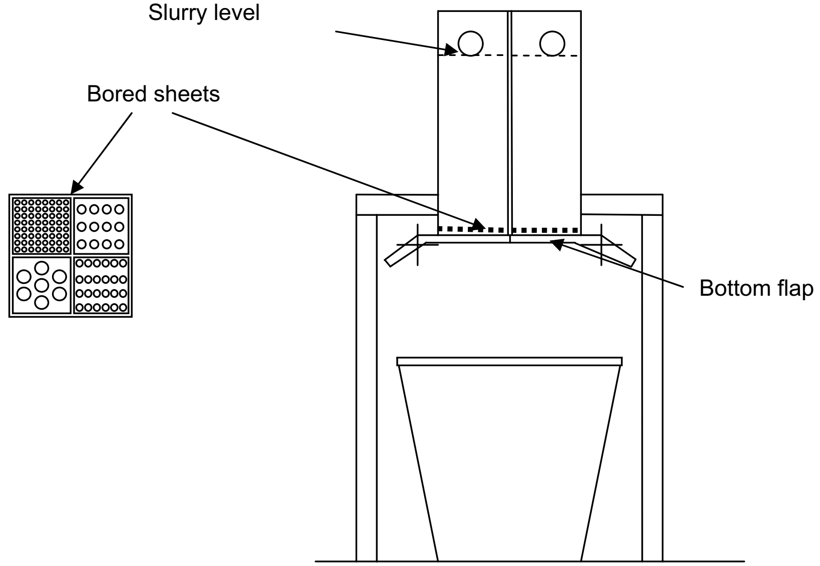

Figure 5. Diagram of the "clogging meter".

depth. Eight experiments were conducted with this equipment. All eight experiments involved farmers using the same new spreader. This means that the differences observed in the frequency of blockages are only due to slurry consistency (and not to differences within spreaders).

Results

Influence of housing design on blocking phenomena

The farmers who were consulted considered that one blockage per day would be tolerable. When two or more blockages occur each day, farmers want to give up with this technology as wasted time is important and unblocking operations may be dangerous. Blockage occurs mainly with straw (78 %) inside the rotary distributor (75 %).

Figure 6 reports blockage frequency for each estimated class of risk. It can be observed that blockage occurrences are less frequent for the anticipated moderate risks than for the anticipated

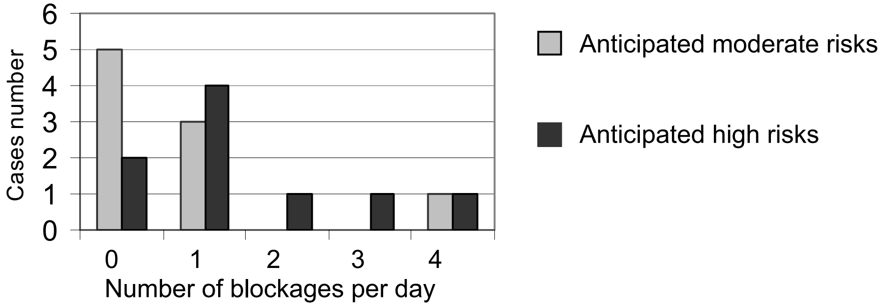

Figure 6. Blockage frequency for each anticipated class of risk.

high risks. The two cases relating four blockages per day are actually related to the same spreader which is suspected to have serious malfunctions. Therefore these two particular cases can reasonably be omitted. Despite this omission, it is not possible to explain the large variety of blockage occurrences, especially in "high risks" class.
Large variability of farm practices (bedding material, slurry crushing, slurry dilution, etc) probably explains the difficulty of predicting blockage problems in relation to housing design. The total number of farms was not sufficient to analyse the weight of each parameter. Therefore, direct reference to slurry composition was expected to be more significant for risk prediction.

Influence of slurry composition on blockages

Collected data were used to calculate a blockage index i_{bl} which was compared with blockage frequency. Highest correlations were selected and led to equation 2.

$$i_{bl} = (DM)^{1.3} \times (L)^{0.8} \quad (2)$$

Where i_{bl} is the calculated blockage index, DM is the dry matter content in percentage and L is the total cumulated length (m) of straw pieces. Only straw pieces exceeding 20 mm are considered. Figure 7 shows the results for 13 samples.
Blockage frequency can be estimated from blockage index (i_{bl}) through equation 3:

$$\text{Estimated blockage frequency} = i_{bl} / 12.1 \quad (3)$$

This result confirms that blockages are created by straw accumulation. When the slurry does not contain any straw, no blockage is observed. For similar straw content, the dry matter content increases the risk of blockages. Fibres which mainly constitute the dry matter mass act as a cement linking the straw pieces.

Testing equipment

Collected data were compared with blockage frequency. Low correlations were observed with fluidity, whilst a good correlation was obtained with "clogging meter" results as shown in Figure 8.
No risk of blockages can be expected when the clogging index is less than 60. Blockage frequency can be estimated from "clogging index" (i_{cl}) through a linear correlation (equation 4):

$$\text{Estimated blockage frequency} = (i_{cl} - 60) / 23.9 \text{ for } 60 < i_{cl} < 150 \quad (4)$$

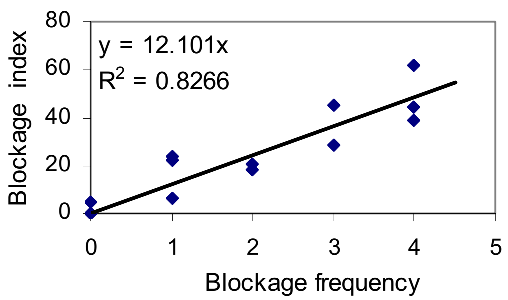

Figure 7. Correlation between calculated blockage index and actual blockage frequency.

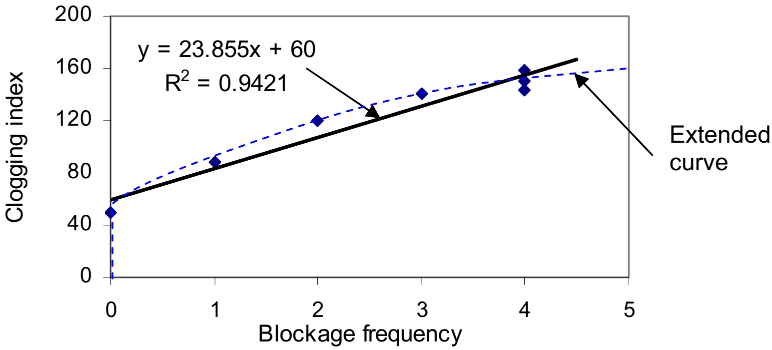

Figure 8. Correlation between measured “clogging index” and real blockage frequency.

Beyond this interval, we may consider a quite permanent blockage. A small increase of the clogging index will mean a large increase of the blocking frequency. It suggests an asymptotic evolution of the extended curve (dotted line Figure 8) leading to a maximum (clogging index 160).
The good correlation enables the use of the “clogging meter” to evaluate the blocking risk of any particular slurry with the referenced spreader. It also enables the comparison of different machines by establishing similar relationships between “clogging indices” and blockage frequencies observed with the spreaders under test.

Discussion

In the present work, blockage and clogging were equally considered as they both lead to flow interruption : initial clogging will finally result in complete real blockages. Phenomena reported by farmers are clearly described as blockages affecting one or several hoses. Usually farmers will not identify partial pipe obstruction because flow rate measurements would be necessary to detect the flow restrictions. These flow perturbations may also result from two other phenomena largely related to slurry consistency.
One is the progressive restriction of hose sections due to deposits. It originates from slurry sedimentation and is mainly revealed after non working periods while the manure dries in the circuit. It is therefore necessary to rinse all the pipes after use.
The other phenomenon is the flow restriction due to increased head losses generated by high slurry viscosity. Slurry viscosity (η_s) is related to slurry characteristics in accordance with equation 5 (Türk, 1994) :

$$\eta_s = \frac{4\tau_0}{\pi \cdot D} + k(\frac{\pi}{4}D)^{n-1} \qquad (5)$$

where D is the shear rate. Values of , *k* and *n* are provided by Tables according to manure origin and dry matter content. Head losses due to slurry viscosity will reduce the flow rate in the longest pipes and alter the distribution evenness. Similarly, transverse slopes will also modify the spreading distribution due to flow perturbation (Sauter *et al.*, 2004).

Conclusions

No precise relationship could be established between cattle housing design and blockage risk, but the adverse influence of straw content in the slurry is certain. Therefore, this problem should be systematically considered in new building projects. The proposed method can be used for this

purpose. Testing apparatus can also be used to evaluate the efficiency of future remedies. Unsatisfying housing cannot be easily re-engineered. Therefore solutions have to be found among farm practices and it will be possible to evaluate them by blockage risk assessment.
Various experiments have been reported on precision spreading of liquid manure. Spatial modulation of the application rate is actually feasible. For these practices, it is necessary to ensure the prerequisite of the reliable operation of the spreader. In this way, it is not only blockage phenomena which should be considered, but also investigations on flow steadiness and distribution which have still to be carried out.

Acknowledgements

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Study of organic substrate production by composting swine manure with wood shavings

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Abstract

The great amount of waste discharged by the booming livestock industry in China and the defects of conventional soilless substrates both have led toPOST http://www.konferensverktyg.com/dotntes as an available alternative to abate the serious livestock waste pollution. However, few researches so far are pertinent to it. In this paper, the appropriate proportion of swine manure in composting organic substrates was studied in a 4-treatment experiment with a control using the same bulking agent (wood shavings mixed with 5% tea leaves and 5% herb residues). In 100.5l lab vessels, the swine manure was composted respectively at 20%, 30%, 40% in the trials and 30% lake silt corrected by 0.5% urea in the control. The initial humidity level of each treatment was 60±2%. While being aerated actively at approximately 0.3m^3/min at intervals of 10min/hr, the mixture was composed for 29 days. Composting temperature, moisture content, pH, electrical conductivity, organic matter, total N, total P and total porosity of each treatment were measured to analyze their evolution. With reference to the chosen substrates, the results indicate that 30% swine manure with initial C/N ratio of about 40 is more desirable for composting organic substrates.

Keywords: organic substrate, composting, swine manure, wood shavings

Introduction

The booming intensive livestock-raising industry in China has recently brought about severe pollution by discharging livestock waste directly into the immediate environment. Statistical data show that the national gross amount of discharged livestock waste exceeds 20 billion tons. It has become the primary pollution pressure, exceeding the sum of industry waste and consumption residues (Yun *et al.*, 2003).

Composting is one of the few natural processes available for disposal of solid pollution, combined with resource regeneration via stabilising organic wastes. Diverse studies have concentrated on this field. Arja and Marrita (1997) analyzed the evolution of chemical and microbiological parameters during manure and straw co-composting in a drum system. Jennhung and Shanglien (1999) focused their research on the organic matter transformation during composting pig manure via chemical and spectroscopic analysis. Additionally, with the growing demand for various substrates used in soilless planting, the defects of the conventional substrates have come into consideration: peat, rockwool and vermiculite are either putting out secondary pollution or suffering resource exhaustion (Guanghua and Weijie, 2002). Composting is an available alternative to alleviate the serious livestock waste pollution and meanwhile produce organic substrates for soilless planting. However, few researches at present are pertinent to composting organic substrates and to appropriate manure proportions.

The objective of this study was to investigate the evolution of some physical and chemical parameters in increasing percentages of fresh swine manure, composting with wood shavings, and thus to obtain the most desirable proportion for organic substrate production.

Materials and methods

The experimental materials

The bulking agent was wood shavings blended with tea leaves and herb residues as composting additives. The solid swine manure for composting was obtained from the grower hog barn of the Huajiachi Campus of Zhejiang University (Table 1). Lake silt was corrected with urea as the N supplement for the wood shavings, for its TN was much lower than that of swine manure in the other treatments. The moisture content, organic matter (OM), total carbon (TC), total nitrogen (TN) and total phosphorus (TP) of all composting materials were measured prior to the tests (Table 1).

The equipment

The tests were conducted using 4 identical 100.5l cylindrical plastic vessels, 0.90m high and 0.40m in diameter. Each container was insulated with 100mm of mineral wool with an RSI value of 2.5m^{3o}C/W (Suzelle *et al.*, 2002). For aeration purposes, an air plenum, 100mm in height, was designed at the bottom of each vessel, supported by a round metal board with 16 holes of 20mm in diameter distributing radially at half of its internal radius. The wall of the vessel at the level of the plenum had one perforation for a plastic tube of 32mm internal diameter, inserted to introduce fresh air at a rate of approximately 0.3m^3/min (Yufeng *et al.*, 1998).

The method

In the designed experiment with control, the solid swine manure was mixed with the bulking agent at a mass percent of 0, 20, 30, and 40, respectively, based on a total wet weight of approximately 45kg in each lab vessel. The treatments were correspondingly labelled Control, Trial 1, Trial 2 and Trial 3. The control replaced the swine manure with 30% lake silt corrected by 0.5% urea as N supplement. Tea leaves 5% and herb residues 5% were added uniformly into the bulks as additives to improve the composting conditions like pH, C/N ratio and to reduce the odour emission and N loss, mainly as NH_3 (Yan *et al.*, 2002). The composition proportions of each bulk are shown in Table 2. In addition, the initial moisture content of each treatment was maintained equally and adjusted at about 60±2% by tap water (Yufeng *et al.*, 1998). The composting materials were mixed homogenously before piling in the lab vessels and each bulk was turned manually once on the 12th day (indicated by an arrow in Figure 1) during the whole 29-day composting.

Table 1. Characteristics of the experimental materials.

Material	Characteristics					
	Moisture content (%)	OM (%)	TC (%)	TN (%)	TP (%)	C/N
Swine manure	75.0	96.22	55.62	2.53	3.17	22.0
Wood shavings	24.5	69.30	40.06	0.26	0.09	154.1
Tea residues	12.1	77.16	44.60	2.26	0.88	19.7
Herb residues	28.3	42.05	24.31	1.40	0.82	17.4
Lake silt	81.4	14.05	8.12	0.33	0.31	24.6

Note: All analysis was reported on a dry weight (d.w.) basis; the total carbon (T.C.) was calculated from {OM (%)/1.73}; the C/N ratio from {TC (%)/TN (%)}.

Table 2. Compost composition for the experimental tests.

Material	Unit	Experiment group			
		Trial 1	Trial 2	Trial 3	Control
Swine manure	% w.w.	20	30	40	0
Wood shavings	% w.w.	70	60	50	60
Lake silt	% w.w.	-	-	-	30
Tea leaves	% w.w.	5	5	5	5
Herb residues	% w.w.	5	5	5	5
Urea	% w.w.	-	-	-	0.5
Total	% w.w.	100	100	100	100
Moisture content	% d.w.	60.0	59.9	62.1	60.9
C/N ratio		48.9	40.2	34.5	68.3

Note: all composting materials were mixed at proportions of wet weight (w.w.); the moisture content was calculated on the basis of dry weight (d.w.).

Active aeration did not begin until the 3rd day of the composting so as to preserve the initial heat produced by the aerobic fermentation of microorganisms in the bulks. Two days after, the temperature started to mount quickly and the aeration was activated to provide sufficient oxygen for the respiration of the aerobic microorganisms and to inhibit the probable overheating in the bulks which could imperil the normal multiplication of the microbes (Tongbin *et al.*, 2002). The fresh air was first pushed actively through the tube into the air plenum to blend evenly there and then driven into the heaps via the small pores in the metal board at the bottom of each container. The aeration was adjusted at the most appropriate rate of 0.29-0.33m^3/min at intervals of 10min/hr. During curing, the daily composting temperature was measured manually at a depth of 30-40cm from the surface of each bulk at about 10:00 a.m.. Test samples were also collected at that depth because the intense fermentation there was considered more representative of the general composting situation of every vessel (Qifei *et al.*, 2002). Sampling was done 5 times totally at intervals of 7 days during the whole composting and the initial samples were analyzed on the first composting day. The moisture content, pH, EC, organic matter, total N, total P of all samples throughout the whole composting were tested, whereas the total porosity was measured only for the last 4 samples as one of the evaluation criteria for the terminal products.
After 29 days of composting, the bulk temperature of the heaps had almost dropped to the ambient temperature. The chemical parameters of the mixtures, such as OM, TC, TN and TP, had almost approached a relatively steady level with neglectable evolution. Thus, the composting was considered to enter its relative mass balance.

Analytical procedures

Immediately after sampling, the samples were transported to the laboratory and homogenised manually. Sub-samples were taken for immediate analysis of pH and EC. The rest was dried in a heating cabinet for the chemical analysis of OM, TN and TP.
All samples were analyzed in triplicate using standard methods (APHA *et al*., 1990). The moisture content was determined by drying at 103ºC for 24 hr; the pH was tested with a probe on 50.0g sample materials soaked in 50ml distilled water for 30min. Saturated media extract (SME) was applied to determine the EC (Qiansheng *et al.*, 2000). The OM equated to the volatile portion

burned by potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid (H_2SO_4) and was converted to TC by a factor of 1.73 (Mebius, 1960) .The TN and TP were determined via digesting the materials with sulfuric acid (H_2SO_4) and peroxide (H_2O_2) at 200 ºC. The total porosity was measured by a standard cutting ring with a capacity of 100ml (Yande and Zhiguo, 2002).

Results

Evolution of composting temperature

The bulk temperature of each group during the active composting is presented in Figure 1. In general, temperatures from 52ºC to 60ºC are considered to maintain the greatest thermophilic activity in composting systems (MacGregor *et al.*, 1981).In the first 7 days, the bulk temperature of all heaps quickly rose to their peaks, especially Trial 1, whose temperature rose rapidly to its summit almost on the 3rd day (Figure 1). Afterwards, Trials 2 and 3 continued their thermophilic composting above 52ºC. By contrast, the temperature of Control and Trial 1 began to drop rapidly after the relatively stable maintenance above 52ºC for 4 or 5 days (Figure 1). Considering the potential shortage of pore oxygen required for the aerobic composting, all bulks were turned manually after 11 days (marked by an arrow in Figure 1). This led to temperature recovery in the latter 2 treatments and the continuation of thermophilic composting in the former. From the 16th day, the temperature of all treatments started to drop, tending daily to that of the ambience. At the end of the composting, the bulk temperature in Trials 1 and 2 had approached to the ambience, comparable to that of the rest. It was probably the result of the secondary fermentation in Control and the prolonged duration induced by more available organic components and active microbes in Trial 3.

Evolution of physical and chemical parameters

The evolution of physical parameters as pH and EC and chemical parameters as OM, TN, TP is presented respectively in Figures 2-6.
The pH of each bulk presented homologous evolution in the trials, all of which arrived at the maximum around the 7th composting day and afterwards decreased until the end. The control showed similar evolution to the trials until about the 21st day when, in contrary, it began to rise (Figure 2). The evolution of EC in all treatments presented similar decline during the whole composting except for a mild rise of the control after the 21st day (Figure 3). The evolution of OM and TN was more complicated, though relatively similar in Trials 2 and 3, i.e. an obvious OM rise in the first 7 days, a drop following for 7 days and afterwards an increase (Figure 4); continuous TN reduction until the 21st day followed by a rise (Figure 5). The TP presented consistent evolution: a drop in the first and last 7 days and an increase during the middle two weeks (Figure 6).

Discussion

Analysis of the physical and chemical evolution

In the first 7 days, the N in each heap was decomposed into ammoniacal nitrogen (NH_4^+-N) and emitted primarily in the form of NH_3, but C decomposition then was not as intensive. As a result, the TNs all dropped (Figure 5) and by contrast the pH rose in response to the accumulation of NH_4^+-N in the bulks (Figure 2). The OM increased in Trial 2, Trial 3 and Control (Figure 4) as a result of N decomposition and moisture evaporation, whereas the corresponding OM decline in Trial 1 was the result of rapid C decomposition at the bulk temperatures above 52ºC (Figure 1). Moreover, the drop of TP in all vessels (Figure 6) indicated that the P decomposition primarily occurred in this phase.

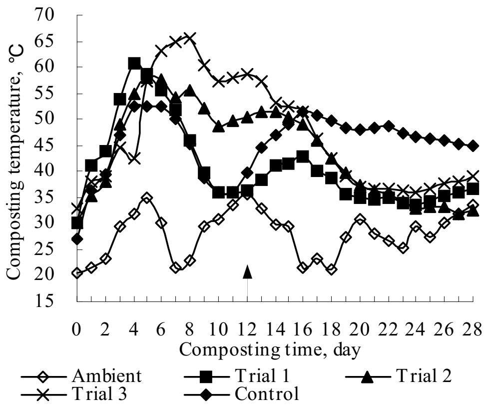

Figure 1. Evolution of composting temperature.

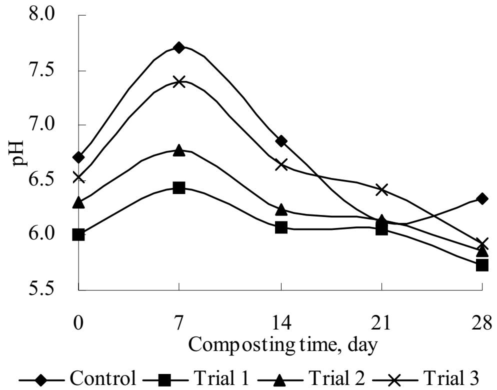

Figure 2. Evolution of pH.

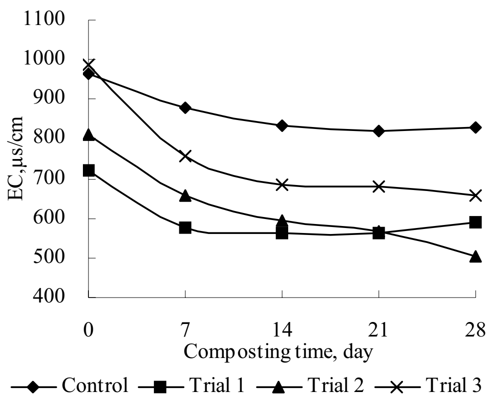

Figure 3. Evolution of EC.

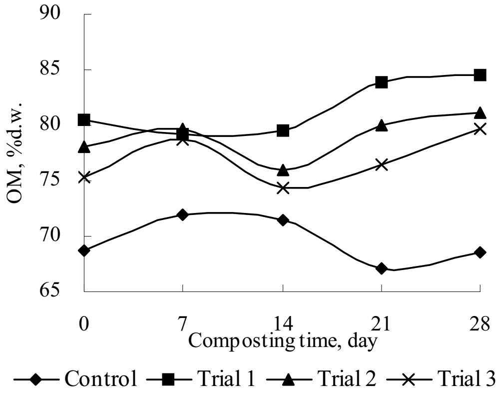

Figure 4. Evolution of OM.

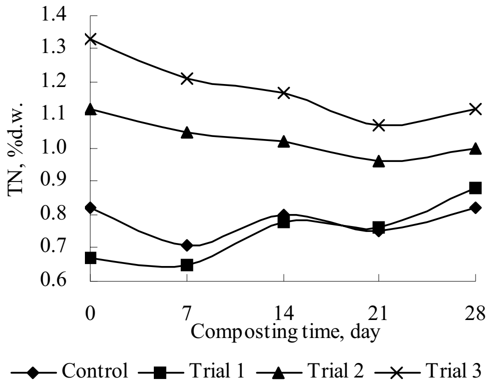

Figure 5. Evolution of TN.

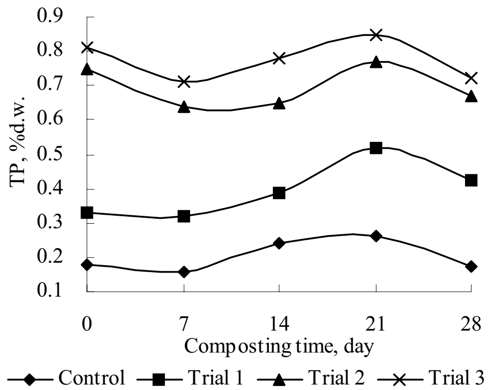

Figure 6. Evolution of TP.

In the following week, the bulk temperatures above 52ºC in Trials 2 and 3 (Figure 1) led to C decomposition and the OM began to drop correspondingly (Figure 4). Meanwhile, N decomposition in them resumed and thus the TN declined (Figure 5). Since P decomposition rate was far slower than that of C, the TP increased relatively (Figure 6). The declining bulk temperature in Trial 1 and Control (Figure 1) revealed weak C decomposing which caused the mild OM evolution in Figure 2. Additionally, part of the NH_4^+-N accumulation in the bulks began to stabilise into nitrate nitrogen (NO_3^--N) with the deceleration of N decomposition, which produced the following drop of pH.

The manual turn on the 12th day led to changes in the composting evolution by improving the micro-aeration condition of the bulks. The temperature of Trials 2 and 3 thus maintained at a relatively high level (Figure 1) and their evolution of pH, TN and TP was similar to that in the last period. Moreover, N and C decomposition resumed because of the bulk-temperature recovery in Control, but not in Trial 1 as its organic components had almost decomposed (Figs. 4 and 5).

After the 14th day, substance concentration had reached its peak, which indicated the start of maturing. It ended up with the increase of OM in the trials (Figure 4) and TN in all bulks (Figure 5). The OM rise (Figure 4) in Control did not appear until the 21st day in view of its secondary fermentation, which made the remaining N decompose and thus the NH_4^+-N production created the increase of pH (Figure 2). By contrast, the relative rise of OM and TN caused TP decline contrarily (Figure 6). At the end of the composting, most water-soluble salt was broken down with the organic components in the bulks, which led to further decrease of EC in each trial (Figure 3), while the rising EC in Control in the last week implied the influence of its initial composting materials with lake silt that normally contained higher active metallic ions.

Comparison of the parameters of the obtained substrates with reference values

By comparison of the terminal physical-chemical parameters with reference values in Table 3, the total porosity, OM and TP of Control were 39, 68.49, 0.17, respectively, all of which exceeded their corresponding desirable ranges; the EC in Trial 1 was 589 and it was below the minimum value 600. Therefore, the organic substrates produced in Trial 1 and Control were not adequate for efficient soilless planting. Although the organic substrates of Trial 3 were applicable for planting as their critical parameters in Table 3 were all in the reference ranges, the prolonged composting (Figure 1) made it less practical for composting industrialization than Trial 2. Therefore, Trial 2 of 30% solid swine manure with initial C/N ratio of about 40 (Table 2), was more desirable for composting organic substrates, considering comprehensively the composting duration and the parameters of the obtained substrates.

Table 3. Comparison of the parameters and reference values.

Parameter	Unit	Experiment group				
		Trial 1	Trial 2	Trial 3	Control	Reference value
Total porosity	ml/100ml	50	56	54	39	50~90
pH		5.73	5.86	5.93	6.34	5.3~6.9
EC	μs/cm	589	642	657	829	600~1500
OM	%d.w.	84.47	81.05	79.66	68.49	70~90
TN	%d.w.	0.88	1.00	1.12	0.82	0.8~1.5
TP	%d.w.	0.42	0.67	0.72	0.17	0.4~1.0

Conclusions

The composting of organic substrates by solid swine manure was similar to that of organic fertilisers with regard to the evolution of bulk temperature, pH, EC, OM, TN and TP. The decomposition of N and P primarily occurred when the bulk temperature rose rapidly, while C decomposed mainly in the thermophilic composting phase.

The total porosity in Control and the EC of Trial 1 were beyond the reference values, in combination to the over-prolonged composting duration of Trial 3. The comparison indicated that 30% solid swine manure, i.e. a composting mixture with initial C/N ratio of about 40 was desirable for composting organic substrates.

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Torque-controlled bottom conveyor velocity on longitudinal distribution during the application of solid manure

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Abstract

To improve distribution accuracy during the spreading of solid farmyard manure in a longitudinal direction, a DLC (drive line control) system for solid manure spreaders has been developed. For the examination of distribution accuracy in a longitudinal and lateral direction, a spreading trial with collection trays was carried out. Three application rates (5t, 10t, 20 t ha^{-1}) were examined both with and without the DLC system. The variation coefficients of lateral distribution (VK_Q) ranged between 11.7% and 16.5%. At values between 15.6% and 35.7%, the variation coefficients of longitudinal distribution (VK_L) were significantly higher both with and without the DLC system. The DLC system did not have any influence on VK_L. Variability was rather caused by small-scale differences than by differences over the examined travel distance.

Keywords: Solid manure spreader, accuracy of distribution, longitudinal distribution, torque control

Introduction

When spreading solid manure and secondary raw material fertilizers, the nutrients must be spread over the area as evenly as possible in order to avoid over- or under-fertilizing in certain locations. This requires the development of techniques which guarantee the precise spreading of these materials. While the variation coefficients of lateral distribution of current spreading units meet these demands using a combination of beaters and distributing plates, longitudinal distribution is still considered unsatisfactory (Redelberger, 1991). Distribution in small areas (Bockisch *et al*., 1992; Reloe, 1993) and over the entire unloading distance (Carlson and Anderson, 1990; Malgeryd et. al, 2000) exhibits high variation coefficients for longitudinal distribution. Uneven longitudinal distribution is attributed to different dung lying heights as well as slip between the load and the conveyor bottom (Reloe, 1993). The control of conveyor bottom advance by means of the torque at the spreading rollers (Carlson and Anderson, 1990) has long been considered a potential solution to this problem. For precise solid manure spreading in field trials, such a system has already been developed by Malgeryd *et al*. (2000). Practical implementation, however, has failed so far due to the great technical requirements and the small importance of longitudinal distribution in the standardized test procedure (DIN EN 13080), during which longitudinal distribution is only evaluated based on weight loss over the entire unloading distance. Longitudinal distribution is not measured with the resolution used for lateral distribution.

Material and methods

DLC System

In the present trial, the implementation of DLC System was realized in a large-volume solid manure spreader (Bergmann company, TSW 660) with a loading volume of 20 m^3. The spreading unit of the solid manure spreader is equipped with two vertical beaters and two distributing plates.

The principle of DLC (drive line control) is based on the linear connection between the torque at the spreading elements and actual mass flow (Hügle, 1999). With the aid of a control circuit, bottom conveyor velocity is adapted to a given torque. In a job computer, torque curves are stored for different materials and application rates, which can be selected at an operating terminal in the driver´s cab (figure 1). Depending on the driving speed, which is measured at a wheel equipped with a rotational speed sensor (DW 20, Walterscheid company), the set torque value is calculated according to equation 1.

$$M_{set} = m * v + M_{idle} \tag{1}$$

M_{set} = set torque value [Nm]
M_{idle} = torque at idling speed [Nm]
m = inclination corresponding to a characteristic curve for application rate and material
v = driving speed [m/s]

The actual torque value at the beaters and distributing plates is measured at the drive shaft using a contactless inductive torque measuring hub (SF 250, Walterscheid company). The job computer compares the set value with the actual value every 0,1 second and uses an electromagnetic proportional valve to control the speed of the oil-hydraulic bottom conveyor drive. An interface at the job computer allows the data of the control process to be read out on-line with a PC.
The rotational speed of the beaters is controlled by sensors (DW 20, Walterscheid company) and if the speed of the beaters is too low, a blockage of the bottom conveyor advance prevents the beaters from getting stuck.

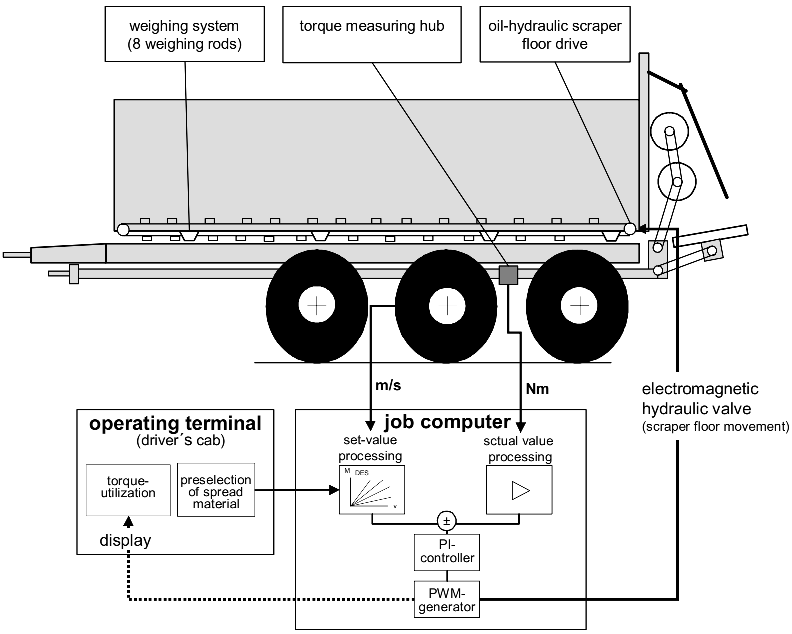

Figure 1. Functional diagram of the DLC system.

Experimental set-up

The spread pattern during solid manure spreading was determined in both a lateral and longitudinal direction with the aid of collection trays. Three application rates (10 t ha^{-1}, 20 t ha^{-1}, 30 t ha^{-1}) were examined both with and without the DLC system.
For the measurement of lateral distribution, the spread pattern was determined unilaterally using trays (50x50x5 cm) over a working width of 14 m in three blocks (figure 2). The variation coefficients of lateral distribution (VK_Q) were calculated for a working width of 12 m.
Longitudinal distribution was also measured with the aid of collection trays. Over a total length of 120 m and at a distance of 4 m and 8 m from the tramline, four rows of trays (blocks) were set up, which were 12m long and comprised 20 trays each (58x34x11 cm). In order to calculate the variation coefficient of longitudinal distribution (VK_L), the tray contents of the 4m row of one block were added to the tray contents of the 8m row of another block to simulate the spread pattern.
The material used was fresh deep litter manure from a stall for mother cows. The quantity of litter in the stall was 8 kg of long straw per day. Without prior homogenizing, the solid manure was loaded by a telescopic loader in order to achieve great variability in spreader loading. After the two variants of an application rate had been spread, the spreader was loaded again. The first 10% of

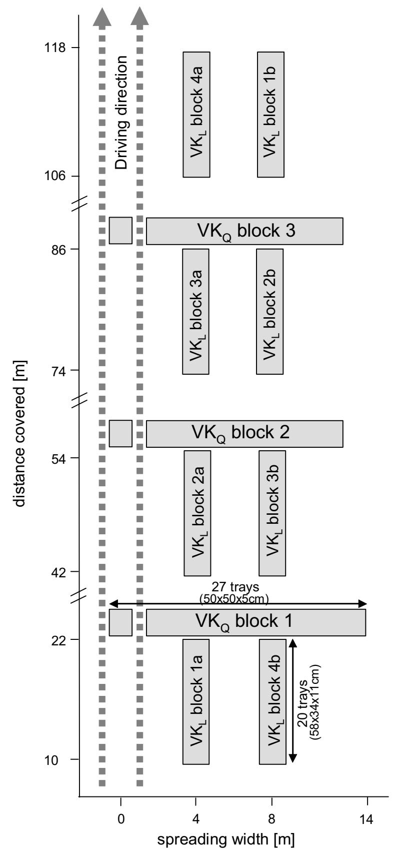

Figure 2. Set-up of each trial variant for the measurement of the variation coefficients of lateral distribution (VK_Q) and longitudinal distribution (VK_L).

the loading volume was discarded and not considered in the trial procedure in order to reach the most uniform trial conditions possible.
The first measurement series was positioned after an initial travel distance of 10 m. It was therefore guaranteed that the spreader always worked at the set application rate.
A weighing system (MC2020 PTB, Moba company) installed at the spreading vehicle allowed the solid manure quantity actually spread to be measured.

Results

Depending on the application rate, the variation coefficients of lateral distribution (VK_Q) ranged between 11.7% and 16.5% (Table 1). At values between 17.0% and 35.7%, the variation coefficients of longitudinal distribution (VK_L) were significantly higher than those of lateral distribution. With increasing application rate, VK_L was lower (15.6% to 31.6%). It must be taken into consideration, however, that at a low application rate the variation coefficient is more strongly influenced by a deviation of 1 t ha^{-1} of fresh mass spread than at a large application rate. Thus, the variation coefficient does not allow different application rates to be evaluated. The variation coefficients do not show that the DLC system provided improved longitudinal distribution (VK_L).
The unilaterally recorded spread patterns of lateral distribution are shown in Figure 3 (left). At application rates of 5 t ha^{-1} and 10 t ha^{-1}, the spread flanks are rather flat, which enables overlapping errors to be kept small. Figure 3 (right) shows the spread patterns of longitudinal distribution of the trial variants with the DLC System over the tested distance of 120 m. It can be clearly seen that variance within the trial blocks is larger than between the trial blocks. Only at the largest application rate (20 t_{DLC}) can a difference in the quantities applied be detected between the trial blocks at an average of 16 t ha^{-1} in block 1 and block 4 and 20 t ha^{-1} in block 2 and block 3.
The online data of the job computer in Figure 4 provides advanced information about the function of DLC system. In all three trial runs with the DLC system, there was an adjustment phase after start-off, during which the system adapted the set torque value to the driving speed. At an application rate of 10t ha^{-1}, a travel distance of 20m after start-off was required in order to reach the set value. In the other two variants, the set torque value was reached after a shorter travel distance. The adjustment phase thus lasted longer than expected. As a result, part of the spreading process in the first block took place during the adjustment phase.
During the later spreading process, a set-value deviation and a torque-dependent control process of the DLC system only occurred in the trial series $20t_{with\ DLC}$. However, an improvement with regard to the accuracy of longitudinal distribution could not be established. Instead, the process data show that even extreme fluctuations occur after the control process has begun, which have a rather unfavourable effect on the spread pattern. After a travel distance of 80m, the torque rose very

Table 1. Variation coefficients of lateral distribution (VK_Q) and longitudinal distribution (VK_L) at different application rates.

Quantity [t ha^{-1}]	VK_Q[a]	VK_L	
		without DLC system	with DLC system
5t	16,5 %	35,7 %	31,6 %
10t	11,7 %	21,6 %	25,1 %
20t	14,4 %	17,0 %	15,6 %

[a]calculation based on a tramline distance of 12 m

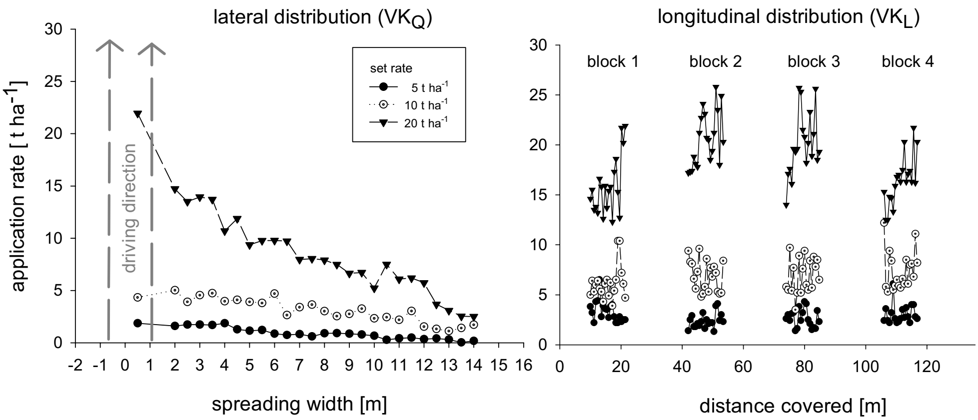

Figure 3. Unilateral spread pattern for the measurement of lateral distribution at different application rates (left) Solid manure distribution in a longitudinal direction with DLC system as a function of the application rate. The quantities applied are shown including the calculated value of overlapping (right).

sharply, which led to a reduction of bottom conveyor velocity. DLC system reduced bottom conveyor velocity and the torque, which led to the torque dropping below the set value and resulted in an upward adjustment of bottom conveyor velocity. For a short time, this fluctuation around the set value led to an uneven spreading process (cf. figure 4), which is not so clearly discernible in the spread pattern of the tray trial in block 3 (cf. figure 3, right).

Even though the solid manure spreader used for variant $20t_{\text{with DLC}}$ was loaded with enough material for the entire spreading trial, diminishing bulk density affected the torque values. After a travel distance of 110m, the torque decreased. As a result, bottom conveyor velocity was increased by the system, and the set value was able to be kept virtually constant until the end of the trial.

Conclusions

The present trial showed that the lateral distribution of the tested solid manure spreader with a broadcast plate distributor from the Bergmann company (type TSW 660) is sufficiently optimized, whereas there are larger deficits with regard to longitudinal distribution, especially on a small scale. Neither on a small-area scale nor over the longer unloading distance was any improvement in longitudinal distribution determined which was caused by the DLC system. Only in one out of six trials did the torque deviate from the set value, which would be the prerequisite for the start of a torque-dependent control process. Obviously, the design of the spreader guarantees sufficiently even material supply and thus virtually constant torque even if the materials are less homogeneous. The use of collection trays showed that longitudinal distribution (VK_L) over the travel distance of 120m is more strongly influenced by small-scale variability than by varying quantities over the unloading distance of 120m. For the smoothing of short-term torque fluctuations, physical transmission between the bottom conveyor and the torque at the spreading elements is too slow for the DLC system to exert an influence on the spread pattern on this scale.

In the trial, it was determined that given the same dissolution of the material VK_Q was significantly better than VK_L. Therefore, the accuracy of longitudinal distribution should be considered and optimized in order to reach an appropriate balance between the two parameters.

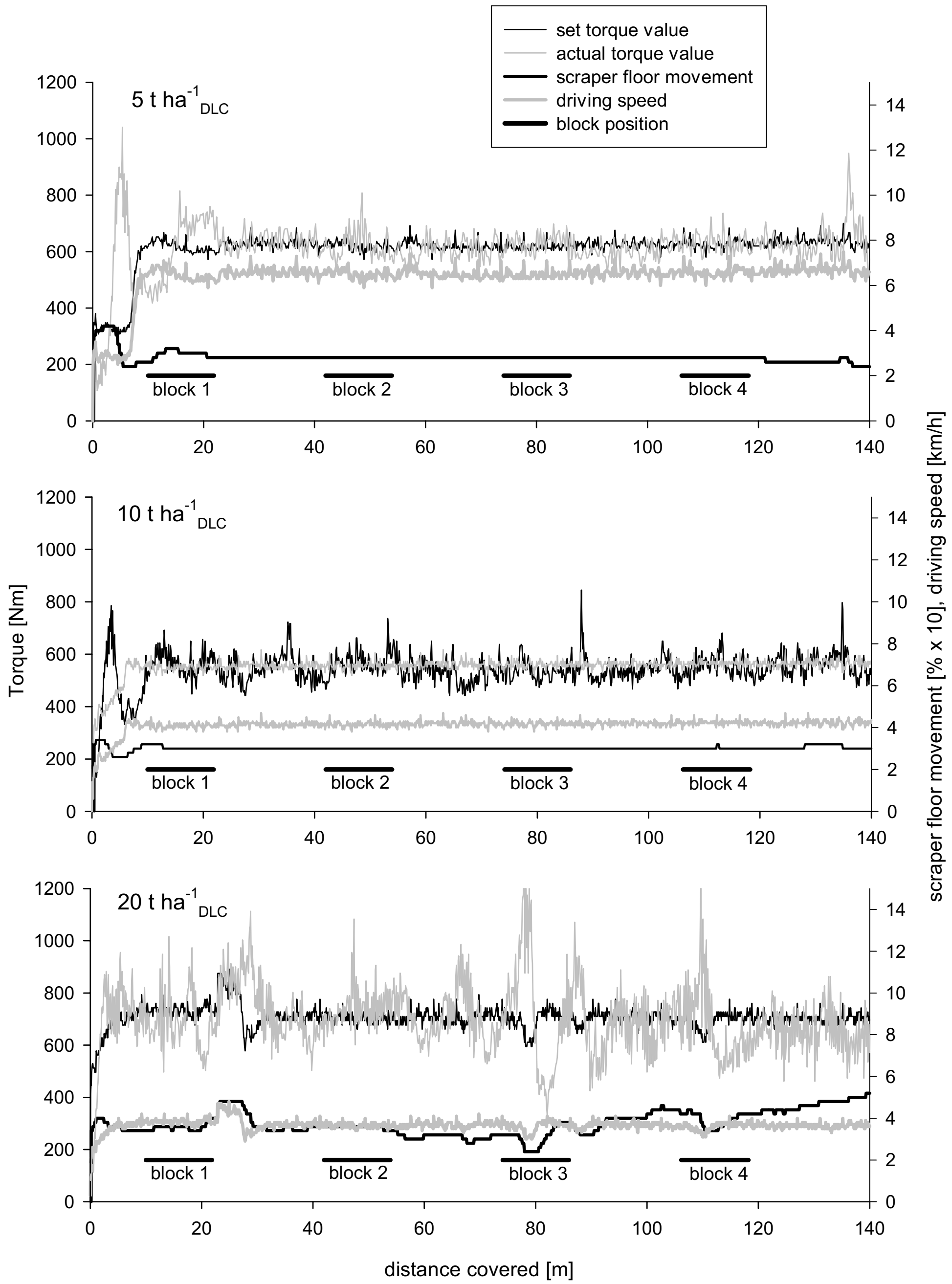

Figure 4. Process data of the DLC system (online) during the spreading trial with the DLC system. The location of the measurement series (blocks) is shown in the diagram.

Since longitudinal distribution is subject to large fluctuations in particular on a small scale, it is sensible to use collection trays.

However, the process data showed that the described DLC system can make the following contributions towards increased process reliability during solid manure spreading:

- Material preselection and set value calculation allow for very easy and reproducible determination of the application rate The selection of application rates at the operating terminal meets the demand for greater ease of operation of solid manure spreaders using the aid of given setting aids (Redelberger, 1991).
- The DLC system enables application rates to be kept constant even under different load conditions. Especially at the end of the spreading process, the system enables bottom conveyor velocity to be adapted to the decreasing bulk height. In Figure 5, this is shown using data recorded outside the trial series. As bulk density decreases, the torque is stabilized at distances between 620m and 660m.
- Driving-speed-dependent torque measurement allows differences in driving speed to be evened out with the aid of the DLC system.
- The display of torque exploitation on the operating terminal allows the capacity of the spreading vehicle to be fully exploited while maintaining the optimal driving speed, which shortens the spreading time.

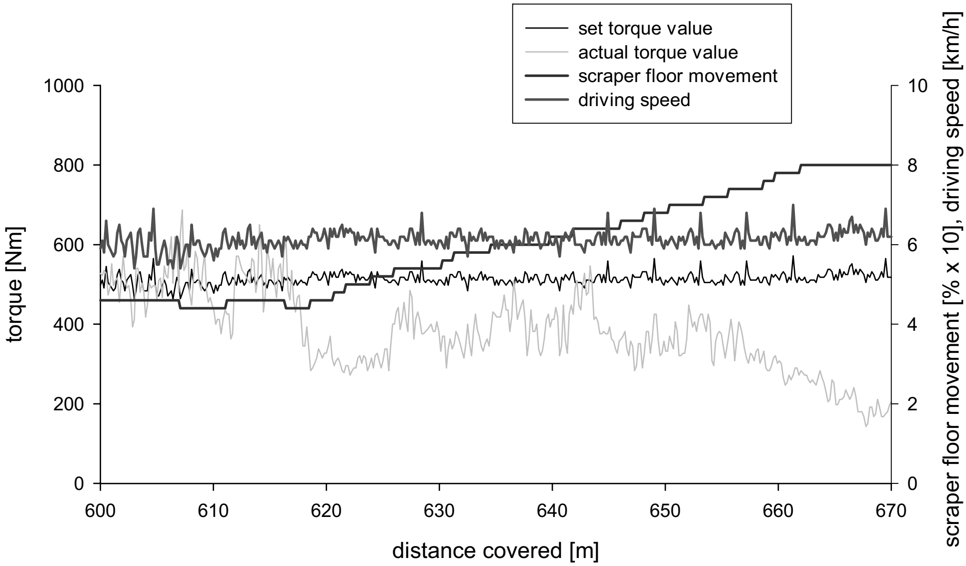

Figure 5. Process data of the DLC system (online) at the end of the spreading process and decreasing bulk density.

Acknowledgements

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Rapid analysis of liquid hog manure using near-infrared spectroscopy in flowing condition

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Abstract

The goal of this study is to investigate the possibilities of using near-infrared spectroscopy (NIRS) to determine the compositional properties of liquid hog manure. Currently, the NIRS flow-through measuring system is used in pig fattening trials for the examination of liquid manure. The hog manure (n=128) for the study was collected from a commercial pig farm and analyzed for total amounts of nitrogen, ammonium nitrogen, dry matter and organic dry matter using NIR methodology. Samples were scanned from 960 to 1690 nm with a diode-array spectrometer in a specially-developed flow-through cell. Measurements were carried out in transflection mode.

Keywords: NIRS, hog manure, transflection, flow-through measurement

Introduction

Near-infrared spectroscopy (NIRS) is an alternative method of rapid analysis used to determine the composition of agricultural materials. NIRS can rapidly and reliably estimate samples based only on the relationship between spectral and compositional properties of a sample set. NIRS-based techniques are widely adopted in many agricultural applications, e.g. for the measurement of protein, fat and water in many agricultural products. It has not yet been widely applied for liquid manure aside from some investigations, for example, the studies from Millmier *et al*., regarding near-infrared sensing of manure nutrients (Millmier *et al*., 2000), NIRS analyses of poultry, and the determination of carbon, total nitrogen and ammonium nitrogen in dairy manure and dried dairy manure from Reeves and Kessel (Reeves and Kessel, 2000a), (Reeves and Kessel, 2000b), (Reeves *et al*., 2002). Malley *et al*., have found transflectance works well for hog manure (Malley *et al*., 2001), (Malley *et al*., 2002).

Since this method of analytical testing is fast, cost effective, portable and real time, it has the capability of analyzing many compositional properties of liquid manures, which can be useful in many ways, e.g. as an analytical experimental tool. Furthermore, it can be deployed to optimize the use of liquid manure as an organic crop fertilizer. This technique assists in matching the variable nutrient contents of manures to soil and crop needs and, correspondently, in avoiding over-fertilization and the leaching of nutrients into ground and surface water. In this respect, NIRS is a suitable measuring technique which facilitates real-time flow-through analysis of the liquid manure constituents without any sample pretreatment, and in a non-destructive way. At the present time, most manure is analyzed by conventional wet chemical methods. These methods are usually very time consuming and expensive and are limited to a restricted number of more or less representative samples. Because of this, the present study aims to investigate the possibilities of using NIRS to determine the compositional properties of liquid hog manure.

Materials and methods

Manure and NIRS

Liquid manure is a complex suspension with a liquid and a solid phase. Both phases contain substantial information of interest. Therefore, the sample presented to the NIR detector has to follow the principles of transflection, which combines reflection and transmission. The incident beam of the measuring head is transmitted through the sample and then scattered back from a reflector. It is recorded similar to the diffuse reflection of the particles. In this way, liquid and particulate properties of a sample can be recorded simultaneously. For samples with low dry matter content, where transmission dominates, it is necessary to limit the path length of the measuring cell (Kawano, 2002).
The feasibility of measuring the major nutrients present in liquid hog manure using NIRS in a flow-through measuring mode has been tested at the Institute for Agricultural Process Engineering at the University of Kiel, Germany. The goal of the study was to develop a measuring cell that would enable the analysis of liquid manure without the risk of clogging. It was aimed at allowing representative monitoring of large amounts of flowing manure in a bypass mode. This would avoid the need of taking erroneous samples and would limit the time delay necessary for laboratory analyses.

Measuring cell

The measuring cell is built of polyoxymethylen (POM). POM is a thermoplastic material with very good mechanical, chemical and thermal properties. It is acid-proof, has a low co-efficient of friction and shows good resistance to wear.
Figure 1 depicts the internal layout of the measuring cell that is attached to the measuring head of the spectrometer. The liquid manure sample flows through the measuring cell in a layer of 3mm between two glass plates (silicate) and is irradiated with near-infrared light. The cell is backed with a ceramic disc opposite the measuring head, along with the light source and the diode-array detector.
The hydrodynamic design of the measuring cell (Figure 2) is intended to provide a uniformly distributed flow across the measuring window. When entering the measuring cell, the cross section of the flow changes. To avoid separation within the manure, three built-in pins cause turbulence

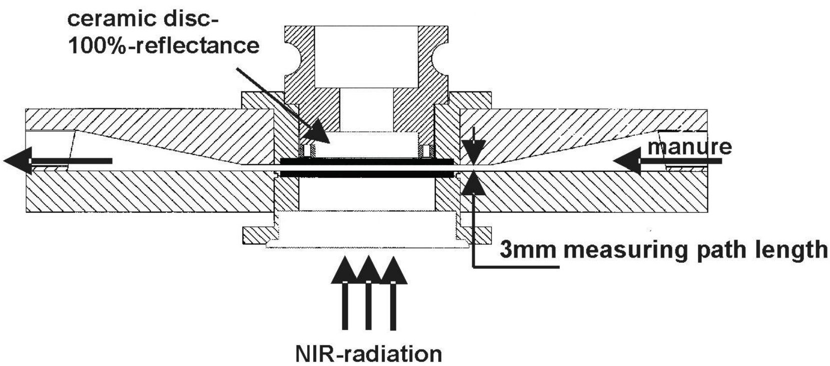

Figure 1. Flow-through measuring cell.

that generates remixing, so that the stream of the flowing liquid manure is evenly distributed across the entire measuring surface.

To avoid clogging, the maximum sizes of particles within the manure have to be smaller than 3 mm. Hog manure usually fulfills this requirement without pretreatment. In the case of manure with larger particles, they have to be macerated to the requested size prior to the measurement with this cell. The measuring head of the spectrometer is protected from contamination from the manure because it is attached to the glass plate of the measuring cell. The cleanliness of the glass in the cell has to be checked regularly and cleaned as needed. Cleaning apparatuses are integrated into the system. Periodic referencing of the spectrometer must be carried out anyways, which implies a clean optical path.

NIR-Prototype

Based on the measuring cell described above, a prototype for an operating NIR-measuring system has been constructed and tested (Figure 3).

The prototype consists<A[consists|exists]> of a spectrometer (1) ZEISS CORONA 45 NIR, measuring cell (2), electric pump (3), multi-way valve (4), sample compartment unit with sample bottle (5), frequency inverter (6) and PC (7).

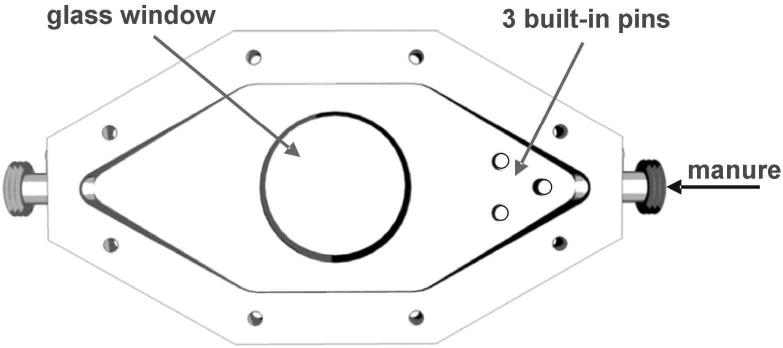

Figure 2. Flow-through measuring cell, interior view.

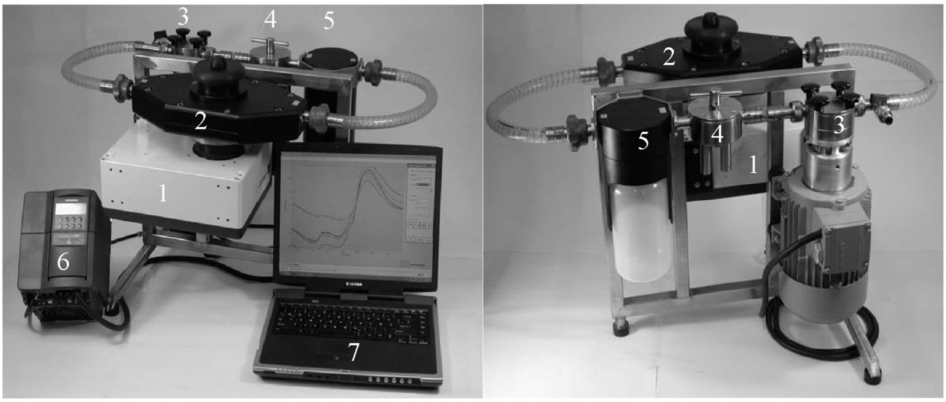

Figure 3. NIR-prototype (front and back view).

The pump conveys the liquid manure with constant velocity in the closed system loop. The first cycles are used for homogenization. After the attached sample has reached a homogeneous state, the scanning procedure of the spectrometer can be started while the manure still flows through the cell. Spectral data is recorded with the control computer. Valves for water and compressed air allow for the cleaning of the system (Figure 4).

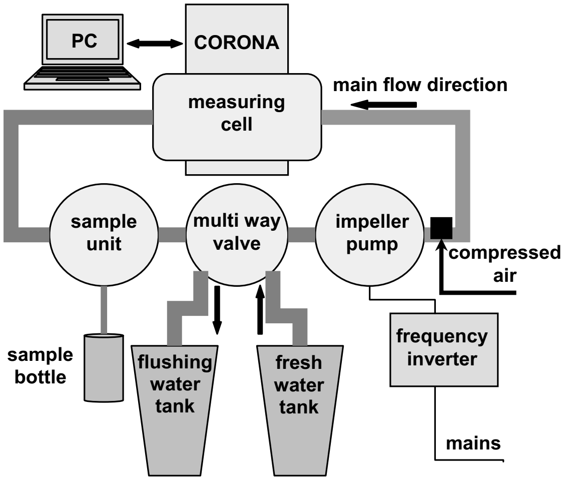

Figure 4. Functional block diagram of the NIR-prototype.

Samples

One hundred and twenty eight (128) representative manure samples were collected from 24 pig pens during a fattening trial on a commercial farm. From each pen, 3 sample bottles (1l) were collected and scanned with the NIR-Prototype. After scanning, the samples were immediately frozen and stored at -18°C until reference analysis in the laboratory. Reference analyses were performed by a certified laboratory for total nitrogen (N), ammonium nitrogen (NH_4^+-N), dry matter (DM) and organic dry matter (ODM).

Calibration procedure

The possibility of using NIR to perform rapid analyses and to predict constituents in unknown samples highly depends on the accuracy of reference data and the quality of the calibration used. Calibrations were developed with The Unscrambler/Camo Process AS/Norway, using principal component analyses (PCA) and partial least squares regressions (PLS). Calibration that showed the highest R^2 and lowest SEP (standard error of prediction) between NIR-predicted and chemically measured values were selected as the best (Williams, 2001). The calibration procedure was repeated for each constituent.

Results

Composition of samples

Results of the reference analysis for the 128 manure samples are listed in Table 1. Values for total N ranged from 0.59 % to 1.17 %. The NH_4^+-N-content varied from 0.40 % to 0.68 %, for DM from 4.37 % to 15.04 %, and for ODM from 3.16 % to 11.88 %. The mean coefficient of variation (CV %) was highest for ODM, with 21.15 %. Mean CVs for total N were 13.29%, for NH_4-N 12.02 % and for DM 15.69 %.
Estimates of the laboratory's precision in analyzing the hog manure were made by calculating SD and CV for each sample. Table 2 demonstrates SD and CV values, calculated for the 128 liquid hog manure samples. The coefficients of variation ranged from 0.01% to 12% for total N, from 0.03% to 8.55% for NH_4^+-N, from 0.02% to 14.83% for DM, and from 0.003% to 14.88% for ODM. The samples with CVs higher than 5 % were not used for calibration and were kept out from the data set.

Calibration and validation procedure

The measured and predicted data were matched in calibrations by means of PLS1 procedures. In this algorithm, calibrations were developed for constituents individually. Outliers were identified by viewing plots of scores for each constituents in the Unscrambler software. From the data set for NH_4^+-N, 11 were removed and for total N, 4 samples were identified and deleted as outliers. Outliers were not identified for DM and ODM constituents. The calibrations were thereby developed (Figure 5).
The quality of the calibration was estimated using two types of validations. The first was based on a leave one-out cross validation. The results are shown in Table 3.

Table 1. Average chemical composition of the 128 liquid hog manure samples.

Constituent	Mean	Range	SD-mean	CV %-mean
Total N %	0.75	0.59-1.17	0.098	13.29
NH_4-N %	0.50	0.40-0.68	0.060	12.02
DM %	7.51	4.37-15.04	1.179	15.69
ODM %	5.87	3.16-11.88	1.242	21.15

Table 2. Range, mean and median of standard deviation (SD) and coefficient of variation (CV) values calculated for each sample.

Constituent	Range SD	Mean SD	Median SD	Range CV %	Mean CV%	Median CV%
Total N %	0.0001-0.21	0.010	0.006	0.01-12	1.37	0.81
NH_4^+-N %	0.0001-0.04	0.012	0.009	0.03-8.55	2.38	1.98
DM %	0.0002-0.59	0.098	0.068	0.02-14.83	1.38	0.92
ODM %	0.0002-0.80	0.79	0.51	0.003-14.88	1.42	0.85

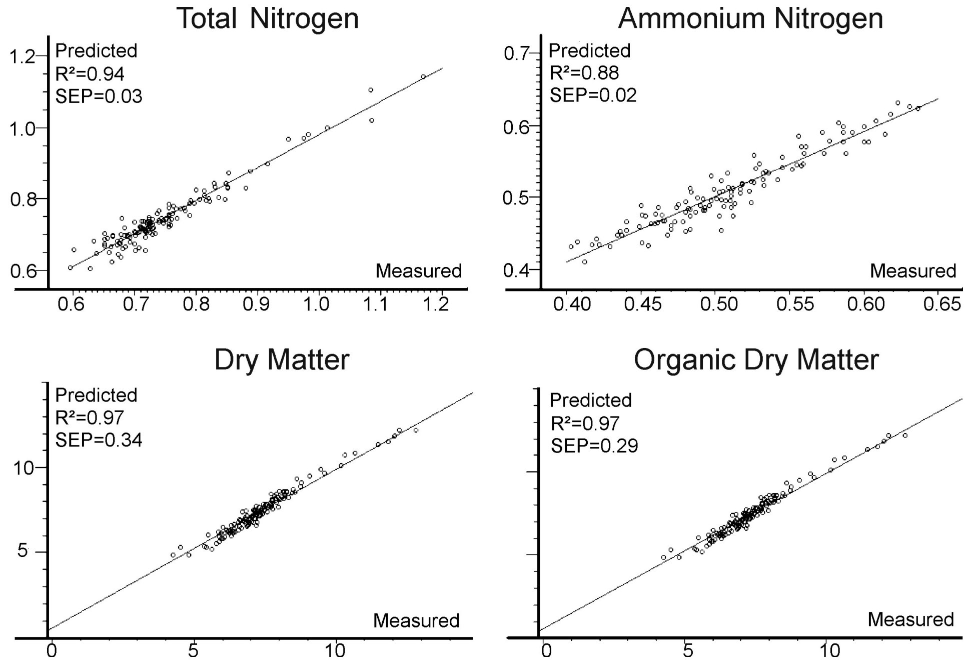

Figure 5. Linear regression relationships for total nitrogen, ammonium nitrogen, dry matter and organic dry matter.

Table 3. Partial least squares regression results using 1-out cross validation.

Constituent	Calibration						1-out cross validation				
	n*	PC**	r^2	SEC***	Slope	Bias	PC	R^2	SEP	Slope	Bias
Total N %	124	12	0.97	0.021	0.94	$4.84 \cdot 10^{-8}$	12	0.94	0.027	0.95	$7.39 \cdot 10^{-5}$
NH_4^+-N %	117	13	0.89	0.017	0.89	$6.54 \cdot 10^{-7}$	13	0.88	0.024	0.83	$9.79 \cdot 10^{-5}$
DM %	128	8	0.98	0.287	0.96	$8.56 \cdot 10^{-8}$	8	0.97	0.340	0.94	0.0078
ODM %	128	8	0.97	0.249	0.95	$2.88 \cdot 10^{-7}$	8	0.97	0.295	0.93	0.0080

*n = number of samples
**PC = number of principal components
***SEC = standard error of calibration

The second method was carried out using a test-set validation with random selection of a calibration set and test set from the basic data set. The calibration for ammonium nitrogen was tested using 71 samples for calibration and 46 test samples. Total nitrogen, dry matter and organic dry matter were also tested using 77 calibration samples and 51 test samples. The result of PLS regression using test set validation are presented in Table 4.
The R^2 between NIRS predicted concentrations, and the concentrations determined by chemical analysis using 1-out cross validation and test-set validation were, for total N, 0.95 for NH_4^+-N, 0.89

Table 4. Partial least squares regression results using test-set validation.

Constituent	Calibration						Test-set validation					
	n	PC	r^2	SEC	Slope	Bias	n	PC	R^2	SEP	Slope	Bias
Total N %	77	10	0.95	0.023	0.91	$2.86 \cdot 10^{-8}$	51	10	0.94	0.032	0.89	0.0053
NH_4^+-N %	71	11	0.93	0.019	0.87	$1.28 \cdot 10^{-6}$	46	11	0.88	0.024	0.88	0.0007
DM %	77	8	0.98	0.304	0.96	$1.25 \cdot 10^{-6}$	51	8	0.97	0.276	1.03	0.0999
ODM %	77	8	0.98	0.239	0.96	$9.50 \cdot 10^{-7}$	51	8	0.97	0.264	0.99	0.0097

for DM, and ODM was 0.97. SEP for all constituents ranged from 0.024 for NH_4-N to 0.34 for DM for 1-out cross validation and were almost identical for test-set validation.

Discussion

The high values of principal components demonstrate the complexity of the calculated models. The analysis of the results of both validations used to estimate the quality of the calibrations are based primarily on the values of r^2 and SEP. High r^2 and small SEP indicates the likelihood of good estimates. The r^2 between NIR-predicted and chemically-measured values is >0.88 for all constituents and SEP is <0.34, which indicates a fairly good estimation of the calibration models. The comparison of the results of this study with the results of similar studies with static NIRS measurements illustrate that flow-through NIRS-measurements of liquid manure are more precise and accurate. For example, Malley *et al*. (2001), showed values of r^2 and SEP as being 0.83/0.045 for NH_4^+-N and for total N, 0.87/0.044. Another factor in accuracy of measurement is the sample volume. The flow-through cell used in this study uses a sample volume of 1 l, which allows a higher representativeness of the measurement. The regression results of the investigations by Millmier *et al*. (2000), making static NIR-measurements of liquid pig pit manure with a very low sample volume (approximately 70 to 80 ml) showed r^2 values for NH_4^+-N of 0.79 and for total N of 0.89.

Conclusion

The study demonstrates that NIRS calibrations for total and ammonium nitrogen, as well as for dry matter and organic dry matter, can be developed and used to determine the composition of manure. These results are useful in indicating the potential of NIRS to be used for the rapid analysis of manure.

Currently, the NIRS flow-through cell and the manure calibrations for the constituents mentioned above, are applied and evaluated in a pig fattening trial to monitor the metabolic utilization of crude protein and essential amino acids of the growing pigs. Compared to the conventional chemical analyses in the laboratory, the potential of NIRS provides several advantages such as instant availability of data, accuracy and high analysis productivity.

Acknowledgements

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Development and evaluation of a precision solid and semi-solid manure land applicator

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Abstract

Two prototype precision applicators adapted to solid and semi-solid livestock manure were designed, fabricated and evaluated with the goal of improving the transversal and longitudinal uniformity of distribution of manure and also to accommodate other modes of application than broadcast surface application. A study of the performances of two discharge conveying systems (scraper and system of 4 screw conveyors) was carried out. The specific energy required to unload the machine with the screw conveyors was found to be higher than with the scraper conveyor. The effects of the conveyor velocity, inclination angle of the sidewalls and flow-control gate on the power requirements of the conveying systems and discharge rate were highlighted. A transverse distribution system was implemented on the machines and allowed for improved transversal uniformity of application (C.V. < 10%). Numerical modeling using the discrete element method was applied to the first-generation precision land applicator. The simulated results for the distribution across the width of the machine were in close agreement with the experimental results.

Keywords: manure land application, banded application, broadcast application, uniformity of application

Introduction

Manures are inevitable by-products of livestock production that can be effectively recycled by soil-crop systems through land application. The most important technical aspects of land application equipment in terms of optimizing the agronomic value of organic fertilizers are those related to the control of the application rate of the product and to its controlled distribution in the field. Using the currently available land application technology for solid and semi-solid manure, it is however very difficult to obtain an acceptable uniformity of product distribution in both the transversal and longitudinal directions and to effectively control the application rate (Thirion and Chabot, 2003; Frick *et al*., 2001; SRI 1998).
The general objective of the work reported herein was to develop a precision solid and semi-solid manure land applicator capable of achieving banded and broadcast surface application with improved control of the application rate as well as transversal and longitudinal uniformity of distribution.

Materials and methods

This section describes the development of two prototype precision land applicators that were designed and built within the scope of this research study along with the testing and evaluation methods that were utilized in assessing their performances.

General design considerations for land application systems

The discharge of solid and semi-solid manure in land application equipment is generally achieved using variable speed linear conveyors that may be combined with variable orifices. A precise control of the discharge rate with those systems is often difficult to obtain because of the variability in the physical and flow characteristics of the handled manure (Barrington *et al*., 1997; Cemagref, 1997). In order to reach the same levels of performance as those achieved by liquid manure land application systems, it is required to apply solid and semi-solid manure to cropped land in a controlled manner (i.e. coefficient of variation of the application rates lower than 20% in the case of uniform application) and to accommodate different modes of application (broadcast or banded surface applications, direct incorporation or injection). Additionally, with the recent focus on environmental and health concerns, new design decisions are based on environmental and agronomic concerns as well as economic and technical considerations. In other words, the system will not only be assessed in terms of performance and power requirements, but also in terms of surface and/or groundwater contamination potential and other environmental factors. This means that new designs for land applicators will require dynamic control of application rates to be based on the nutrient requirements of the plant and soil and the nutrient content of the manure. Other design considerations include the elimination of frequent calibration and maintaining an application width that reduces the time spent in the field.

Testing of manure spreaders from an environmental point of view includes measurements of parameters that affect the nutrient utilization, such as transversal and longitudinal evenness of distribution, optimum working width, ability to maintain a specific rate during the feeding-out process and the possibilities for the farmer to set the spreader at the desired rate (Malgeryd and Wetterberg, 1996). The test methods should preferably be designed so as to resemble practical spreading as much as possible. The evenness of distribution should be measured at a realistic speed and calculated with methods that reflect the best possible evenness that can be achieved in the field (Malgeryd and Wetterberg, 1996).

Key performance parameters for land application equipment include:

- *Application rate*: the quantity of manure that is applied to the land expressed in terms of mass per unit area (e.g. kg/m^2, tonne/ha).
- *Discharge rate*: the quantity of manure that exits the application equipment expressed in terms of mass per unit time (e.g. kg/s, tonne/min).
- *Maximum application width*: the maximum distance, measured perpendicularly to the travel direction, over which manure can be applied during a single pass of the equipment (e.g. m).
- *Effective application width*: the distance, measured perpendicularly to the travel direction, between adjacent passes of the equipment required to obtain a uniform application rate; it is equal to the maximum application width minus any required overlap (e.g. m).
- When a uniform application rate is required over a large area of land (e.g. field scale), two additional performance indicators need to be considered:
- *Longitudinal uniformity of application*: the degree to which the application rate remains constant along the travel direction of the equipment; if the discharge rate varies, then the travel speed needs to be modified accordingly in order to maintain a uniform application rate.
- *Transversal uniformity of application*: the degree to which the application rate remains constant perpendicularly to the travel direction; if the application rate varies across the maximum application width, then it might be necessary to overlap adjacent passes of the equipment in order to maintain a uniform resulting application rate.

First-generation prototype

The first-generation prototype was built from a commercial manure spreader (New Idea, model 362; Figure1). Four load cells were installed between the spreader hopper and frame for continuous mass measurement. The hopper also included inclinable sidewalls and a hydraulically actuated gate was installed at the discharge-end of the hopper to further control the flow rate of product. Two types of discharge conveyors were implemented on the first-generation prototype (scraper and screw conveyors (augers)). The scraper conveyor consisted of a conventional chain and slat device that spanned the full width and length of the hopper. The screw conveyor system had four 0.305 m diameter, standard pitch (2 right-hand, 2 left-hand flighting) screws installed across the entire width of the floor to eliminate bridging in the hopper and to provide an even flow rate across the entire width at the back of the spreader.
A transverse distribution system was added to this machine to perform surface banded application (Figure 1 and Figure 2). A transverse screw conveyor (0.305 m diameter; 3-m length) housed in a PVC tube featuring six adjustable apertures was installed at the back of the machine, with a transition hopper linking the main discharge augers to the transverse conveyor. The two discharge systems (system of 4 augers and scraper conveyor) on the first-generation prototype were extensively tested. The experiments were carried out using beef feedlot manure that had been stored in swaths for about five months and that had an average total solids concentration (TS) of 57.0% ± 2.8% on a wet mass basis. The manure contained straw and presented large clumps. The effects of the velocity at which the discharge conveying system is operated, vertical position of the flow-control gate and inclination angle of the sidewalls on the flow rate and energy requirements were investigated. The transverse distribution system was tested for uniformity of distribution using composted poultry manure. The mass of compost collected under each aperture was weighed using a laboratory scale during static unloading tests.

Second-generation prototype

A second-generation prototype precision land applicator was developed (Figure 1). The second machine was entirely designed and built at the University of Saskatchewan and includes several features to accommodate current and future research needs. The frame of that machine was made sturdier and designed to provide ease of attachment for all the components. The second-generation transverse distribution system was made of the same screw conveyor housed in an improved rolled steel tube. This new design allows the machine to perform precision broadcast surface application through a continuous slot, or banded surface application using six adjustable apertures. The bottom of the transition hopper is tapered as to join the transverse tube without

Figure 1. First- (left) and second- (right) generation prototypes of the precision land applicator.

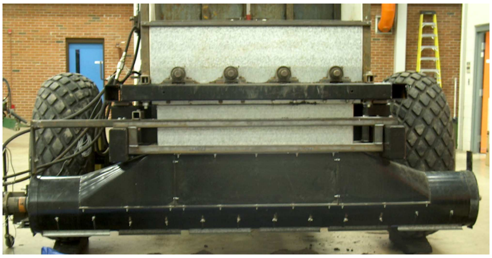

Figure 2. Plastic tube with adjustable apertures used on the first generation prototype (left) and steel tube with adjustable apertures creating a continuous slot used on the second generation prototype (right).

creating 90-degree angles. This feature was added to facilitate the transition from the main discharge conveyors to the transverse screw conveyor.

The second-generation prototype, with the transverse distribution system, was tested for longitudinal and transversal uniformity of application using composting beef feedlot manure (TS of 34.1% ± 4.6%). Additional tests were carried out using composted dairy cattle manure (TS of 59.3% ± 3.9%).

Results and discussion

Main discharge conveying systems on first-generation prototype

European Standard EN 13080 (CEN, 2002) was used as the basis of the experiments and data analysis included in this study. Figure 3 summarizes the results obtained for the power requirements of the two conveying systems as well as their characteristic flow rate, for experiments carried out with beef feedlot manure. The experimental results for both the specific energy and characteristic flow rate were analyzed to highlight the effect of the operational parameters. The results of the statistical analysis indicated a significant effect of the gate on the specific energy for both conveying systems at the 5% level. The characteristic flow rate of the scraper conveyor was

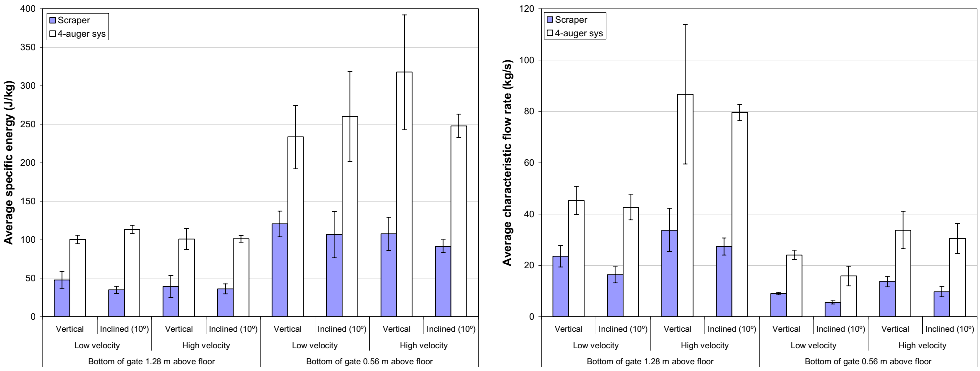

Figure 3. Specific energy (left) required by the conveying systems for the unloading of the spreader and characteristic flow rate (right) obtained as a function of the operating parameters (the error bars correspond to the standard deviation).

significantly affected by the position of the gate, the velocity of the conveyor and the inclination angle of the sidewalls. In the case of the characteristic flow rate of the system of 4 augers, the significant factors were the gate, the velocity of the conveyor and the interaction between these two parameters. The system of 4 augers required significantly more energy to move the mass of manure out of the spreader when compared to the scraper conveyor. As expected, the usage of a flow-control gate had a significant effect on the power required to unload the spreader, as reflected by the values of specific energy. The effect of the gate was significant for both conveying systems. The statistical analysis also demonstrated that the vertical position of the gate, the velocity of the conveyor and the angle of the sidewalls all influenced the characteristic flow rate obtained when the scraper conveyor was used. As expected, the characteristic flow rate was higher when the gate was at its higher position and when the conveyor was operated at high velocity. For the angle of the sidewalls, the reduction of the flow section resulting from the inclination of the sidewalls caused the characteristic flow rate to become significantly smaller when compared to the results obtained with vertical sidewalls. The results obtained with the 4-auger system indicated significant effects of the vertical position of the gate and conveyor velocity. The statistical analysis also highlighted the interaction of conveyor velocity and gate opening. At the high velocity setting, the effect of the vertical position of the gate on the characteristic flow rate became more important. The 4-auger system featured 2 left-hand flighting augers next to 2 right-hand augers. This promoted the flow of product towards the center of the spreader, making the effect of the angle of the sidewalls less significant.

Transverse distribution conveyor evaluation on first generation prototype

Laboratory testing of the first-generation transverse distribution system was carried out using a homogeneous and dry poultry manure compost (approximately 60% total solids). The main discharge augers were operated at 30 rpm and the velocity of the transverse conveyor was 60 rpm. As illustrated on Figure 4, satisfactory results were obtained for the uniformity of distribution across the width of the transverse distribution system, with an average coefficient of variation of 6.0%. The transverse conveyor required 0.35 kW of hydraulic power on average during the laboratory tests.

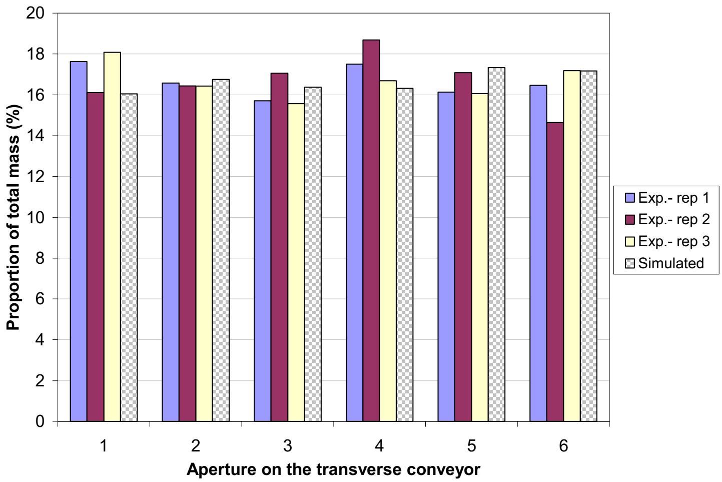

Figure 4. Experimental and simulated mass distribution across the transverse conveyor for compost spreading using the first-generation prototype for precision banded application.

Longitudinal distribution on second-generation prototype using the transverse conveyor

Field testing of the second-generation prototype was carried out using beef cattle manure. Filtering had to be applied to the signal produced by the load cells that appeared to be affected by vibrations in the mechanical drive system. With the main discharge augers operated at 12 rpm and the transverse conveyor running at 110 rpm, the results of four experimental runs yielded an average longitudinal coefficient of variation of 50.0% ± 2.8%. The results obtained with composted dairy cattle manure using the same operating velocities indicated a longitudinal coefficient of variation of 31.0%. The longitudinal flow rate curve obtained with composted dairy cattle manure is presented on Figure 5. The discharge curve suggested that a relatively even flow rate was achieved by the machine.

Transverse distribution conveyor evaluation on second-generation prototype

Laboratory testing of the second-generation transverse distribution system was carried out using composted dairy cattle manure. An average coefficient of variation of 7.8% was obtained for three replications of the experiments at velocities of 12 and 110 rpm for the main discharge augers and transverse conveyor, respectively. It should be born in mind that the second-generation transverse distribution system was tested for precision broadcast application using a continuous slot. The apertures are therefore transversely wider and more susceptible to variation in the amount of manure discharged. Fine tuning of the circumferential position and size of the apertures could yield even lower values for the transversal coefficient of variation. The transverse conveyor required 0.48 kW of hydraulic power on average while the average power requirements of the main discharge augers were 4.43 kW during the transversal distribution tests.

Numerical modeling

The discrete element method (DEM) is an explicit numerical method of modeling the dynamic behaviour of assemblies of distinct objects (Cundall, 1971). It makes use of contact mechanics between particles in an assembly and between particles and the physical boundaries of the domain

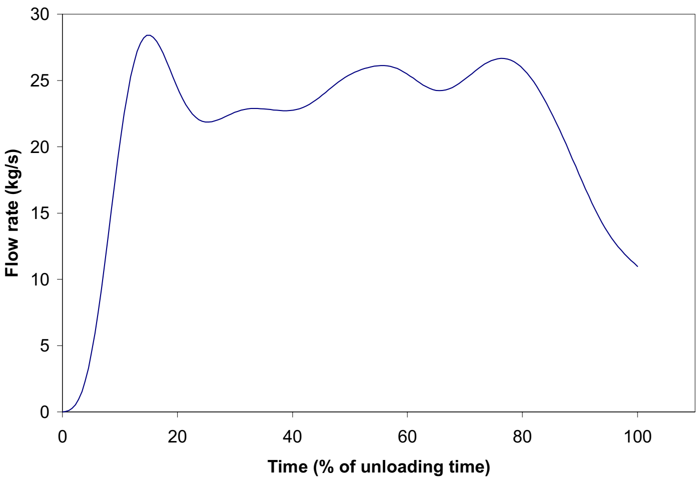

Figure 5. Flow rate as a function of time for the second generation prototype spreading composted dairy cattle manure.

to model the dynamics of systems of particles. The DEM was applied to the flow of organic fertilizers in land application equipment. Selected mechanical systems were modeled along with various types of organic fertilizers. The results suggested that the constitutive model of the product plays a critical role in the accuracy of the machine-product interactions models. It was also shown that DE models of machine-product interactions have the potential to become powerful engineering tools for the design and optimization of manure handling and land application machinery. This is illustrated by the model that was developed for the first-generation prototype land applicator (Figure 6). The model was capable of predicting with satisfactory accuracy the mass distribution across the width of the transverse distribution conveyor (Figure 4).

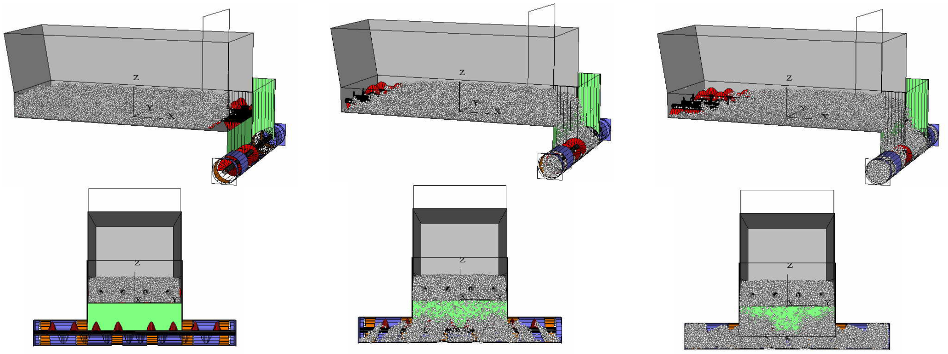

Figure 6. Simulation of the first generation prototype land applicator with the transverse conveyor for banded application. The top images represent a general view of the machine with the corresponding right-side view directly underneath each top image. The initial state of the model is illustrated along with two stages of the unloading process.

Conclusions

Two precision land applicator prototypes were designed, fabricated and evaluated. Improved uniformity of product distribution was achieved, especially in the transversal direction with coefficients of variation below 8%. The type of product spread was found to have an influence on the performance of the equipment, but it was demonstrate that more precise manure land application is achievable. Numerical models of the machine-product interactions taking place in manure handling and land application machinery were developed and the predicted mass distribution across a transverse distribution system was in good agreement with experimental results. Such models have the potential to become very potent engineering tools in the development of improved technological options for the land application of solid and semi-solid manure.

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Potential for on-site and on-line analysis of hog manure using visual and near-infrared reflectance spectroscopy

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Abstract

In this research the feasibility of a mobile *VISNIR* spectroscopy instrument (Zeiss Corona 45 *VISNIR* fibre remote) for on-site and on-line analysis of hog manure was investigated. The sensor was calibrated using the one-out cross-validation technique on a set of hog manure samples collected in the spring of 2004 and validated for its 'true' prediction accuracy on a set of samples collected in the spring of 2003 from different Flemish farms.
Dry matter content (*DM*), organic matter content (*OM*), total nitrogen (*N*), ammonium nitrogen (NH_4-N), phosphorus (*P*), magnesium (*Mg*), potassium (*K*) and calcium (*Ca*) were predicted on the prediction set with R^2 values of 0.91, 0.90, 0.86, 0.76, 0.75, 0.80, 0.69 and 0.59, and *RPD* values of 3.22, 3.00, 2.63, 2.00, 1.78, 1.84, 1.68 and 1.30, respectively.

Keywords: manure, phosphorus, nitrogen, potassium, NIR spectroscopy

Introduction

During the last decade environmental concerns have led to new policies forcing the European livestock industry to reduce the water pollution from land-application of manure (Anonymous, 1991). At the same time modern agriculture uses tons of artificial fertilisers to obtain high crop productivities. Although it is recognised that manure can increase crop yields by improving soil structure and by adding nutrients, farmers are not eager to replace the larger part of their artificial fertilisation by manure. And even when they accept to use manure, they are very sceptical towards reducing the artificial fertilisation doses. The main reason for this behaviour is that the farmers worry about productivity losses resulting from lack of a certain nutrient due to the unknown composition of the manure.
Matching fertiliser application to the soil reserve, measured by soil sampling, and the crop needs, found in literature, can be easily done with artificial fertilisers, since their composition is known and guaranteed. Therefore, manure can only become a viable alternative for artificial fertilisers, since their composition is known before application. This composition determination is mostly done by wet chemical analysis, which is a very time costly (several days) and quite expensive procedure. Moreover, the time delay induced by the wet chemical analysis makes good manure nutrient management very difficult, since the land application may be completed before the sample results are known (Millmier *et al*., 2000). A rapid and accurate on-farm analysis technique could tackle this problem, converting the manure into a viable alternative for a large part of the artificial fertilisation.

Literature review

During recent decades, near infrared (*NIR*) reflectance spectroscopy has proven to be a valuable, non-destructive technique for rapid analysis of quality and composition of agricultural products (Shenk *et al.*, 1992; Reyns *et al*., 2001; Reyns, 2002; De Belie *et al*., 2003). Reeves and Van Kessel

(2000) used two fibre-optic based scanning monochromators to determine ammonium-nitrogen (*NH4-N*), moisture, total carbon (*C*) and total *N* in dairy manures. They reported that a scanning monochromator ranging from 400 to 2300 nm can be a viable alternative to other quick tests available on the market, whereas one using only the 400 to 1098 nm region is not. Millmier *et al.* (2000) scanned swine lagoon effluent, liquid swine pit manure and solid beef feedlot with a scanning monochromator ranging from 400 to 2498 nm. They concluded that total solids, total Kjeldahl *N*, ammonium-*N* and potassium (*K*) are predictable, while the prediction of phosphorus (*P*) needs further research. To obtain these promising results they unfortunately had to remove between 2 and 24% of the samples as outliers. Malley *et al.* (2002) analyzed hog manure and manure-amended soils using a monochromator ranging from 400 to 2500 nm with a sample cell in transflectance mode. They obtained very good results for a set of 64 manure samples from seven storage facilities, but were less successful for a set of 75 manure samples from 25 facilities. Saeys *et al.* (2004) scanned 169 hog manure samples in reflectance mode using a diode array instrument ranging from 400 to 1710 nm. They concluded that approximate quantitative predictions could be made for total *N*, ammonium-*N* and *K*, while for dry matter (*DM*), organic matter (*OM*), *P* and magnesium (*Mg*) only discrimination between high and low values could be made. Prediction of calcium (*Ca*), sodium (*Na*) and pH were found not to be possible (yet).

Materials and methods

Manure samples

A calibration set of 420 hog manure samples was collected in the spring of 2004 from almost as many farms in Flanders, Belgium. A set of 164 hog manure samples collected in the spring of 2003 and used by Saeys *et al.* (2004) was used as validation set. Approximately 1 L of each sample was collected and mixed. All samples were stored in a closed container at 4°C from the time of sampling until the time of analysis. Previous work has shown that samples can be stored for several weeks in this way with little or no change in the components of interest (Reeves and Van Kessel, 2000).

Chemical analysis

Sampling and analysis for *pH*, *DM*, *OM*, total Kjeldahl *N*, ammonium *N*, *P*, *K*, *Na*, *Ca* and *Mg* were performed by the Soil Service of Belgium (Heverlee, Belgium) using the official analysis methods described by the Flemish institute for technological research (Anonymous, 2002).

Spectroscopic device and measurement

The 420 samples were scanned in the laboratory using a Zeiss Corona 45 *VISNIR* 1.7 fibre diode array instrument equipped with a remote measuring head. This instrument has the same diode array configuration as the one used by Saeys *et al.* (2004). Since it is a robust device having no moving parts, it can be used on mobile machinery for on-line measurement of grain quality on combines (Reyns *et al.*, 2001), moisture content for an on-line soil compaction sensor (Mouazen *et al.*, 2004) or manure composition on a slurry tanker. The only difference is that the remote measuring head, that has the same 45° detector positioning configuration and external lamp, is linked to the sensor by a fibre optic cable. This makes it possible to place the measuring head in the manure, preserving the sensor in a safe housing (Figure 1). To be able to investigate the 'true' prediction accuracy of the calibration models, 164 hog manure samples used by Saeys *et al.* (2004), that had been stored for more than a year in closed containers at 4°C, were scanned on the same instrument and the predicted concentrations were compared to the measured concentrations.

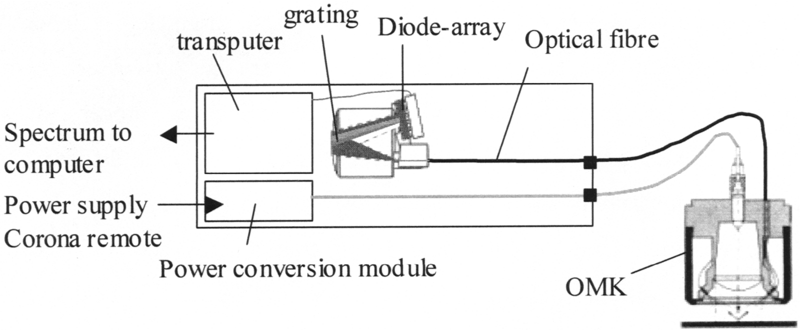

Figure 1. Schematic drawing of the Zeiss Corona45 VISNIR 1.7 remote. (Reyns, 2002); OMK: measurement head.

Statistical analysis

The coefficients of determination R^2 between the different constituents were calculated to check if the correlations and grouping found by Saeys *et al.* (2004) were also present in this data set. The development of the *NIR* calibrations was performed using group wise Partial Least Squares Regression (*PLS*) in The Unscrambler 7.8 software (Camo Inc.), based on a leave one-out cross-validation. The number of latent variables was chosen as proposed by the software. A full multiplicative scatter correction and a second derivative were applied for the *DM* group and the *N* group, respectively, because previous research by Saeys *et al.* (2004) has shown that these spectral pre-processings are the most suited. The accuracy of each calibration was evaluated based on the coefficients of determination R^2 for predicted vs. measured compositions in cross validation and prediction, and the ratio of standard deviation of dataset (*SD*) to root mean square error of cross validation (*RMSECV*) or prediction (*RMSEP*). The ratio of *SD* to *RMSECV* or *RMSEP*, which is called the ratio of prediction to deviation (*RPD*) is the factor by which the prediction accuracy has been increased compared to using the mean composition for all samples.

Results and discussion

Range of the calibration data set

The reliability of a *NIR* spectroscopic calibration will be restricted to the range of constituent values and the variation in measurement conditions taken into account during calibration (Williams, 2003). The sample consistency varied from liquid like samples with few suspended solids (4·150 g L^{-1} *DM*) to that of a highly viscous slurry (212·77 g L^{-1} *DM*). The constituent concentrations ranged from 10 fold for *K* to 181 fold for *Mg*. Thus, the dataset included a large amount of compositional and physical variation, justifying this feasibility study for on-site and on-line analysis of hog manure based on this sample set.

Constituent correlations

The coefficients of determination R^2 between the different constituents measured by the wet chemical analysis are listed in Table 1. The concentrations of *OM*, *P*, *Ca* and *Mg* are correlated to that of *DM* with R^2 values of 0·97, 0·82, 0·74 and 0·84, respectively, whereas the concentrations of *NH4-N* and *K* are correlated to the total *N* content with R^2 values of 0·79 and 0·77, respectively. These group-wise correlations are comparable to the ones found by Saeys *et al.* (2004),

introducing a division into two groups, namely a *DM*-group of constituents that are correlated with *DM* content and a *N*-group with constituents that are correlated with the total *N* content. The spectroscopic basis of the first group is expected to rely mostly on the *O-H* and C-*H* bonds, while the second group would rely more on the presence of *N-H* bonds.
A plausible explanation of the correlations among *P*, *Ca* and *Mg* and with *OM* and *DM* is that they are constituents of phytate, a significant component of grains in the feed, which is indigestible for hogs unless the enzyme phytase is supplemented. As a consequence, mineral *P* and *Ca* are supplemented to hog feed.
It should be noted that the components of the *N*-group and the components of the *DM*-group are also correlated. The correlation between *Mg*, *P* and *NH4-N* and with *DM* can probably be explained by the formation of struvite ($NH_4MgPO_4.6H_2O$), which has been found to cause settling of the mineral *P* and *Mg* in manure (Bril and Salomons, 1990), whereas the correlation between mineral *Ca* and *P* and with *DM* is explained by the formation of apatite ($Ca_5(PO_4)_3OH$). Since there is far more NH_4-*N* than *Ca*, *Mg* and *P* present in manure, almost all mineral *Ca*, *Mg* and *P* precipitate while a large part of the NH_4-*N* stays in solution.

Table 1. Coefficients of determination (R^2) between constituents as determined by wet chemical analysis.

	DM	OM	P	Ca	Mg	Total N	NH_4-N	K
DM	1.00							
OM	**0.97**	1.00						
P	**0.82**	**0.77**	1.00					
Ca	**0.74**	**0.64**	**0.83**	1.00				
Mg	**0.84**	**0.78**	**0.87**	**0.76**	1.00			
Total N	0.79	0.76	0.58	0.48	0.65	1.00		
NH_4-N	0.54	0.52	0.35	0.31	0.4	**0.79**	1.00	
K	0.51	0.48	0.33	0.26	0.41	**0.77**	**0.65**	1.00

Constituent group partial least squares (PLS) calibrations

The above mentioned correlations between the constituent variables, suggesting a common spectroscopic basis, made it interesting to use *PLS2* to model all the information of one group at the same time, reducing the noise sensitivity of the individual component calibrations (Bjørsvik and Martens, 1992). The cross validation results are listed in Table 2.

Validation

The concentrations predicted by the established calibrations for the samples collected in the spring of 2003, but scanned in the spring of 2004, are plotted against the measured concentrations for these samples in Figure 2. Although a small year-specific bias is present for all constituents, the *RPD* and R^2 values (Table 2) are more positive about the true prediction accuracy for *DM*, *OM*, total *N*, NH_4-*N* and *K* (measured in 2003) than the values obtained for the leave one-out cross-validation on the spring 2004 data set.
A possible reason for the less positive prediction results for *Mg*, *P* and *Ca* can be the fact that these components are not spectrally active in the considered range. Their *NIR* prediction relies

Table 2. Prediction results for the different components.

	Cross validation (spring 2004 data set)		Prediction (spring 2003 data set)	
Constituent	R^2_{cv}	RPD_{cv}	R^2_p	RPD_p
DM	0.88	2.92	0.91	3.22
OM	0.87	2.79	0.90	3.00
P	0.80	2.24	0.75	1.78
Ca	0.65	1.70	0.59	1.30
Mg	0.86	2.65	0.80	1.84
Total N	0.81	2.28	0.86	2.63
NH_4-N	0.56	1.51	0.76	2.00
K	0.60	1.58	0.69	1.68

completely on their correlations to other components such as *DM*, *OM* or total *N*, which have spectrally active C-*H*, *O-H* or *N-H* bonds. These relations might have been slightly different for the spring 2003 samples, compared to the spring 2004 samples. These prediction results on an independent sample set therefore give a better insight into the 'true' prediction accuracy of the composition sensor.

Conclusions

This research demonstrated the potential of a mobile VISNIR spectroscope for on-site and on-line analysis of hog manure.

Although further research will be necessary to optimise calibration and sample presentation on-line, in principle this sensor can be mounted on a slurry tanker to predict the composition of small manure volumes on-line during tank filling. It might also become the basis of a precision manure application system, where the applied dose is controlled based on the measured composition. This sensor could therefore promote a manure management that is more environmentally and economically sound than the present one based on a mean composition for a complete storage facility.

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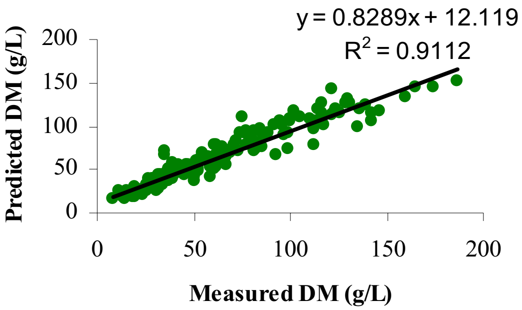
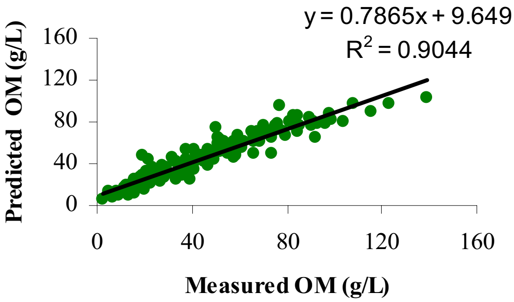
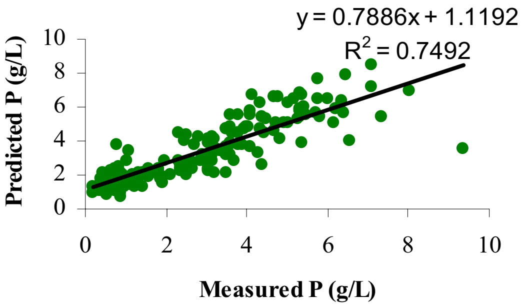
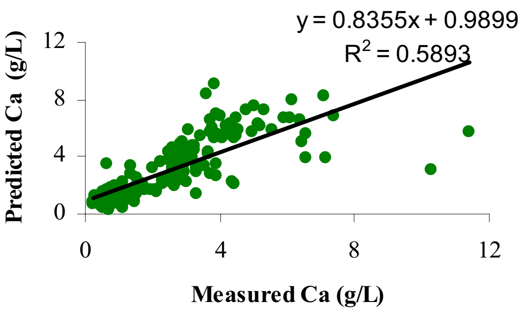

y = 0.8289x + 12.119
R2 = 0.9112
Predicted DM (g/L)
200
150
100
50
0
0
50
100
150
200
Measured DM (g/L)


y = 0.7865x + 9.649
R2 = 0.9044
Predicted OM (g/L)
160
120
80
40
0
0
40
80
120
160
Measured OM (g/L)


y = 0.7886x + 1.1192
R2 = 0.7492
Predicted P (g/L)
10
8
6
4
2
0
0
2
4
6
8
10
Measured P (g/L)


y = 0.8355x + 0.9899
R2 = 0.5893
Predicted Ca (g/L)
12
8
4
0
0
4
8
12
Measured Ca (g/L)

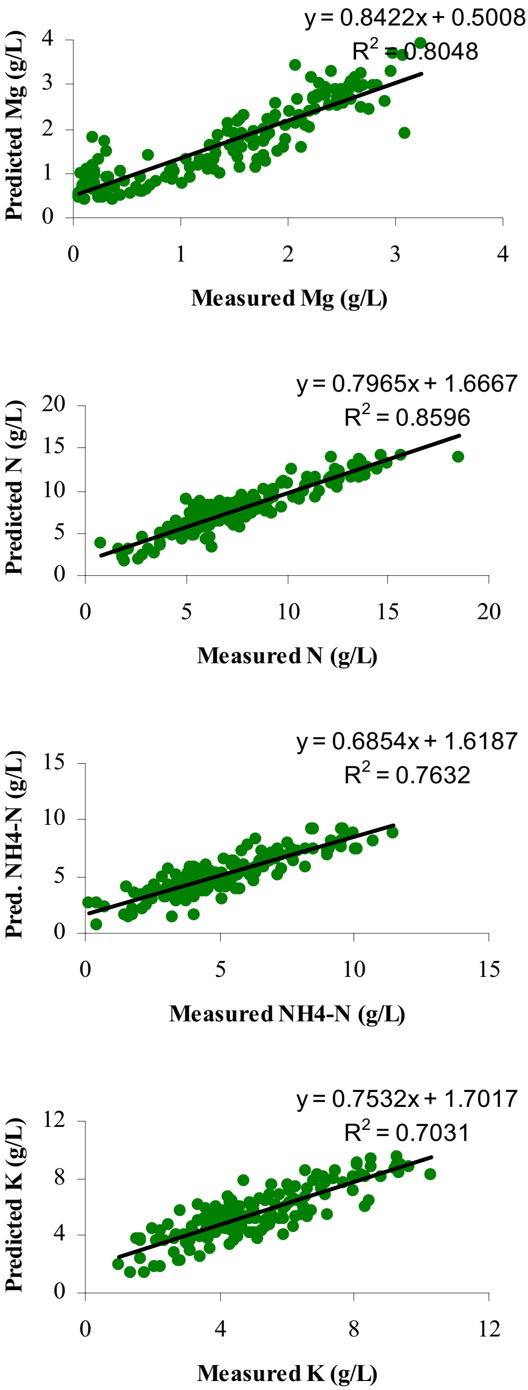


Figure 2. Scatter plots and regression lines of predicted vs. measured concentrations for all constituents of the validation dataset (spring 2003 collected).

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Analysis of milk quality

Milk analyses: a comparison between a simple IR-instrument for use on farm level and available IR-methods

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Abstract

The aim of the present study was to test a new, mid infrared (MIR) instrument for milk analyses at farm level (FMA2001) by comparing the analytical accuracy with existing laboratory MIR instruments (FT-120 and Milkoscan5000). Milk samples were collected at five farms on two occasions at the monthly official milk-recording scheme. In total, 511 samples were analysed for fat, protein, and lactose with the IR instruments. In addition, on every farm, milk samples were randomly taken (in total 89 samples) and analysed with chemical reference methods. The presented overall accuracy was given as an estimation of the accuracy for the whole system, including errors of instrument, sampling, transportation, storage etc., compared against chemical reference methods. The accuracy given as coefficient of variation (CV%) was for fat 4.9%, 2.5% and 2.7%, and for protein 2.6%, 1.6% and 1.9% for the different instruments FMA2001, FT-120 and Milkoscan5000, respectively. CV% for lactose was 2.0% for FMA2001 and 1.9% for FT-120. It was concluded that the FMA2001 is a suitable instrument with satisfactory accuracy to be used for milk analysis at farm level for management purposes.

Keywords: milk analysis, on-farm analysis, IR instrument

Introduction

The trend in dairy production is towards larger herds employing a high degree of automated management with techniques that usually have different built-in data collecting systems. Frequent daily registrations can be made on milk yield, concentrate feed intake, cow weight, and cow activity. The registrations can be used as tools for various management decisions. In addition in some countries, milk yield, milk composition and milk somatic cell count (SCC) is recorded once a month by the official milk-recording scheme. These monthly milk recordings are primarily used for genetic evaluation, but also for different management purposes. However, it can be questioned if the monthly registration is enough for management decisions at the individual cow level or at herd level (Svennersten-Sjaunja *et al*., 1998).

Milk yield has a relative day-to-day variation of 5-6% with the different milk components, fat, protein, and lactose having a relative daily variation of 7%, 2%, and 1%, respectively (Sjaunja, 1986; Syrstad, 1977). For calculations of feed ratios a more frequent analysis of the milk constituents would therefore be preferable especially for the cows in critical periods of lactation, such as before peak lactation and at the end of lactation. Another advantage with frequent milk analyses could be to improve feed calculations and thereby reduce the feed costs since feed represents a major expenditure in dairy production. In addition, frequent analyses of milk composition could be used for detection of disturbances at udder quarter level.

However, the limiting factor for milk analyses at farm level has been the availability of equipment. Instruments that have been introduced to the market recently, use different measurement techniques such as ultrasound and infrared spectroscopy. The aim of the present study was to test the analytical accuracy of one analytical instrument for milk when used at farm level. Furthermore, a discussion of whether or not the accuracy could fulfil the demand for estimations of the energy requirements is included.

Material and methods

Farms

The experiment was carried out on five Swedish farms. The average number of cows per farm was 56 (46-68). On one of the farms the cows were housed in a tied-up system, while the cows on the other four farms were housed in loose housing. The cow breeds were Swedish Red and White Breed (SRB), Swedish Holstein (SLB) or crossbreeds between these two. Cows in different lactation numbers and different lactation stages were represented on all farms.

Experimental design

Milk samples were collected in connection with the monthly official milk-recording scheme. Sampling was repeated at two different occasions for four of the farms; at one farm sampling was done once. Samples were taken from all cows in lactation and in total 511 milk samples were analysed for fat, protein, and lactose content.
Directly after the milking (both morning and evening), milk samples were analysed at the farm with the FMA2001 instrument (referred to as FMA). In addition to the samples sent to the official milk recording, identical samples were taken for further analyses to the Swedish University of Agricultural Sciences laboratory, Uppsala, Sweden. The milk analyses at the University's laboratory were done with the FTIR instrument FT-120. At every milking, samples were randomly taken for chemical reference analyses (fat, protein and lactose). The analyses were done at Steins Laboratory in Lund, Sweden. In total 89 reference samples were analysed.

Analytical methods

The milk analyses were done with three different analytical instruments, which employ mid infrared (MIR) spectroscopy. They were FMA2001 (Miris AB, Uppsala), FT-120 and Milkoscan5000 (both from Foss Electric, Denmark). The reference methods used were Röse-Gottlieb for fat, Kjeldahl for protein, and Luff-Schoorl for lactose.

Description of FMA2001

The major difference between the instruments used at the laboratories (FT120 and Milkoscan 5000) and FMA is that FMA does not have a built-in homogeniser for milk fat. To overcome the problem with homogenising milk, a patent-pending method is used. As with Miloscan5000, the FMA has different filters for the specific milk components. The FMA method uses four wavebands, where the wavebands for fat are 5.7 and 3.5 µm, for protein 6.5 µm, and for lactose 9.6 µm. FT120 is a Fourier transform infrared (FTIR) spectroscopic method and can include hundreds of wavebands. FMA is pre-calibrated at the factory and needs no further calibration at the farm. Before start of analyses, the manufacturer recommends that the instrument should be tested with a check solution and be cleaned after each 10^{th} sample. The time required for one analysis is 40-60 seconds, depending on the sample temperature. In contrast to FT120 and Milkoscan5000, the FMA is portable. As soon as the instrument is provided with electrical power the analysis can start.

Statistical evaluation

Since the morning and evening milk samples from FMA were analysed separately, a mean from these results was calculated. The statistical calculations were done with the package SAS version 8.02. To test the effect of the different analytical methods analysis of variance was used with the procedure general linear model (GLM) according to the following model:

$Y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + e_{ijk}$
where
Y_{ijk} = fat, protein or lactose of i:th analytical method and j:th herd and k:th occasion
μ = mean
α_i = effect of the i:th analytical method (n=4)
β_j = effect of the j:th herd (n=5)
$\alpha\beta_{ij}$ = effect of the ij:th interaction between method and herd
e_{ijk} = residual term

The analytical accuracy in this field study was estimated from regression analyses between the different IR methods and chemical analyses for the milk components fat, protein, and lactose. The residual standard deviation, root mean standard error (RMSE), for the estimated regression line describes the accuracy of the analytical method. Another term for accuracy is RMSEP (root mean standard error of prediction), which was used to describe the accuracy during an evaluation. RMSEP or RMSE in percent of the mean was also used and denoted CV% (coefficient of variation).

Results

Comparison of instrument outputs

When the analytical results from the different instruments were compared, the effect of instrument and herd was statistically significant ($P<0.001$) for fat. There was no difference between FMA and FT-120, while the values from Milkoscan5000 were significantly lower compared to the other IR method. For protein, only the effect of herd was significant ($p<0.001$) when using these instruments. There was no difference between FMA, FT-120 and the Milkoscan5000 for protein. (Table 1).

Table 1. Milk fat and milk protein content (%) analysed with the different IR methods (FMA2001, Milkoscan5000 and FT-120). Results are presented as least squares of means (LSM), n=511.

	Analytical methods		
	FMA	FT-120	Milkoscan5000
Fat	4.98^a	4.93^a	4.83^b
Protein	3.65	3.64	3.63

[a,b]Different letters within row give statistically significant differences between values ($p<0.05$)

Comparison with the reference analysis

In Figures 1, 2 and 3 the means of the different analytical instruments are given for fat, protein and lactose in relation to the reference analyses. On six of nine occasions the Milkooscan5000 had a lower content compared to the reference, while the fat content measured by FMA and FT-120 was above the reference. For protein almost all analytical instruments were above the reference with the exception for FT-120 on occasion 1 and FMA on occassion 2.

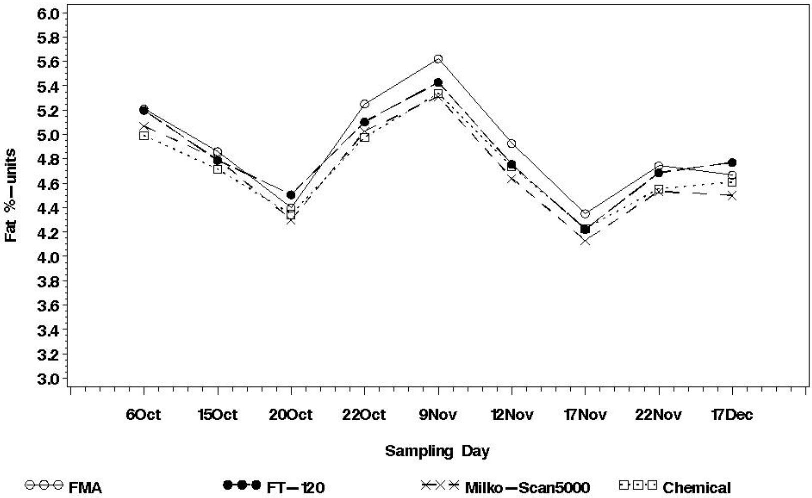

Figure 1. Means of milk fat content at different sampling occasions and herds, measured with three IR instruments, FMA2001, FT-120 and Milkoscan5000 and chemical analyses with Röse-Gottlieb.

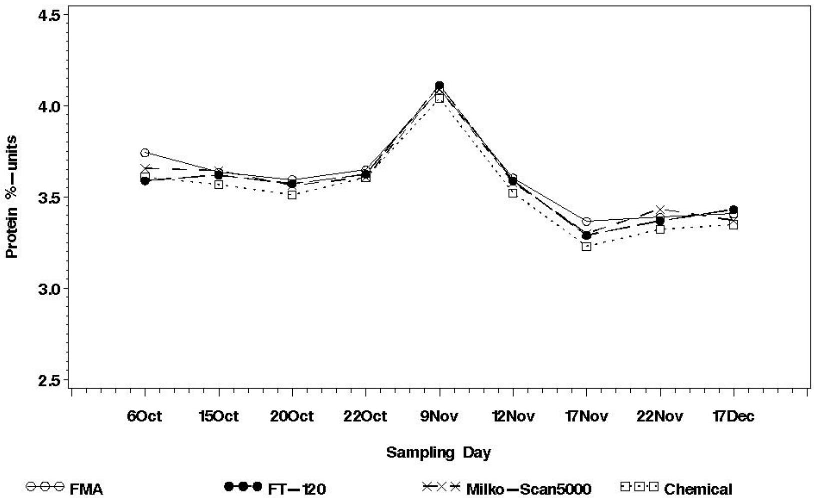

Figure 2. Means of milk protein content at different sampling occasions and herds, measured with three IR instruments, FMA2001, FT-120 and Milkoscan5000 and chemical analyses with Kjeldahl.

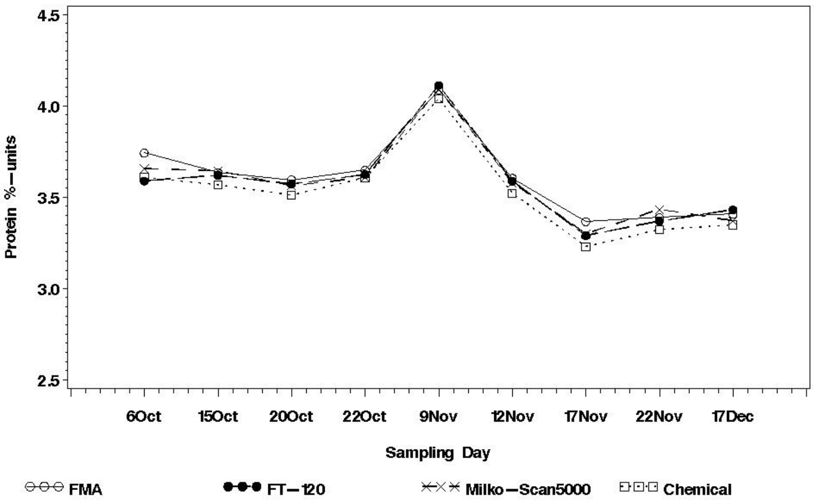

Figure 3. Means of milk lactose content at different sampling occasions and herds, measured with three IR instruments, FMA2001 and FT-120 and chemical analyses with Luff-Schoorl.

According to the analysis of variance, there was a statistically significant effect of the instrument for fat ($p<0.05$), while the effect of herd was significant for fat, protein and lactose ($p<0.001$). The FMA was 0.2 units higher than reference for fat and 0.1 units for protein and lactose. For protein the statistically significant difference was between reference and FMA. The statistically significant difference ($p<0.01$) for lactose was between reference and the other (Table 2)

Analytical accuracy for the different IR instruments

In Table 3 the analytical accuracy during field conditions are given in relation to the reference analysis. The fat analyses had a higher deviation for the FMA compared to the other instruments. For both protein and lactose the deviations were lower.

Table 2. Fat, protein, and lactose content (%) in the milk analysed with the different IR methods (FMA2001, Milkoscan5000 and FT-120) and chemical reference method (fat, Röse-Gottlieb; protein, Kjeldahl; and lactose, Luff-Schoorl). Results are presented as least squares of means (LSM), n=89.

	Analytical methods			
	FMA	FT-120	Milkoscan5000	Reference
Fat	4.89^{a}	4.79^{a,b}	4.66^{b}	4.69^{b}
Protein	3.65^{a}	3.58^{a,b}	3.59^{a,b}	3.52^{b}
Lactose	4.70^{a}	4.74^{a}	-	4.83^{b}

^{a,b} Different letters within row give statistical significant differences between values ($p<0.05$)

Table 3. Analytical accuracy for the different IR methods (FMA2001, Milkoscan5000 and FT-120) in relation to chemical reference methods (fat, Röse-Gottlieb; protein, Kjeldahl; lactose, Luff-Schoorl). Accuracy is given as root mean square error of prediction (RMSEP), coefficient of variation (CV%), coefficient of determination (R^2) and coefficient of correlation (r) for fat, protein, and lactose.

		FMA	FT-120	Milkoscan5000
Fat	n	68	87	87
	RMSEP	0.24	0.12	0.13
	CV%	4.9	2.5	2.7
	R^2	0.86	0.97	0.97
	r	0.93	0.98	0.98
protein	n	70	87	87
	RMSEP	0.096	0.056	0.067
	CV%	2.6	1.6	1.9
	R^2	0.94	0.98	0.97
	r	0.97	0.99	0.98
lactose	n	70	87	-
	RMSEP	0.096	0.088	-
	CV%	2	1.9	-
	R^2	0.87	0.90	-
	r	0.93	0.95	-

Discussion

This study compares a new analytical instrument for milk analysis with two other IR instruments on farms. To be meaningful, major differences between the instruments have to be taken into consideration.

Milkoscan5000 and FT-120 are both instruments to be used in the laboratory while the FMA2001 is intended for use directly at the farm. The FMA is pre-calibrated at the factory, its functionality is checked with a special solution. The laboratory instruments are stationary and are usually calibrated every second week against chemical calibration samples. According to the specifications it is possible to run the samples with FMA without preheating the milk when the environmental room temperature is between 15-30° C. In this study the indoor environmental temperature varied between 0-30° C when the milk analyses were done with the FMA. Prior to testing, the milk samples are pre-heated to 40° C when analysed with the laboratory instruments. Though the prerequisites for the instruments differed, only minor deviations were observed in the analytical results for the milk components. The most marked difference was between the FMA and the Milkoscan5000 with 0.15% and 0.02% units for fat and protein, respectively.

The analytical accuracy, CV%, showed somewhat better values for the laboratory instruments. However, it should be noted that in the field conditions it was inferior to the specifications for all the tested instruments. This could partly be explained by the size of the study, which was rather small, and that the study was done under field conditions.

As expected, the CV was highest for fat content regardless of instrument. Special considerations must be made with respect to the physics of milk fat during analysis. Usually the milk has to be homogenised since the milk fat globules differ in size and can cause a light scattering effect. Furthermore, the creaming process starts during storage, which normally requires that samples should be preheated and mixed prior to analysis. Even though milk samples analysed with FMA were neither preheated nor homogenised, the analytical accuracy was slightly below 5%, compared to the laboratory instruments where the accuracy was 2.5 and 2.7 %. Noteworthy is that, according to Food Analysis (1998), a CV below 5% is acceptable, depending on the type of analysis (Smith, 1998). The CV for protein was also somewhat higher for FMA compared to the laboratory instruments, while it was the same for FT-120 and FMA for lactose analyses.

The biological variation in the population must be considered when evaluating the accuracy of different methods. The relative biological day-to-day variation for fat is 0.35 RMSEP-units (Syrstad, 1977; Sjaunja, 1986). The analytical accuracy for an instrument in RMSEP-units, ought to be less than the day-to-day variation within cow. The RMSEP for fat with the FMA instrument was 0.24, which can be compared to the day-to-day variation of 0.35 RMSEP. This implies that the order of ranking between cows on a single analysis is achieved with high probability. It can therefore be concluded that the FMA instrument shows promise of satisfactory reliability to be used for milk analysis at farm level for management purposes.

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Evaluation of ions sodium and potassium in milk as criteria of changes in the blood-milk barrier: a lactation study

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Abstract

Electrical conductivity (EC) and ion concentrations of sodium and potassium, which have the strongest effect on EC in milk, have been investigated in quarter foremilk samples from 8 cows over a whole lactation period. Results indicated a consistent trend for ion concentrations during a lactation period with a total increase in sodium of 37% and a total decrease in potassium of 18%. Electrical conductivity did not show a consistent trend during the lactation.
For healthy lactating udders, thresholds of concentrations of < 500 mg/l for sodium and > 1400 mg/l for potassium are described in literature, irrespective of the stage of lactation. However, as a result of this study, a systematic change in the ion concentration throughout the lactation period was observed. For sodium a monthly increase of 4% and for potassium a decrease of 2% was registered.

Keywords: udder health, potassium, sodium, electrical conductivity, lactation study

Introduction

The magnitude of costs caused by mastitis and the potential to reduce expenses by means of early detection emphasizes the need for the development of earliest possible detection of mastitis.
Electrical conductivity (EC) is a key parameter for udder health. Ions influencing EC most are sodium, potassium and chloride. The normal secretion of sodium and potassium is controlled by active pumping systems on the basal and lateral membranes of the secretory cells. The pumps operate in such a way that sodium is pumped out of the secretory cell (into the extra cellular fluid) and potassium is pumped in the opposite direction (Kitchen, 1981). The sodium-potassium ratio in the extra-cellular fluid is about the same as in blood (1 : 3). An infection of the udder results in damage of the udder-blood-barrier. Injured duct and secretory epithelium (Capuco *et al*., 1986, Burvenich *et al*., 1988) reacts with an opening up of the tight junction between secretory cells and an increased permeability of the blood capillaries (Schalm, 1977; Bramley, 1992). While sodium and chloride pour from the extra cellular fluid into the lumen of the alveolus, the potassium level decreases proportionally in order to maintain the osmotic pressure (Kitchen, 1981; Peaker, 1977). The increases in sodium and chloride and the decrease in potassium levels have been used as a method of monitoring udder health (Kitchen, 1981). Changes in electrical conductivity can best be measured by analysing foremilk (Spahr *et al*., 1983, Barth and Graupner, 1999). Concentration thresholds of < 500 mg/l for sodium and > 1400 mg/l for potassium are reported in literature for healthy lactating udders, irrespective of the stage of lactation (Wendt *et al*., 1994).
Measurements of the sodium and potassium ion concentrations in foremilk are part of a project that aims at the development of a sensor set-up, which allows a quarter sensitive determination of udder health during the milking process. Results of a literature study on the parameters electrical conductivity and ion concentrations in milk revealed no feasible data. Therefore, a study on lactation had been initiated focusing on the following questions:

- What is a normal slope of ion concentration change during a whole lactation?
- Which natural deviations in ion concentration are possible?
- How to differentiate between an infected and non-infected udder quarter?

Material and methods

Field investigations were carried out in a dairy farm in Germany with high performance German Holstein cows. Four of eight cows were in the first and the other four in the second lactation stage. The dairy farm had a milking interval of 8 - 8 - 8 hours. Quarter samples were collected from all cows in the morning (5 a.m.) and in the evening (9 p.m.) daily over a period of 11 months in 2003. Following the preparation of teat cups, about 5 ml of strict foremilk were obtained separately from each quarter in less than 1 minute and collected in sterile vials. All samples were examined for electrical conductivity as well as sodium and potassium ion concentrations. Immediately after sampling, the milk was frozen and stored at a temperature of -18°C. Freezing was necessary in order to avoid the adding of sodium-containing preservatives, which would have falsified the measurement of ion concentrations. Electrical conductivity was measured using a conductivity meter WTW (LF, 323/SET). The meter has an accuracy of +/- 0.5 % at an operating temperature of -10 + 55°C. The ions sodium and potassium were measured using an atomic absorption spectrometer (AAS vario 6 Jena Analytik). A sample dilution of 1:77 was applied for the absorption measurements.
Additionally to the analysis of sodium and potassium concentrations, a visual evaluation of the milk texture regarding flakes and cords was carried out by the milker. Final diagnosis of mastitis was confirmed by a veterinarian.
The statistical analysis of variance for the ions sodium, potassium and the electrical conductivity was accomplished using the statistical program SPSS 10.0. Effects were considered significantly different at $p < 0.01$. The correlation coefficients were calculated applying Person Significance (two-sided test).

Results

Potassium

The measured values of potassium in the beginning of the lactation were 1563 mg/l +/- 290 mg/l on average and they decreased to an average of 1282 +/- 391 mg/l during the lactation. Total mean was 1532 +/- 392 mg/l (Figure 1). This is a percentage decrease of 18%. The over all natural deviation of measured concentrations was found to range from a minimum of 1239 mg/l to a maximum of 1751 mg/l for potassium. On basis of exclusively healthy udder quarters potassium concentration in the beginning of the lactation was 1563 +/- 210 mg/l on average and 1391 +/- 253 mg/l at the end.

Sodium

The concentration of sodium increased during the lactation period with the only exception of hot months in summertime. Values of sodium were found between 600 +/- 239 mg/l on average at the beginning of lactation and averaged 840 +/- 472 mg/l at the end of lactation with a total mean of 756 +/- 598 mg/l. This is a increase of 37%. The over all natural deviation of measured sodium concentrations ranged from a minimum of 524 mg/l to a maximum of 1330 mg/l. When excluding udder quarters with diagnosed mastitis, the calculation results in a narrower range for sodium concentration of between 558 +/-198 mg/l and 765 +/- 180 mg/l (Figure 2).
Regarding different influences (e.g. ambient temperature, veterinary treatments, claw trimming) sodium concentrations showed a more sensitive reaction in comparison to potassium.

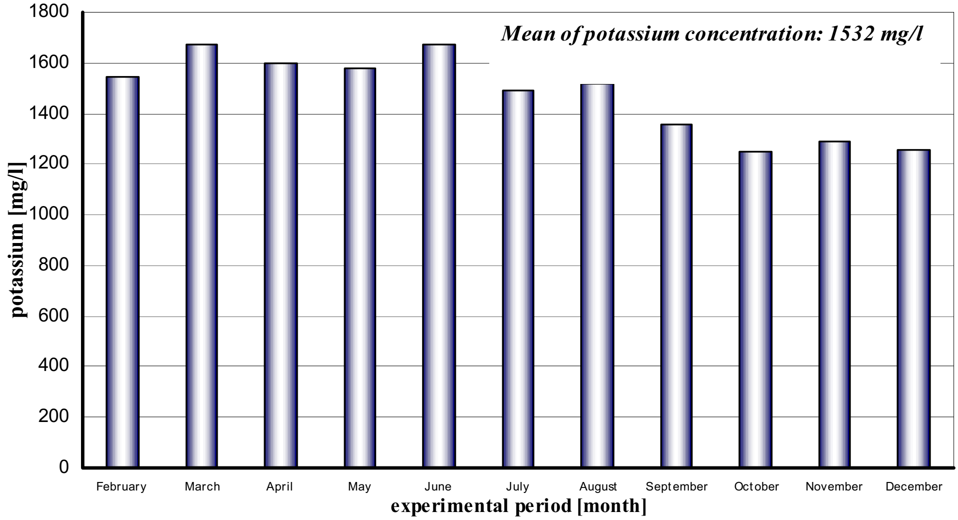

Figure 1. Mean potassium concentrations in foremilk for all udder quarters and all cows during the lactation period.

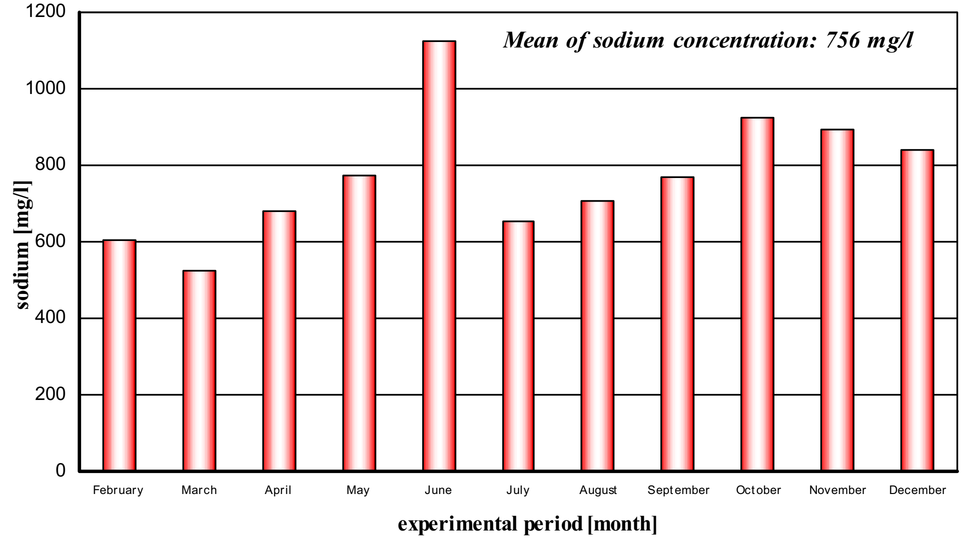

Figure 2. Mean sodium concentrations in foremilk for all udder quarters and all cows during the lactation period.

Electrical conductivity

The parameter electrical conductivity did not show a consistent trend during the lactation period. In general, conductivity varied during the lactation from 5.3 mS/cm to 6.2 mS/cm (see Figure 3). The over all natural deviation of measured electrical conductivity ranged from a minimum of 2.9

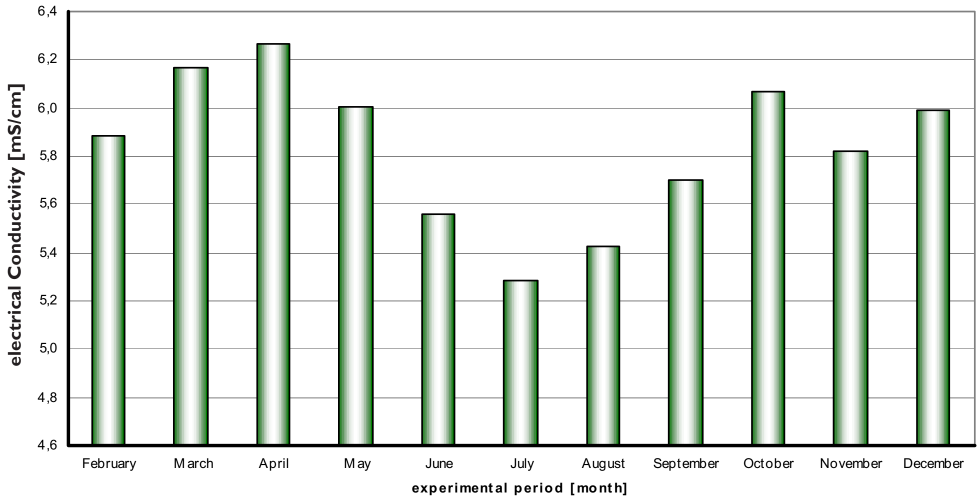

Figure 3. Mean electrical conductivity in foremilk during the lactation period for all udder quarters.

mS/cm to a maximum of 10.6 mS/cm. When excluding udder quarters with diagnosed mastitis from the calculation, the conductivity for the whole lactation was 5.8 +/- 0.4 mS/cm on average. A veterinarian diagnosed mastitis infection for 3 of the 8 cows during the lactation period. Figure 4 shows the sodium concentration of an infected quarter (rear left (h,l)) for cow 20 in the third lactation month. Milk from quarters that were evaluated as contaminated by the milker (visual assessment of cords and flakes in the foremilk) and diagnosed as infected by the veterinarian had a sodium concentration of 1354 +/- 734 mg/l (Figure 4) and a potassium concentration of 1228 +/- 262 mg/l (Figure 5). Electrical conductivity was 7.0 +/- 0.9 mS/cm (Figure 6).

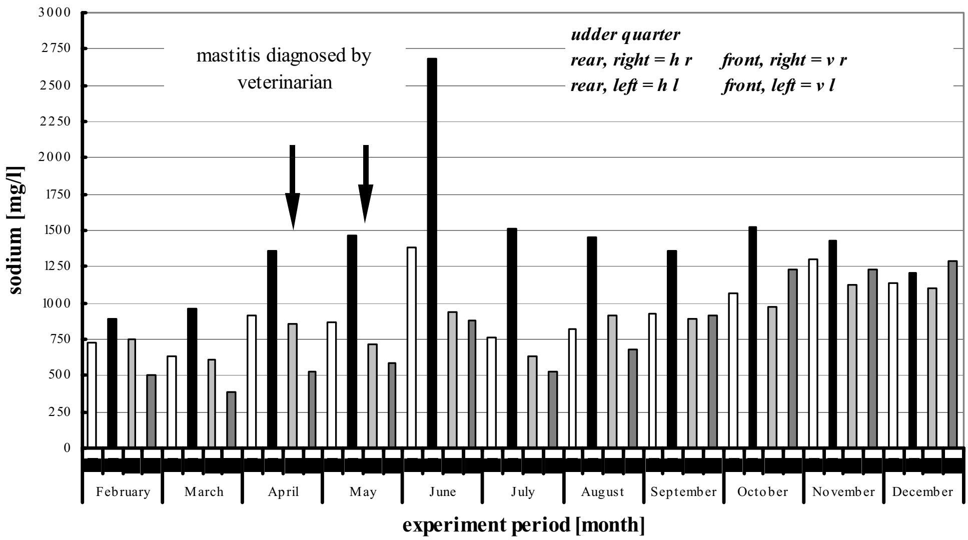

Figure 4. Sodium concentration in foremilk for all udder quarters, cow 20.

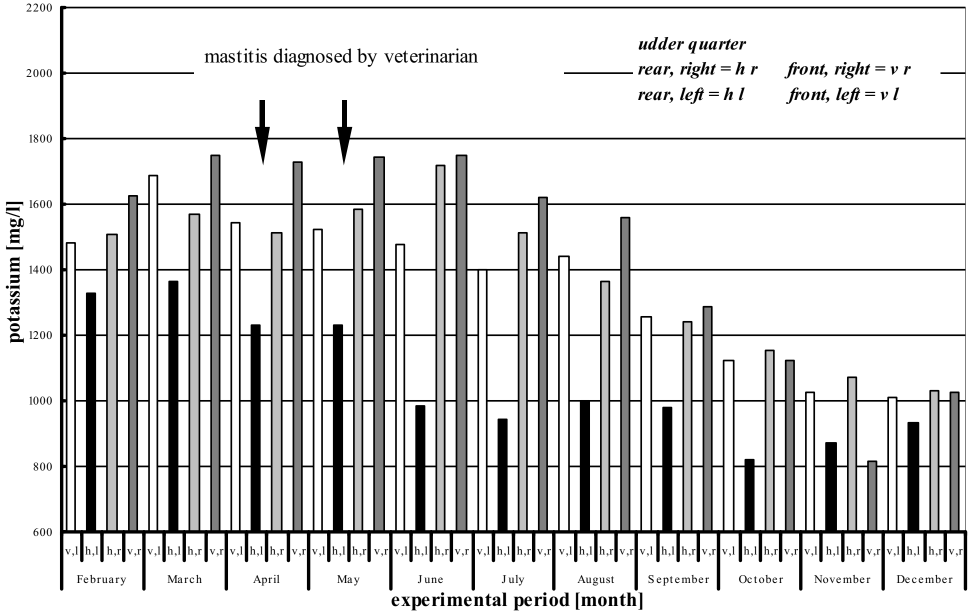

Figure 5. Potassium concentration in foremilk for all udder quarters, cow 20.

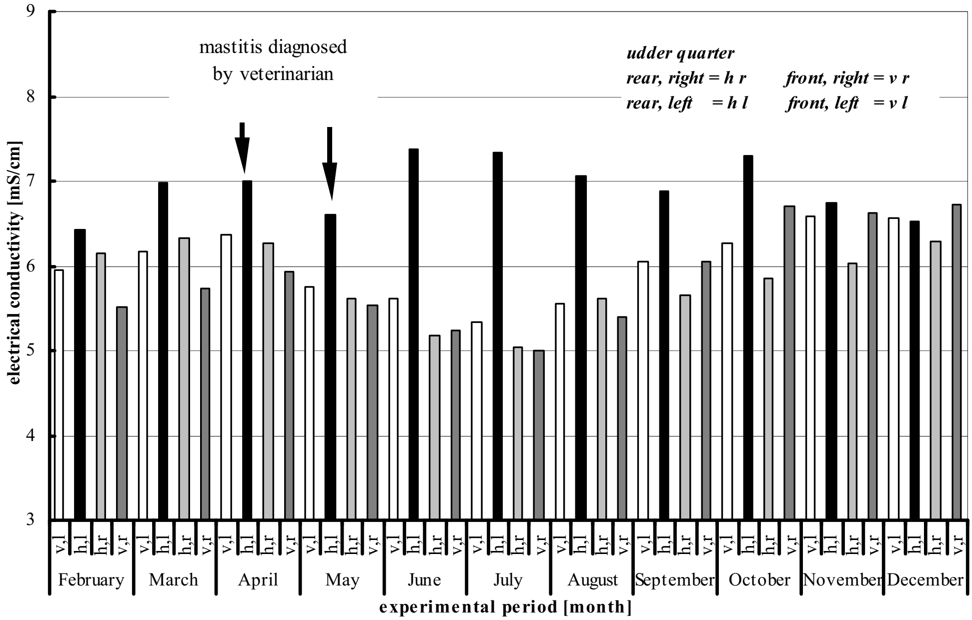

Figure 6. Electrical conductivity concentration in foremilk for all udder quarters, cow 20.

Correlation between ion concentrations and electrical conductivity

Correlation coefficients among variables in foremilk samples are presented in table 1. There is weak negative correlation between sodium and potassium concentration and the potassium-sodium-ratio.
Conductivity was found to be very weakly positively correlated with sodium and even less negatively correlated with potassium-sodium-ratio. A positive correlation consists between potassium and potassium-sodium-ratio.

Table 1. Correlation coefficients among variables in foremilk.

Milk constituents	Conductivity mS/cm	Sodium concentration mg/l	Potassium concentration mg/l	Potassium-sodium-ratio
Electrical Conductivity mS/cm		0.163[a]	-0.094[a]	-0.100[a]
Sodium concentration mg/l	0.163[a]		-0.480[a]	-0.714[a]
Potassium concentration mg/l	-0.094[a]	-0.480[a]		0.676[a]
Potassium-sodium-ratio	-0.100[a]	-0.714[a]	0.676[a]	

[a]Correlation at $p < 0.01$ (2-sides) significance

Conclusions

A first evaluation of the data indicates a typical trend during lactation period with an increase in sodium of 37 % and a decrease in potassium of 18 %. Thresholds of < 500 mg /l for sodium and > 1400 mg/l for potassium found in literature for healthy lactating udders are rather non-specific values because the origin of the milk and the milk fractions used for sampling is unknown. These thresholds could not be fully confirmed. As a result of this study, a systematic change in the ion concentration throughout the lactation period was observed. For sodium a monthly increase of 4 % and for potassium a decrease of 2 % was registered.
Further analyses of the evaluated data and measurements will have to prove possibilities to designate common thresholds and to apply them to different clusters of properties e.g. race, yield groups, and lactation groups. In addition to results of the presented study, counts of somatic cells and investigations on chloride concentrations have to be carried out in order to obtain a full scope of parameters for the early diagnosis of udder diseases.

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On-farm-analysis of milk: a promising challenge

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Abstract

A reliable determination of milk components is not only important for setting the milk price for the farmer, it is also an essential part of milk recording activities related to animal breeding.
Near-Infrared-(NIR) Analysis in conventional laboratories has been established for many years. Although efficiency of analytical procedures and speed of data transmission have been considerably improved in recent years, it still may take on average two days before the results of milk analysis arrive at the farmer.
For some aspects of herd management, e.g. as far as evaluation of udder health is concerned, a shorter delay would be interesting. Therefore for some years solutions for on farm milk analysis are discussed, which would be interesting not only for milk recording purposes (no transport of samples to a laboratory required any more) but would also allow a more efficient herd management.
A milestone on the way to installing those facilities is a project which was initiated about 25 years ago by the French milk recording organisation France Contrôle Laitier (FCL). The first real device, presented in 1986, prepared dried droplets of milk, to be analysed by a NIR-system. The final step up to now was the application on a national level of several prototypes of a system based on a NIR-analyser which was to be linked by fibre optics to up to 12 sensor units, installed in milking parlours.
One of the prototypes of the FCL-system was recently tested at the experimental farm of FAL at Braunschweig, Germany. It was found that the results for fat, protein and lactose, produced by this system, corresponded within a bias +/- 0,05% with the results obtained by a reference laboratory of the local milk recording organisation.
Meanwhile some other devices for on-farm milk analysis are known to be on the market or close to being presented.
It can be expected that this technology will be helpful for the farmer, especially with respect to optimisation of cow feeding and perhaps for early detection of mastitis, but it will also change the profiles of activity of central milk analysing laboratories. Probably the amount of routine analyses will be reduced, but with some certainty there will be a resulting additional demand for evaluating the performance of on farm installations.

Keywords: milk analysis, farm management

Introduction

A correct determination of milk components is not only essential for setting the price of milk to be paid to the milk producing farm but is also of importance for milk recording with respect to genetic aspects.
For many years Near-Infrared-Analysis has been the technical standard in central laboratories. Although efficiency of analytical procedures and speed of data transmission have been considerably improved in recent years, it still may take on average two days before the results of milk analysis will arrive at the farm.

For certain purposes of herd management, e.g. with respect to monitoring udder health, a shorter delay would be helpful. Therefore for some time milk analysis at farm level is discussed. This would allow dairy herd improvement activities without sending samples to a central laboratory and would also be profitable for herd management.
A project of France Contrôle Laitier (FCL) which was initialised about 25 years ago is to be considered as a real milestone of this kind of technology (Table 1). The application of a FCL-prototype at the experimental farm at Braunschweig was offered to FAL by FCL.

Table 1. Development of the French project for on-farm-analyses.

1979:	First ideas
1986:	Formation of a working group for automatic milk yield recording; Goal: NIR-Analysis of dried milk droplets
1993:	Discussion about combining NIR-Technology and fibre optics
1995:	Production and practical test of prototypes

At a conference organised by IDF in Denmark in 2003 a device, using ultrasonic signals for milk analysis, was described (van den Bijgard, 2003), in use for dairy herd management in dairy farms in Brazil.
Analytical results of a compact unit, not designed for dairy herd recording purposes, also based on ultrasonic signals, were evaluated in a further investigation at FAL. The tested system indicates data on fat, protein and lactose. Through external sensors, to be linked to the unit, pH-level and electrical conductivity of samples also can be evaluated.
Both systems included in the experiments provided the option to transmit analytical results to a computer for further evaluation.

Materials and methods

The evaluation of the FCL-system was based on two sets of two representative samples per cow, each set obtained from about 50 cows at the experimental farm of FAL. One sample was analysed by the reference laboratory of the local dairy herd improvement organisation. The second sample was analysed by the experimental device. Based on the results obtained from the reference laboratory the algorithms of the systems were optimised. Results obtained after calibration were compared with the references produced by the laboratory of the dairy herd improvement organisation.
To evaluate the performance of the compact analysing unit (Figure 1) one set of double samples was prepared from 60 milked cows. Data evaluation was done according to the procedures applied for the FCL-system.

Results and discussion

In Tables 2 and 3 the results obtained by the FCL-system are shown. No essential difference to data obtained from the reference laboratory was to be found.
The maximum difference for fat content did not exceed +/- 0,05 % fat (Figure 2). For protein in both data sets only a minor underestimation at higher contents was to be found. It can be concluded that that system can be used for milk analyses related to official recording purposes.

Figure 1. Arrangement for milk analysis with a compact device using ultrasonic signals.

Table 2. Milk composition of reference samples.

	Fat (%)	Protein (%)	Lactose (%)
Set 1			
Average	3,09	3,07	4,75
Std.-Dev.	1,32	0,22	0,20
r(Exp./Ref.)	0,99	0,95	0,87
Set 2			
Average	3,00	3,27	4,82
Std.-Dev.	1,17	0,20	0,18
r(Exp./Ref.)	1,00	0,99	0,99

Table 3. Differences between experimental samples and references.

	Fat (%)	Protein (%)	Lactose (%)
Set 1			
Average bias	0,005	-0,008	0,021
Std.-Dev. of Bias	0,225	0,072	0,114
r(Diff./Ref.)	-0,19	-0,24	0,00
Set 2			
Average bias	0,012	0,005	0,008
Std.-Dev. of Bias	0,030	0,030	0,030
r(Diff./Ref.)	0,00	-0,25	0,13

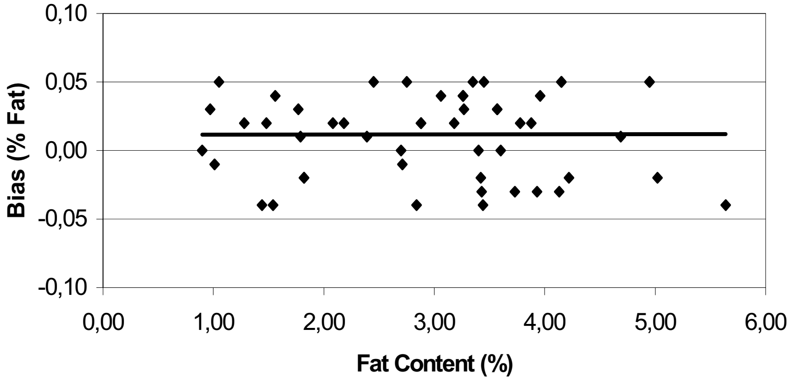

Figure 2. Accuracy of the FCL-Prototype in data set 2 with respect to fat content.

In Table 4 and 5 the results of the initial test of the compact unit are compiled. Since no calibration was possible they do not represent the real level of analytical quality which may be obtained with that device. The obvious linear interactions between references and biases indicate an option for improving the accuracy of measurements by an appropriate calibration, at least for protein and lactose. Further investigations are required to check whether the low level of reproducibility for fat was caused by sampling procedures or due to the performance of the measuring device.

Table 4. Milk composition of reference samples.

	Fat (%)	Protein (%)	Lactose (%)
Average	5.35	3.17	4.75
Std.-Dev.	1.93	0.13	0.20
r(Exp./Ref.)	0.98	0.83	-0.21

Table 5. Differences between experimental samples and references.

	Fat (%)	Protein (%)	Lactose (%)
Average bias	-0.01	-0.24	0.06
Std.-Dev. of Bias	0.42	0.30	0.37
r(Diff./Ref.)	-0.01	-0.97	-0.85

Conclusions

Expectations concerning the application of systems for milk analysis on the dairy farm meanwhile can be considered as being realistic. This technology may not only be useful for optimising cow feeding, but it may also contribute to detection, without major delay, of deterioration of udder health, e.g. by monitoring the lactose contents of milk.

Dairy herd improvement organisations are aware that activity profiles of central milk analysing laboratories may change considerably, since a reduction of standard milk analyses is to be expected. On the other hand the demand for verifications of accuracy and precision of on-farm systems will increase.
Another aspect, not to be underestimated, at least on the national German level, is the reduction of public funding of milk recording activities. Additional costs, resulting for the farmer, probably could considerably exceed the financial input required for installing an on-farm-system for milk analysis.

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Automatic milking

Adaptability of teat cups to different udder forms in automatic milking systems and conventional milking systems

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Abstract

One important reason for udder damages may be the wrong positioning of the milking unit, leading to the teats being pulled by different forces. For this reason the German Agricultural Society has developed a test machine, making it possible to measure four forces at the teats. To examine the influence of the resulting forces caused by different udder formations and differences between the milking systems, three udder formations were tested using different makes of automatic milking systems (AMS) and conventional milking systems (CMS).
Wrong positioning of teat cups was ascertained in both systems. In CMS this was influenced mainly by the milker and the flexibility of short milk tubes, and in AMS mainly by tube guiding and reliable working techniques.

Keywords: milking technique**,** automatic milking systems, force measurements, conventional milking systems, udder formations

Introduction

The technical construction and the condition of the milking equipment may have an influence on udder health and milk quality. One important reason for udder damages can be the wrong positioning of the milking unit. The teats are pulled by different forces because of wrongly placed support arms and milk tubes. Regarding this problem some scientists assert that automatic milking systems (AMS) are better for udder health than conventional milking systems (CMS). Ipema and Benders (1992), Worstorff and Hamann (1998) and Hogeveen *et al*. (2000), for example, expect a higher average milk yield per cow presumably explained by a higher number of milking operations per day. Milking in AMS increased production, lowered somatic cell count and improved teat condition (Svennersten-Sjaunja *et al*. 2000). However, there are other aspects that influence the udder health status. AMS may be more regular in attaching the teat cups. Another aspect is the adaptability of the teat cups to different udder formations. The objective is to simulate the forces exerted on the cows teats by teat cups attached either manually or by an AMS. To examine these aspects and to investigate the influence of the resulting forces, different milking systems were tested, using a test machine developed by the German Agricultural Society (DLG).

Materials and methods

Each simulated teat (Figure 1) contains a sensor which simultaneously measures vertical, rotational , tilting and side forces (Figure 2) to which the teat is subjected.
The forces are measured with the aid of strain-gauged strips (strip tensometer).
The measuring teats are connected with a measuring transformer which is connected with a PC. Data are transmitted to a PC and the milking system can be checked immediately for problems and difficulties . The teats are made of silicon (ISO/DIS 6690, 1995) as depicted in Figure 1. It is

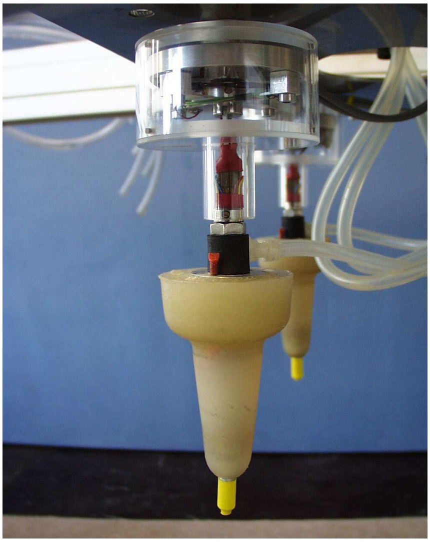

Figure 1. DIN ISO measuring teat.

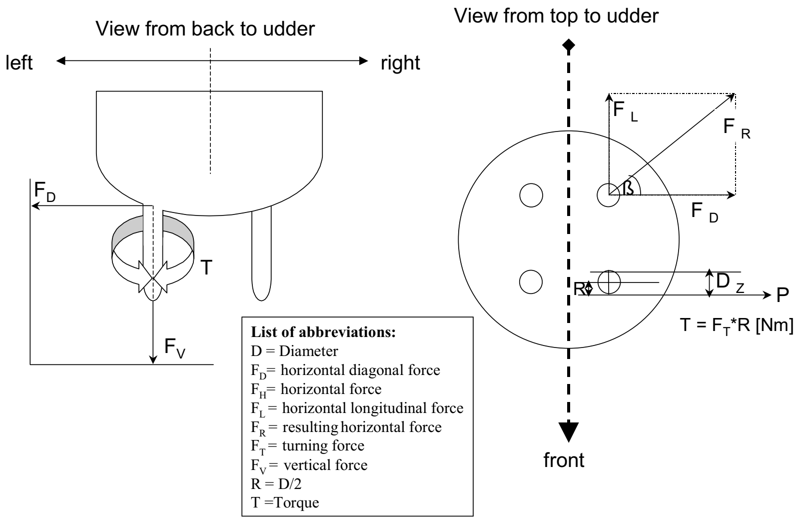

Figure 2. Direction of forces.

possible to adjust three different udder formations: "normal", "stepped" and "wide standing" (Huschke, 2004). In this study only the udder formations "normal" and "stepped" have been investigated (Table 1). The stepped udder formation has a difference of 50 mm between the front and rear teats (Table 1). It is possible to measure the vacuum at teat end (wet-test method).
The teat cups are attached with five repetitions per udder formation in each system. For each repetition the cluster is removed and re-attached by the same milker. The measuring time is 30s. The AMS attaches the teats cups to the test machine udder automatically as in real working practice.
The resulting data provide the basis for calculating mean values.

Table 1. Udder form and udder dimensions.

Udder dimension [mm], α [°]	Normal udder shape (Geidel and Graff, 2004)	Stepped udder shape
Teat distance between front- and rear teat pairs	130	130
Ground distance, teat end	460	460
Distance between rear teats	90	90
Distance between front teats	185	185
Teat length	60	60
Teat diameter D	23	23
Difference between teat pairs front/rear	0	50
Deflection angle of the teat from perpendicular line	0°	0°

It is possible to adjust various milk flows. However, preceding studies have shown that the milk flow has a low influence on the forces. Therefore a milk flow of 5l/min was used for all experiments. Four different types of AMS (n=45) and different makes of conventional Herringbone 30° (n=100) and 50° (n=20) (HBP) and Side-by-Side (n=50) (SbS) milking parlours were tested on different farms.

Results and discussion

Vertical force

Figure 3 depicts the average vertical force at the front and the rear teats in different milking systems with stepped udder formation. The mean values of the right and left front and right and left rear teats were determined, because they have almost the same data. The vertical forces mainly result from the weight of the milking cluster.

The Herringbone parlour 33° shows major differences between the front and rear teats. The maximum is at 25.7 N and the minimum at 6.2 N. That means that the front teats are subjected to a force which is four times higher than the rear teats. In the investigations with normal udder formation maximum major differences of 6 N have been measured. In the Side-by-Side and the Herringbone parlour 50° the difference between the front and the rear teats is not as strong as in the HBP 33°. It is nearly 2/3 to the front teats and 1/3 to the rear teats. With normal udder formation a change in direction in same way has been observed. HBP 50° and SBS show almost the same results. This is the consequence of the same tube guide direction. In both systems the cluster is attached through the rear legs of the cow. The tube guide and the support arm equipment are nearly the same. In the HBP 33° the cluster is attached to the udder from the side of the cow. This is an important reason why there are problems in positioning the cluster exactly, especially for stepped udder formations.

The last two bars of Figure 3 depict the average vertical force in automatic milking systems. It is noticeable that both teat pairs are subjected to nearly the same force. The reason for this is the single tube guide to each teat cup. This means that the adaptability of the cluster to the stepped udder formation is good (Rose *et al*., 2004).

As a second aspect, the standard deviation can be used to obtain further information about attaching the teat cups regularly. The standard deviation appears to be correlated with the corresponding means depicted in Figure 1, except for the ratio of the HBP 33° by comparison with the HBP 50°and the SbS parlour. Normally it should be expected that the standard deviation of HBP 33° is larger than the

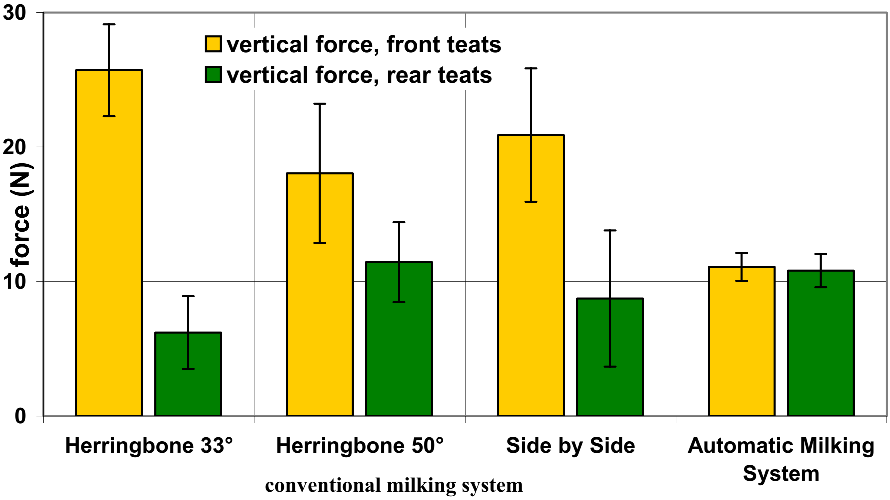

Figure 3. Vertical force at front and rear teats with stepped udder formation.

standard deviation of HBP 50° and SbS parlour. However, the HBP 33° has a lower standard deviation despite its higher force difference at the front and rear teats. One reason for this result seems to be that it is more difficult to attach the milking cluster from the back instead of the side of the cow. A second reason might be that the milking person cannot see the udder very well. Therefore it is difficult to correct the attached milking cluster on the udder, because there is mostly only a simple technique (no support arm) for automatic tube positioning. In the automatic milking system 90 % of all cluster attachments do not need any correction of the milking cluster position on the udder (Hügle *et al.*, 1999). These results confirm the low standard deviations in AMS in Figure 3.

Turning force

The turning force is mostly influenced by the milker, because this force results when the cluster is attached to the teats. Furthermore, it is the result of twisted teat cups. The first consequence is a poor milk flow and milk rate. Further effect can be damage to the udder tissue.
Figure 4 depicts the turning forces in different milking systems. By comparison with the vertical forces, they are at a lower level. The average maximum was found to be 7.18 N at the front teats of the HBP 33°. In the HBP 50° and the SbS parlour, the rear teats are subjected to higher forces than the front teats. By contrast, the HBP 33° has higher turning forces at the front teats with both udder formation. In the automatic milking system the average forces at from front and rear teats are nearly the same. However, it was ascertained that the average data of the turning force with stepped udder form are higher than with normal udder form. This is the consequence of problems in attaching the milking cluster to a stepped udder form by AMS, as noted during our practical tests with different AMS. The higher rear turning forces of the SbS and the HBP 50° result from the order of attaching the teat cups. In most cases the milker attaches the front teat cups to the teats first. Consequently it is more difficult to attach the rear teat cups to the teats. This brings the teat cups and the tubes into wrong positions. It is noticeable on the HBP 33° that the turning force of the front teats is high. This result can also be seen in the SbS and the HBP 50° from the order of attachment of the teat cups, since the front teat cups are attached first or last respectively. The cup which is attached first often suffers a turning force while the other three teat cups are being attached. The milker might have problems in attaching the last cup in the SbS and the HBP 50°.

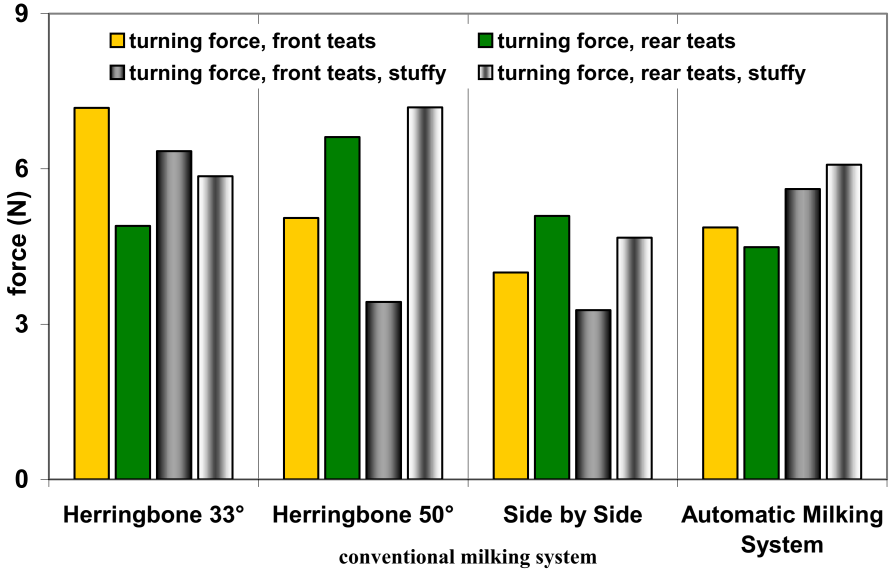

Figure 4. Turning force in different milking systems with normal and stepped udder formation.

There was no big difference between normal and stepped udder formation in CMS. Altogether the turning forces are not very high and do not cause much trouble, except when they are so large that the teat canal is closed and the milk flow is stopped. The problems with the turning forces are nearly the same in all milking systems. In conventional milking parlours the influence exerted by the milker is high.

Horizontal forces

This part includes a view of the resulting horizontal forces. These have been calculated from the horizontal longitudinal and diagonal forces (tilt and side forces).
The horizontal force in different types of conventional milking parlours is depicted in Figure 5. It can be noticed that the horizontal forces with the HBP 33° at the rear teats deviate from the data of the measuring teat. That means there are forces which pull the rear teats to the back part of the cow. This can be a problem for the milk flow and udder health. The reason for this result seems to be the position of the cow in the parlour and the construction of the milking cluster and the support arm. Problems occur especially when the rear teats stand close to each other, the udder form is stepped, and the rear short milk tubes have the same length as the front short milk tubes. In this case it is important to use the support arm exactly and it is recommended that the short rear milk tubes be shortened if there are mainly cows with stepped udder formations in the herd. This is a problem which can appear in all lactations, because in the first lactation the cows often have small udders with teats which are close to each other, and from the second lactation onwards cows often develop stepped udder forms.
Analysing the horizontal forces of the front teats in Figure 5, it is noticeable that the SbS C and HBP 50° have high forces in the front direction of the cow. Both milking systems have the same cluster and are produced by the same company. Therefore it seems that these results are the consequence of the milking cluster construction and the length of the long milk tube. There was only been a simple Y- form tube holder as a support arm. In Figure 5 it can be noticed that there are deviations between different systems of the same make tested. This can be seen at the rear left

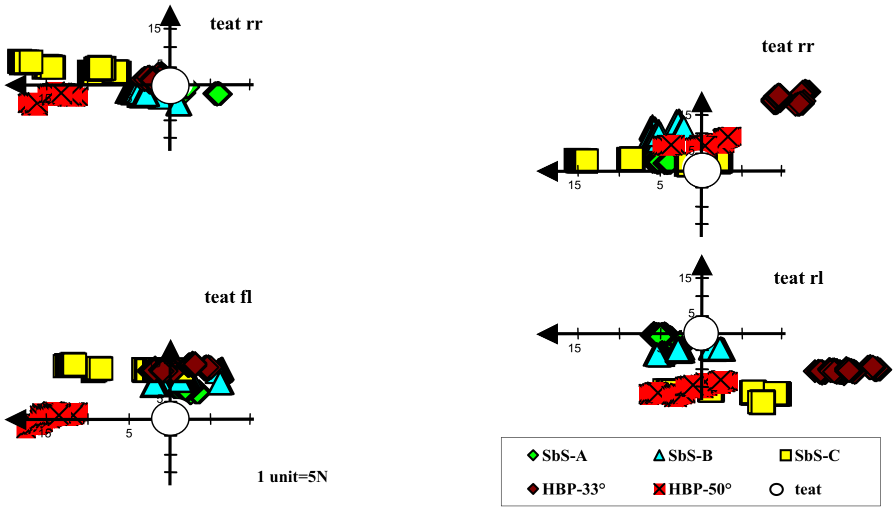

Figure 5. Resulting horizontal forces at the teats in different types of milking parlours with normal udder formation.

teat (especially on the HBP 30° and 50°). There are also differences between the five repetitions. This is influenced by the correct working of the milker and regular maintenance of the milking parlour.
Figure 6 depicts different milking systems with the average horizontal forces occurring. By contrast with Figure 5, Figure 6 includes the automatic milking systems. The data of the AMS A are striking because all four resulting teat forces deviate from the test machine teats. The system does not have good udder adaptability. This is the consequence of the construction of the milking cluster. There

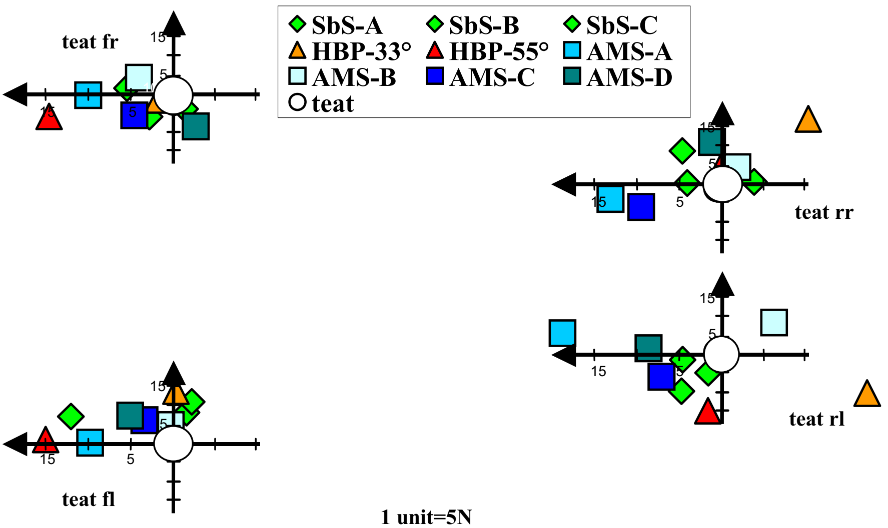

Figure 6. Resulting horizontal forces at the teats in different types of milking systems with normal udder formation.

are strings which connect the teat cups with the system. The AMS C shows a similar trend, but with a lower deviation from the average teat. The results of the AMS B depict some deviations of the left rear teat. This seems to be the consequence of a broken teat cup suspension. Because of this the teat cup cannot be adapted soundly to the teat. This is a general problem with the AMS. There is no milker, so the attachment of the teat cups by a robot is normally more regular than in conventional milking parlours, but reliable operation is very important.
The AMS D shows few deviations, except higher resulting forces at the right left teat. In general all AMS have a good adaptability of the milking cluster to the udder formation. There is only one exception: the construction of the teat cup connection to the cluster of AMS A should be changed. The highest deviations at the front teats in a comparison of all systems were detected in HBP 50°. At the rear teats the highest deviations could be seen at AMS A and HBP 33°.

Conclusions

The adaptability of the milking cluster in AMS can be rated as very positive. All teats are subjected to nearly the same vertical force, which only results from the weight of the teat cups and tubes. Some problems were detected at the horizontal forces.
There are often problems with stepped udder formations in Herringbone milking parlours 33°. There it is important to use the support arms correctly. The Side-by-Side and Herringbone milking parlour 50° have mostly the same and good results. Problems were detected with the vertical forces and the horizontal forces, especially for the front teats at HBP 50°. This is a consequence of the poor to udder visibility for the milker in SbS and HBP 50° parlours.
Exactly positioning of milking cluster could help to reduce forces on the cow' teats and this would reduce the damage to teats, with consequent improvement in udder health.
Reliable working techniques and the construction of clusters have a major influence on the correct positioning of the cluster in automatic milking systems. In conventional milking systems this is mainly influenced by the milker, the construction of cluster and the teat cup liner.
In further studies these factors should be analysed exactly to obtain ideas for solving the problems mentioned above.

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Usability of web-based cameras to observe cows in an automatic milking system

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Abstract

This paper discusses the usability of web based digital cameras to observe cow behaviour in the barn with an automatic milking system (AMS). The aim was to establish the utility of new digital recording technology in observation of the milking process. Four web-based cameras were installed in an experimental barn with an automatic milking system. They followed the washing of teats, attachment of the teat cups and completion of the whole procedure. A total of 300 milkings were observed from a three days' recording session. It has been demonstrated that digital recording equipment can be highly useful for observing the milking process as well as cow behaviour in the barn. Web based cameras provide a useful tool for the stockperson to observe cows' visits to the automatic milking unit and can also help to observe cow's health status as well as the daily routines in the barn.

Keywords: Automatic milking, milking process, monitoring systems, cow behaviour observation

Introduction

The current trend in Europe is to increase both the farm size and the average herd size. At the same time the amount of new technology in the barn is increasing. Technology is nowadays used for feeding, milking, cleaning and observing a cow's health status. Increasing speed of new technology introduced into barns gives new possibilities to observe a cow's wellbeing. However, very little is known of its actual usefulness on-farm. Future observation technology is needed to give more online information about security in the barn and also to observe individual cow behaviour and welfare.

The importance of observing the cow's wellbeing will increase because direct human-cattle contact during milking disappears when transferring from conventional to automatic milking system. When daily human-cattle contact decreases, other ways to observe the changes in a cow's wellbeing become more important. The welfare of an individual cow still has to be secured when the time that a stockperson can devote to each animal decreases. Many different factors affect the welfare of a dairy cow. Environment and human care are the most significant.

Possibilities for detecting deviations in cow behaviour as they occur may have a positive effect on preventing diseases and maintaining the cow's well being. Especially the transfer period, when changing from conventional to automatic milking system, has been found crucial with respect to time needed to observe the cow's wellbeing. It brings an extra workload and includes higher production risks. A transfer period means that a cow and a stockperson have to learn several new things simultaneously: new daily routines, new computer systems, new alarm reports as well as new need to observe cow's wellbeing (Poelarends *et al*., 2004). Hillerton *et al*. (2004) found in their recent study that transferring to new systems can very seldom be done in optimal conditions. This means that extra attention should be paid for example to newly calved cows during transfer period

(Poelarends *et al*., 2004). Animals should be observed also outside the milking unit, so that the deviations in their behaviour can be detected already in the early stage. Changed behaviour is often the very first sign that animal's welfare status is changing. For example Borderas *et al*. (2004) found that cows, who visit milking robot actively, walk better (less limping) than those who less often visit the milking unit. It is essential to detect these changes already in advance, before serious changes in physiology, health or milk yield occurs. New technological devices, such as digital cameras may be used in the barns to help in the essential daily observing routines.

Material and methods

An experiment was carried out at the Suitia experimental farm of the University of Helsinki, with heated loose housing and an AMS. The farm had transferred to AMS in September 2000. Forced cow traffic with the separating gates in the parlour was used. The experimental group consisted of 38 Holstein Friesian cows. Most of the cows (58%) were primiparous, 24% in second, 10% in third and 8% in their fourth lactation.

Video recording

The recording unit consisted of computer software, four web-based cameras (Dynamic Electronics and Protection, DEP) and Showview software. Recordings were saved automatically in removable 120 gigabytes hard disks. Recording was set at five frames per second. With this method approximately four to five days' data could be stored on the hardware. A three days consecutive session was recorded. Workability of the milking process was then observed with the help of the Showview software. Three cameras recorded the situation from the automatic milking system and one was recording overview picture from the barn. The monitoring process is shown in Figure 1. The positions of the cameras are shown in Figure 2.

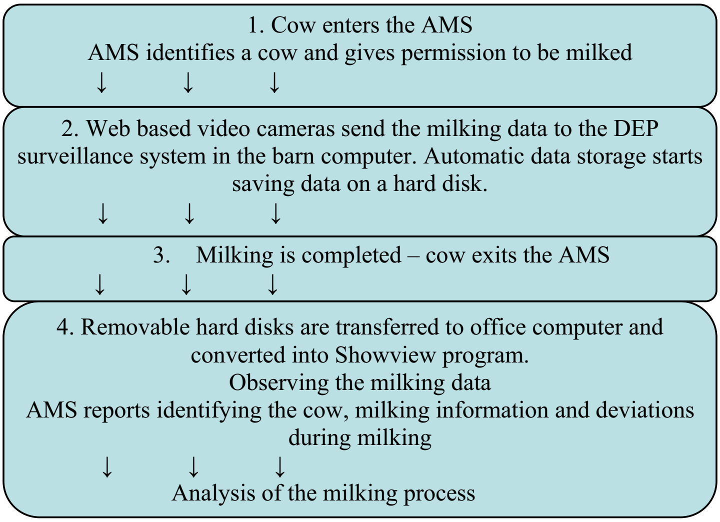

Figure 1. The monitoring process.

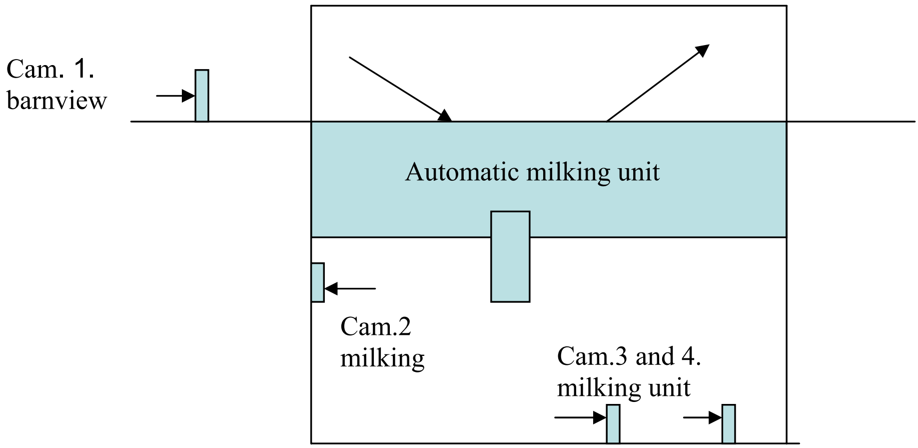

Figure 2. Automatic milking unit and placement of observing cameras.

Performance of the automatic milking process

The milking process was analysed from the video recordings of the 300 milkings that were observed to assess the functioning of the AMS. The results were then compared with the reports provided by the computer programs from the AMS. Reports concerning basic cow information and deviations were used. With the Showview program one could choose the camera and exact time one wanted to observe. One removable hard disk could store 3 days data from four cameras recording 24 h a day. Observation started when a cow walked into the milking unit; her entering time was synchronised with the computer reports and the cow was identified from the list. Notes were done from the 1) washing of teats, 2) attachment of teat cups, 3) detachment and teat spraying. For every milking, it was noted whether the robot washed, milked and sprayed each teat. Deviations, such as kickoffs, machine failures and 'lost teats' were collected and results according to these events were calculated.
A milking process was scored as completely successful if every teat was washed, milked and sprayed. If there were deviations (kickoffs, 'lost teats') but the AMS was able to take compensatory action then the milking was classified as successful.

Categorisation of deviations in the milking process

1. Deviations in the washing process. In this category, the washing of one or several teats was failed. Reasons for failures were 'lost teats'or machine failures.
2. Deviations in the milking process. This category consisted of milkings where one or several teats were not milked. Reasons for this were 'lost teats' or machine failures.
3. Deviations in both on the washing and milking process. This category was the most severe one, as it meant that the milking had failed totally or there were one or several teats that were not washed and milked. These cases were caused by heavy kick offs or 'killing' the machine, which meant that kicks were so strong that the whole milking process stopped. In most of these cases the whole machine stopped and the cow walked out without being milked.
4. Kickoffs during washing. In this category there were failures in the washing process. One or more teats were not washed properly. A cow kicked the washing device so that it was detached. The compensated kickoffs were left out of this category.

5. Kickoffs during milking. The milking process was incomplete in one or more teats. A cow kicked the teatcup off and milking was not completed. The compensated kickoffs were also left out of this category.

Results

The results clearly showed the viability of web based cameras to observe the teat washing and milking processes. It was shown that these small and movable cameras can easily be installed in any part of the barn. The camera outputs remained clear and observable during the whole observation session, even in humid conditions. The recordings were observable also at night time, when the lighting was weaker. A stockperson cleaned the camera lenses once or twice a week with a special cleaning liquid for the camera lenses.
In total 247 (82%) out of 300 milkings were completed successfully (Figure 3.). In this category there might have been failures but the machine was able to compensate the procedure so that all phases of the milking were done properly. In total 47 (16%) incomplete milkings were found. There were failures either in the washing, milking or in both procedures. Six (2%)milkings out of 300 were not assessed because there was either unclear visibility to observe the milking or a stockperson stood in front of the camera lens while treating the cow. Two unclear cases occurred where a cow moved continuously so that the observer could not be sure what was happening.
In the washing process there were deviations in 11 cases (4%). In the milking process there were only 3 (1%) cases in which the milking was incomplete. Then again, there were 11 (4%) cases on which were found lacking in both washing and milking.
Kickoffs were detected in 31 cases out of 294 milkings; 14 of them happened during washing - 1 of them was compensated by the machine, so that the whole procedure was scored successful and 13 (4%) remained uncompensated. During milking 17 of kickoffs were detected - 8 of them were compensated and 9 (3%) were not compensated by the machine. Only a total of 29% of the deviations during washing and milking processes were successfully compensated by the robot.
Observed kickoff situations were compared with the kickoffs in the AMS computer report. It was found that kickoffs consisted of several possible deviations; normal kick off when the milking unit was kicked off by a cow; teatcup dropping on the floor when the teat became empty; cow standing on the milking pipe, leading to teatcup dropping. Also some teatcup dropping occurred when the robot “hand” was trying to attach the teatcup to another teat.

Discussion and conclusions

Web-based digital cameras provide new tools for stock management. For the cost of approximately 4000-5000 euros one can have surveillance system, cameras and the possibility of online

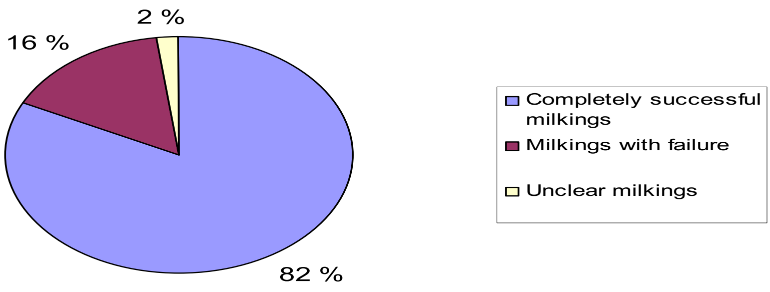

Figure 3. Total results of milking observations.

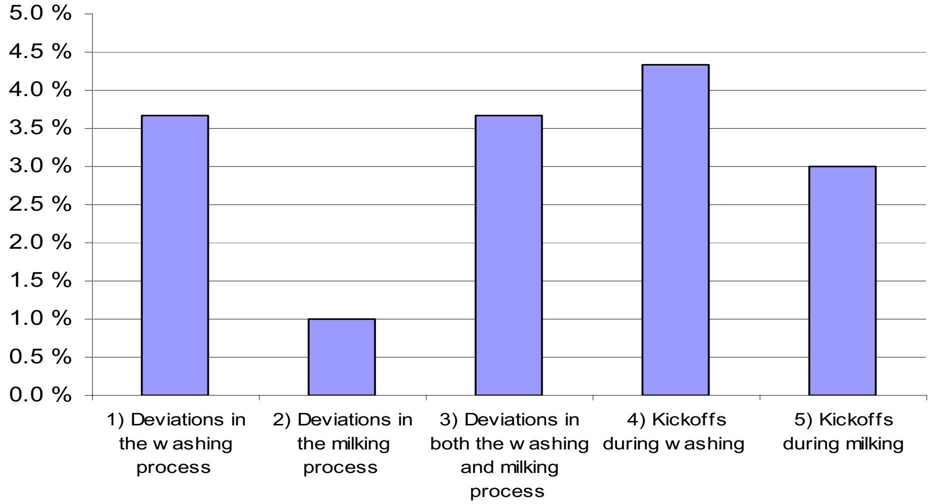

Figure 4. Deviation types in the milking process.

observation in the barn. This kind of equipment may be used for observing the workability of technological devices as well as cow behaviour and health status. In this case it provided interesting additional information, for example when observing cow behaviour - especially problem behaviour in cows during milking. It also helps to find reasons for alerts on the deviation lists. Our study showed clearly that there were three cows with severe problems in adjusting into system and some others that tended to start kicking the robot hand as soon as the noise of washing process started. In these cases the cow's health status should be inspected.

It seemed that in some cases the milking robot did not find a teat to be milked because cows moved or kicked. Therefore the milking interval of one single teat may have been prolonged. This in turn might have caused more pressure on the udder. Then the udder size had changed because of the long milking interval and again the milking unit had difficulties attaching the teat. A vicious circle was obvious. These kinds of problem have to be taken seriously and problem cows need to be observed to make sure that every teat becomes milked. These deviation cows should regularly be picked from the lists and their udder health checked.

At the beginning of transfer phase from a conventional milking unit to AMS this system of observation can help to develop more efficient and patient teaching methods when adapting a cow to new system. Extra attention to a cow's learning and adaptation process should be paid in order to get the cow traffic in a new system working. It has been shown that nervous and anxious animals exhibit more step behaviour (Wenzel *et al*., 2003) and that there is a connection between step behaviour and cow's character (Metz-Stefanowska *et al*., 1992). Wenzel *et al*. (2003) concluded that continuous stepping during milking indicates that cows milked in the automatic milking system are more nervous than those milked in the milking parlour. The web based cameras may easily be used to observe the situation in the barn, especially in a specified area as the milking unit is, from the home or office computer.

In conclusion, the web-based recording system works well in cow behaviour observation during milking and generally in the barn. Recordings are done successfully. The data files can be transferred into the office computer and information concerning the milking process can easily be collected in the office. Digital recording works well on the recorded observations. With the help of the web based camera system the deviations in the milking process are easy to detect. This device can be used as a good additional tool for observing the animals' behaviour in the barn, but also on special occasions like observing automatic milking process.

The total results show that the overall success of the whole milking process was on rather high level (82%). No specific failure type was found. However, 18% of the milkings had serious lacks, which meant that the udders of these cows were not washed and milked properly. It came out clearly that a few trouble cows may easily make the results worse. In this study, a group of three problem cows caused 52% (13/25) of the failures during washing, milking or both. One cow caused 3 out of 4 "killings" of the AMS. It is essential to find out the problems behind the failures, since they are mainly caused by cows that must feel themselves inconvenienced during automatic milking. Most of the deviations were caused by a cow, which means that the milking robot itself works at a satisfying level. However, there were several cows that immediately started kicking and moving when entering into the milking unit. This once again proves the importance of cow's intensified monitoring in the AMS. It also proves the usability of the deviation lists, which should be regularly checked and taken into action immediately when they occur. It also raised questions; what would be the ideal cow character for AMS? It is clear that the machine cannot work reliably if a cow has a strong negative reaction when entering the milking unit. And more important; what kind of accustomization process would be ideal for a cow to adapt successfully to an automatic milking system?

Acknowledgements

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Influence of social rank on animal behaviour of cows milked by an automatic milking system: implementation of automated procedures to estimate the rank and the length of stay in the feeding area

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Abstract

A method to estimate the rank of an animal by analysing displacements at the feeding fence was used to describe the effects of different forms of cow traffic on high and low ranked cows. The calculated dominance values led to plausible results for the daily rhythm of feed intake and of visits to the milking box. The restriction of the access to the feeding area and to the milking box (from free to guided cow traffic), led to a lower use of these resources at the preferred times by cows classified as low ranked.

Keywords: animal behaviour, social rank, cow traffic, automatic milking

Introduction

The social rank of an animal is important regarding its access to restricted resources. In automatic milking systems the milking box represents such an restricted resource. If the cow traffic is guided, this applies also to the feeding area, which only can be reached through the milking box or selection gates. The aim of this investigation was to calculate rank indices based on automatically registered displacements at the feeding fence (according to Rutter *et al*., 1987; Kenwright and Forbes, 1993; Olofsson, 2000) and to clarify whether they can explain differences in milking and feeding behaviour.

Material and methods

Farms and investigated forms of cow traffic

The investigation was based on the data of two farms, each equipped with an automatic milking system and 24 electronic weighing troughs. With these troughs the time as well as the amount of feed intake were recorded. The herd on farm 1 consisted of 49 lactating Simmental cows, and 45 Holstein-Friesian cows were milked on farm 2. On each farm three forms of cow traffic were investigated (Figure 1). In free cow traffic the cows always had access to the feeding area. In guided cow traffic this area could only be reached via the milking box. For the third form of cow traffic, selection gates were installed between the resting and the feeding area. These gates could only be passed by cows that had not yet reached their pre-set minimum time between two milkings (cows without milking permission). On farm 1 each trial lasted 12 days and on farm 2, 10 days. Before each trial the cows had an adaptation period of at least 7 or 12 weeks respectively. A more detailed description can be found in Harms (2005).

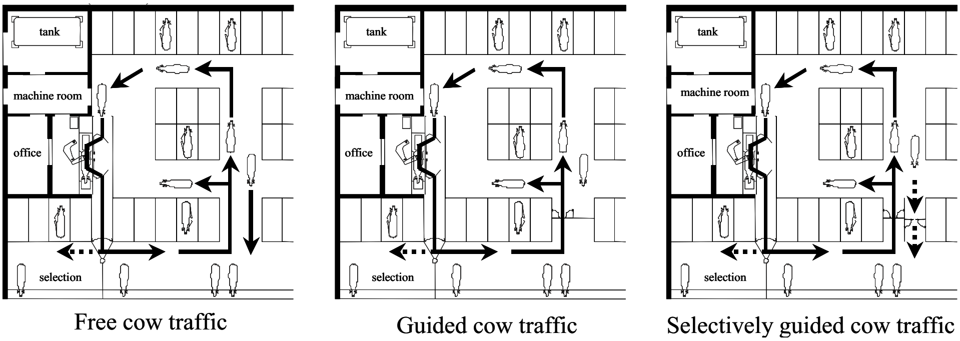

Figure 1. Investigated forms of cow traffic.

Determination of dominance values to quantify the rank of an animal

Dominance values were calculated according to the approach of Rutter *et al*. (1987). If a cow was leaving the feeding lane and her position was occupied by another cow within one minute this was noted as a displacement. A cow was rated as dominant within one cow pair if she displaced the other cow twice as often as she was displaced by the same cow. By dividing the number of cow pairs that a cow dominated, with the total number of cow pairs she participated in, a dominance value could be calculated for each animal. These dominance values could reach values from 0 (subdominant to all cows) to 1 (dominant to all cows). Animals with a dominance value up to 0.4 were classified as low ranked, values of 0.6 and more indicated high ranked cows. Animals with dominance values between 0.4 and 0.6 were not included into the analysis.

Number of animals in the feeding area - automated determination

Using electronic animal identification at the weighing troughs or at the feeding fence respectively, only time and duration of the visits at the fence can be recorded automatically, but not of those in the feeding area. Therefore, based on the approach of Tolkamp and Kyriazakis (1999) (Figure 2), critical intervals (ci) were visually defined to divide (short) intervals within a meal from (longer) intervals between two meals.

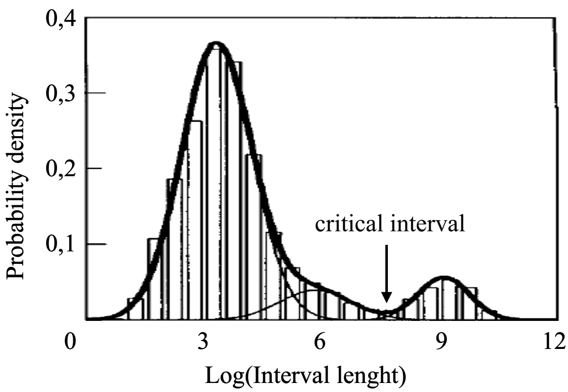

Figure 2. Log-transformation of the intervals to define the critical interval according to Figure 6a in Tolkamp and Kyriazakis, 1999.

The visual analysis of the log-transformed intervals led to different critical intervals for each farm and cow traffic. To make the three forms of cow traffic comparable, three different critical intervals (ci = 30, 50, 82 min) were included in further calculations. On the basis of these intervals the beginning and the duration of each meal were calculated for each cow. Assuming, that animals do not leave the feeding area within a meal, this led to an estimated value for the number of animals in the feeding area at a particular time of the day. The results were verified by comparing them with video recordings on farm 1.

Results

Number of animals in the feeding area - observed and calculated values

In Figure 3 the observed number of animals in the feeding area is compared with the calculated numbers. Calculations were done using the three different critical intervals. All in all a good correlation between the observed and the calculated values was found. They matched best, when the calculation was based on the longest critical interval (82 min). However, it was obvious that the feeding behaviour cannot be described with one critical interval over the whole day. In free cow traffic the number of cows in the feeding area was overrated between 7 and 9 am, whereas in the night hours it was underestimated in all forms of cow traffic. In some cases only the number of animals which had their head in the feeding trough was described by the calculated values.
Nevertheless this analysis showed that the chosen method leads to results (calculated number of animals) that can be used to compare different conditions. Due to the best congruence with the results of the video recordings, further analyses were done with a critical interval of 82 min.

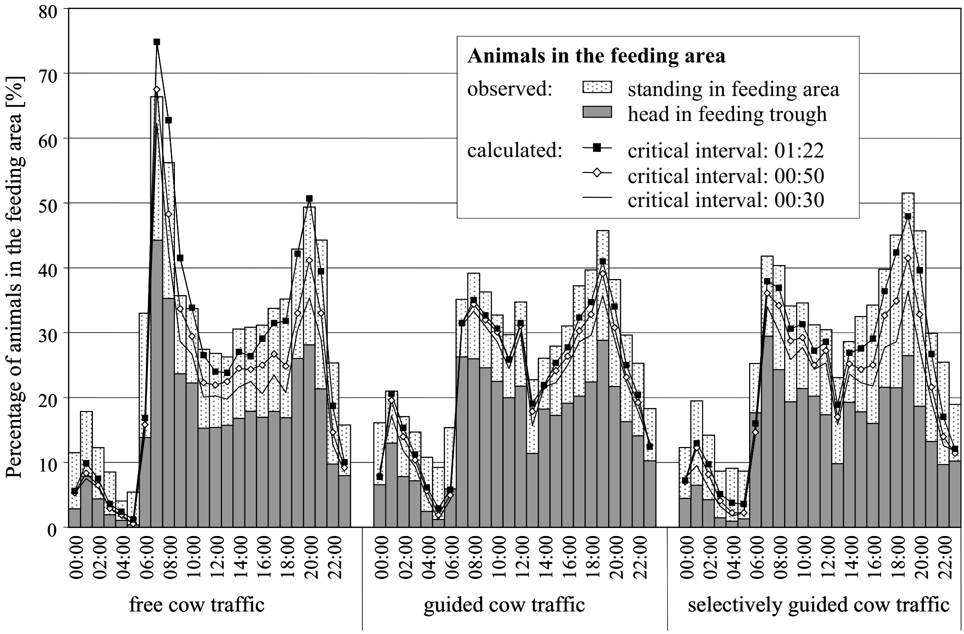

Figure 3. Calculated vs. observed percentage of animals in the feeding area [%] (farm 1).

Differences in the diurnal rhythm of animals with different dominance values

On farm 1 in free cow traffic, only small differences between the two groups of dominance values could be observed, as can be seen in Figure 4. In contrast to this, in guided cow traffic the two groups differed clearly. Between 6:30 and 9:30 am a smaller part of the "low ranked" cows than of the "high ranked" ones stayed in the feeding area. Between 2:30 and 4:00 am this ratio inversed. Selectively guided cow traffic led to results similar to guided cow traffic. Apparently the reason for this effect is the restriction of the access to the feeding area in both forms of guided cow traffic. The visits to the milking box showed also differences between "high" and "low ranked" animals. In both forms of guided cow traffic "high ranked" cows frequented the milking box more often than

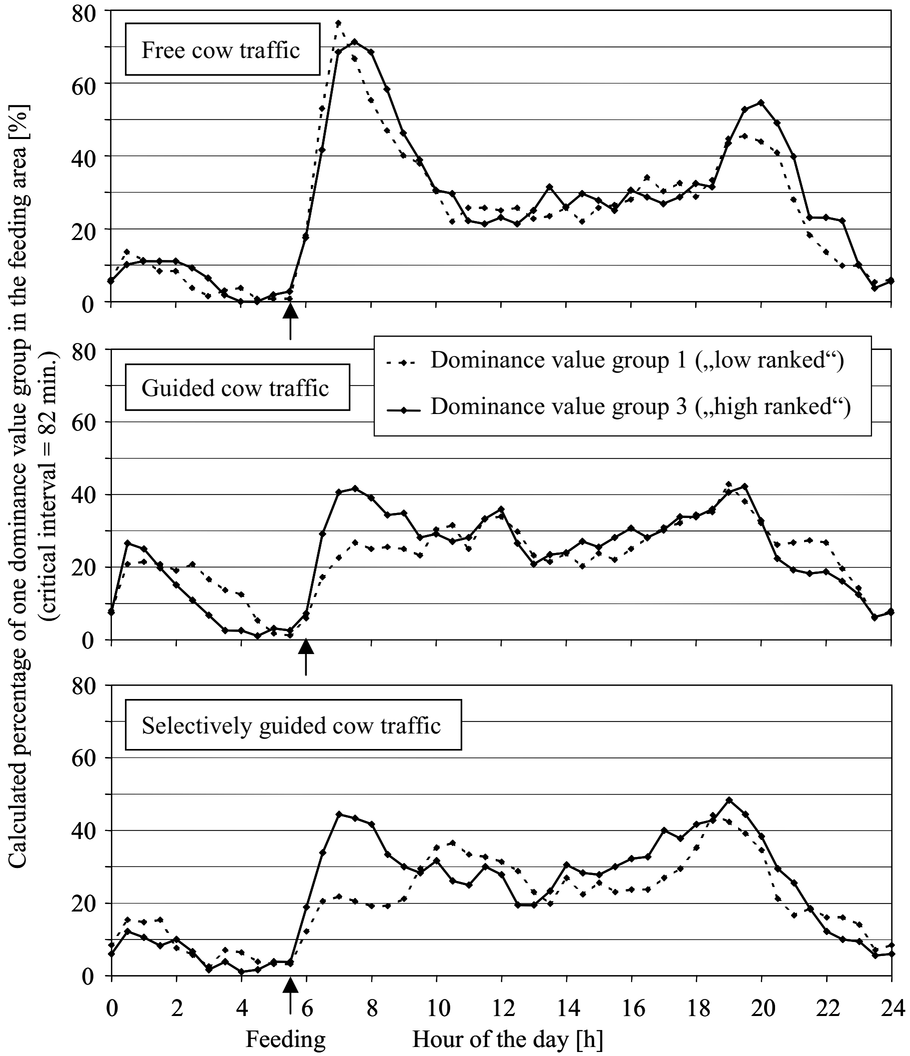

Figure 4. Diurnal distribution of low and high ranked cows in the feeding area in different forms of cow traffic (farm 1).

"low ranked" cows during feeding (5 to 6 am). In free cow traffic only small differences between the two groups were found (Figure 5).

On farm 2 all in all the results were similar to farm 1, but the diurnal rhythm was less pronounced in all three forms of cow traffic (Figure 6). One reason for this might be the less restrictive feeding on farm 2, so the animals had more feed available in the early morning hours. The biggest difference compared to farm 1 was found in selectively guided cow traffic, which showed only a negligible difference between "high" and "low ranked" during feeding on farm 2.

This effect was largely due to the use of active selection gates ("Smart gates™", DeLaval) instead of passive ones between the resting and the feeding area. Cows adapted more easily to these gates and used them more frequently. Furthermore fewer cows passed these gates backwards even if they were open.

Concerning the visits of the milking box, similar effects to those on farm 1 were detected, but the peaks were not so pronounced in all forms of cow traffic. In selectively guided cow traffic the same effect was observed, again the differences between "high" and "low ranked" animals were small compared to farm 1 (Figure 7).

To evaluate these results it has to be taken into account that the average number of milkings / visits of the milking box or feeding periods did not differ between the "high" and "low ranked" cows on

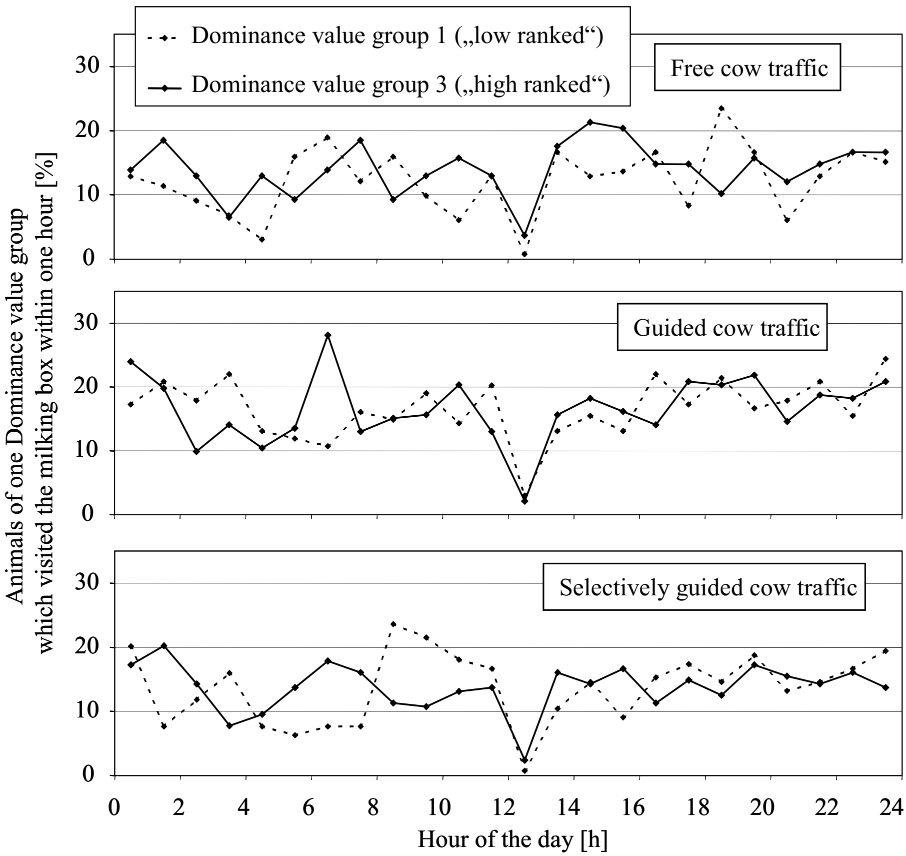

Figure 5. Diurnal distribution of low and high ranked cows visiting the milking box in different forms of cow traffic (farm 1).

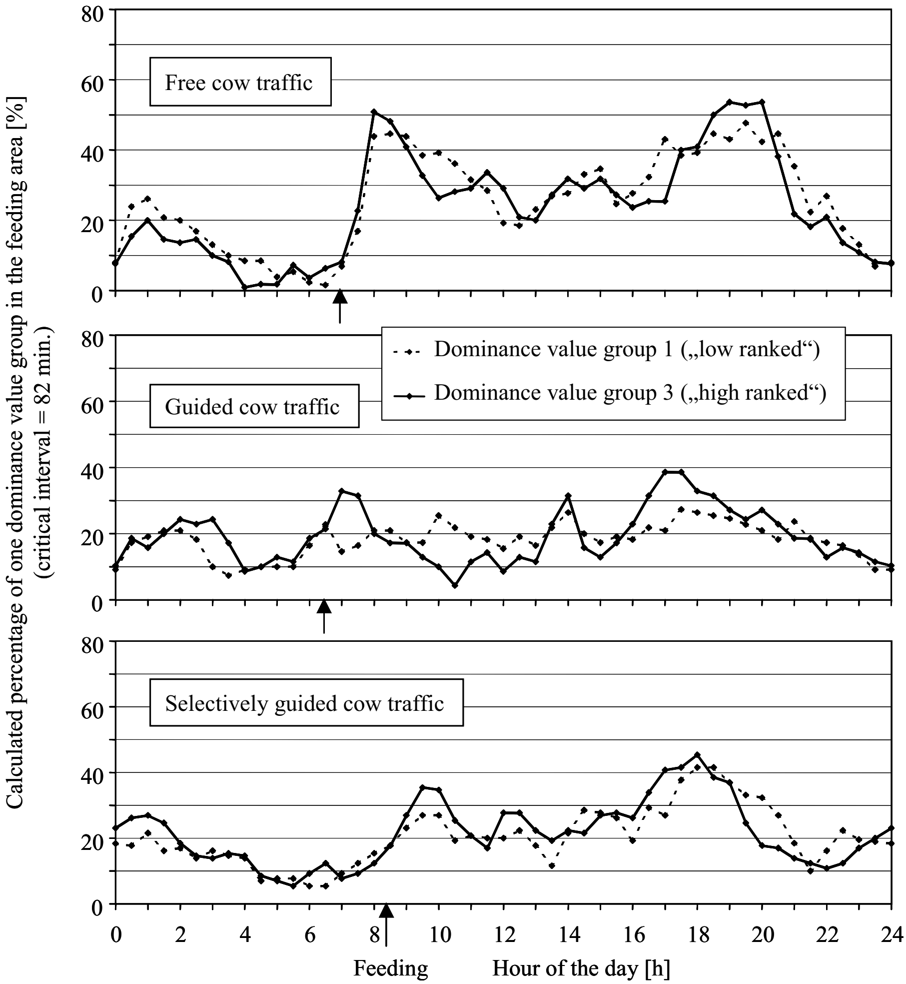

Figure 6. Diurnal distribution of low and high ranked cows in the feeding area in different forms of cow traffic (farm 2).

both farms. The "low ranked" animals were obviously able to compensate by switching to other periods.

Discussion

In this investigation it could be shown, that the number of animals in the feeding area can be explained by calculated feeding periods out of the identifications at the feeding fence. The explanation was best when using a long critical interval (82 min). One possible reason for this is the focus on spatial behaviour. This is also concluded from other experiments (Tölle *et al.*, 2002). To understand the behaviour of an animal it is very important to know the social rank of the animal (e.g. Syme and Syme, 1979). In order to make this information available to a farmer, methods for an automatic estimation are of great importance. By applying the method of Rutter *et al.* (1987),

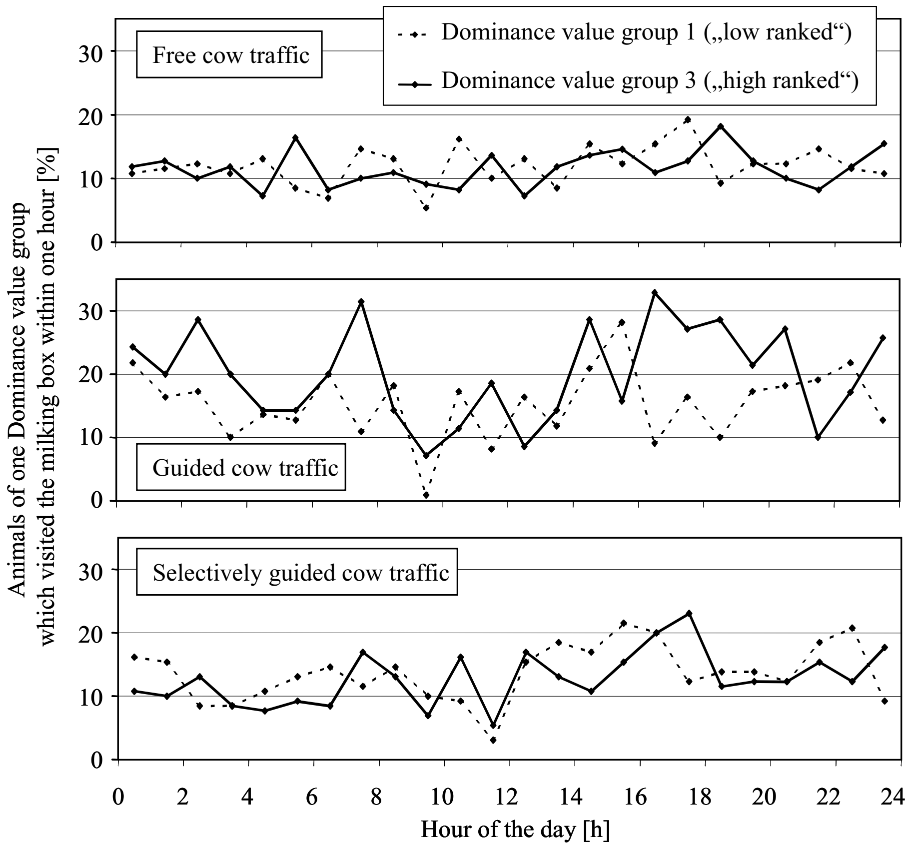

Figure 7. Diurnal distribution of low and high ranked cows visiting the milking box in different forms of cow traffic (farm 2).

dominance values for each animal were calculated based on the displacements at the feeding troughs.

The combination of both methods led to a visualisation of the behaviour, concerning the usage of the milking box and the feeding area over the day. For both resources the dominance values were able to explain differences between "high" and "low ranked" animals in different forms of cow traffic. The results were similar to those found by Ketelaar-de Lauwere *et al*. (1996).

It is reported (Olofsson, 2000) that dominance values can be calculated by using the order between two animals entering the milking box within a short period of time (< 1 min). Combined with the results presented in this investigation this can offer a method which allows the farmer to estimate the effects of different management strategies on high and low ranked animals without the need of investing in additional hardware.

Conclusions

The calculated dominance values showed that differences in social rank lead to differences in the daily rhythm of feed intake and of visits to the milking box. Improved access to the resources feeding area and milking box (from guided to free cow traffic), can reduce the differences between high and low ranked cows at the preferred times (after feeding).

Improved methods (Olofsson, 2000) to determine the rank of an animal without additional hardware could be a further step towards "precision livestock farming", because the social status of an individual cow could be a part of the farmer's decision.

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Monitoring cow health in a milking robot

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Abstract

A system for automatically measuring the physical health of a dairy cow has been developed. Milking robots offer a unique possibility for the dynamic measurement of physical data. Four strain gauge scales were installed in a milking robot in order to measure the weight of each leg separately. The sensors were connected to an amplifier and the data was collected in a PC using a dedicated computer program. From the data it is possible to calculate e.g. the mean weight and the weight variation of each leg, the total weight, the number of kicks and the frequency of kicks. The acquired information can be used to judge restlessness and welfare e.g. hoof diseases. It is also possible to analyze the behaviour of the cow. Long term monitoring was conducted in order to find changes in leg weights and step and kick behaviour.

Keywords: Milking robot, weight, dairy cow, hoof disease, lameness

Introduction

There is a worldwide movement towards automation in cattle keeping, with the objective to fully automate every process from feeding to milking. Automatic milking has become common practice in the dairy industry. Limb disorders cause serious welfare, health and economic problems especially in loose housing of cattle (Klaas *et al*., 2003; Juarez *et al*., 2003). In bigger herds it is complicated to track the early stages of lameness and other disorders. The milking robot offers a unique possibility for the dynamic measurement of body weight. It is probable that injuries and hoof problems can be detected by separately measuring the load on each leg. It is also possible to analyze the step and kick behaviour of the cow during milking and during the different stages of milking, washing, milking and disconnecting. In this way it is possible to monitor the cow's activity level and changes in it.

There are only a few existing technological methods for lameness detection. Guard (2004) states that the most commonly used method is the utilization of pedometers or activity meters worn around the neck. These systems are mainly designed for heat detection but they can also help detect decreased activity levels caused by lameness. Rajkondawar *et al*. (2002) developed a lameness detection system. They used two parallel force-plates to measure the reaction forces of cows walking over the plates. They concluded that the system could recognize lame animals and identify the affected limbs. They did not measure animals over time so early detection of lameness was not possible to judge. They also developed a mathematical scoring system for lameness based on their force-plate system. They stated that with more data the system will have the ability to detect lameness in individual limbs.

Automatic measurements have also been used successfully for detection of other welfare problems and in livestock management. Eberhardt *et al*. (2003) have studied early detection of calf diseases by automatic recording of behavioural changes. Calf diseases cause lethal losses of about 10 - 15 % during the first six weeks. Sucking behaviour of calves was recorded and analyzed. They found that detection of behavioural changes is possible even before symptoms can be seen. However, it was not possible to see if an individual animal was really ill but the system could give a warning of possible problems.

Cveticanin (2003) addressed the problem of livestock weighing with one scaling plate. He introduced fuzzy logic to take care of crowding with good results. At the Silsoe Research Institute in the UK, an automatic system was employed to study clinical and sub-clinical ketosis by four automatic methods: breath sampling, individual risk factor analysis using existing herd management records, time series analysis of daily milk yields and measurement of ketones and urea in milk combined with fuzzy logic to simulate human expertise (Mottram, 2000).

Materials and methods

Four strain gauge scales were installed into a milking robot, Figure 1. The scales were connected to a four channel amplifier and the data was collected by a PC (Figure 1). The Internet was used for remote control and tracking of measurements. Three web cameras were installed and the milking was recorded and stored digitally on the PC. Abnormal behaviour can be seen afterwards from the digital video data. The area of the scales varied from 445 mm x 390 mm to 310 mm x 310 mm depending on location. The structure of the scales is presented in Figure 2.
The measuring frequency was set at 10 Hz, in order to see kicks properly. The duration of one kick can be as short as 0.5 s. More than one hundred milkings per day were recorded. A consequence of this is that data accumulated at 30 Mbytes/day. In addition to this the information from web cameras amounted to17 Gbytes/day. The measured data was preliminarily analyzed using a program made with TestPoint. Figure 3 shows the user interface. The program automatically starts and ends the measurement and saves the data. Further, it has an automatic taring system which operated when the robot was washed.
After the milking, the measured data was further analyzed using another TestPoint made program (the statistics button in Figure 3) and during this the data from the milking robot was connected to the measured data. The user interface of this stage is given in Figure 4. The mean value, standard deviation and number of kicks were calculated for each leg and the behaviour and changes in the values of each cow were followed. At this stage the data is cleaned from useless data. This occurs when for instance one of the legs is not on a scale. In Figure 4 the excluded time has been 1 min from both ends. Occasional peaks due to the cow lifting a leg (kicking) can be noticed. Every rise

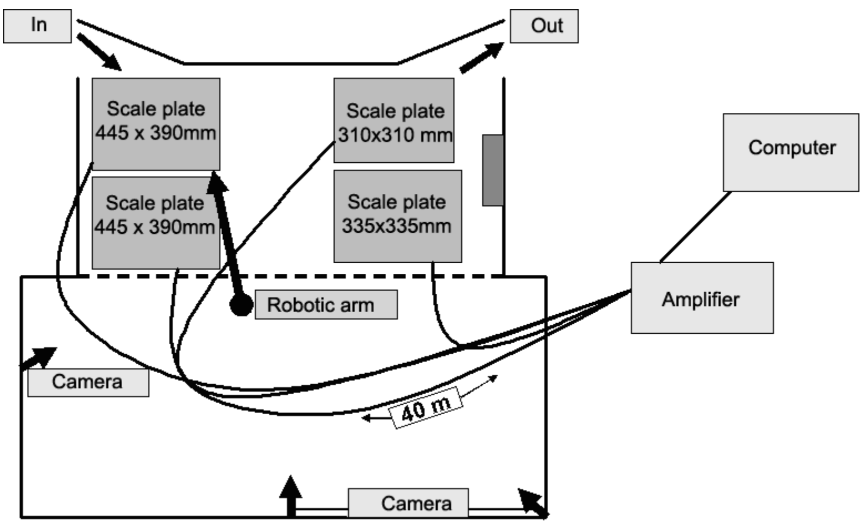

Figure 1. The measuring system.

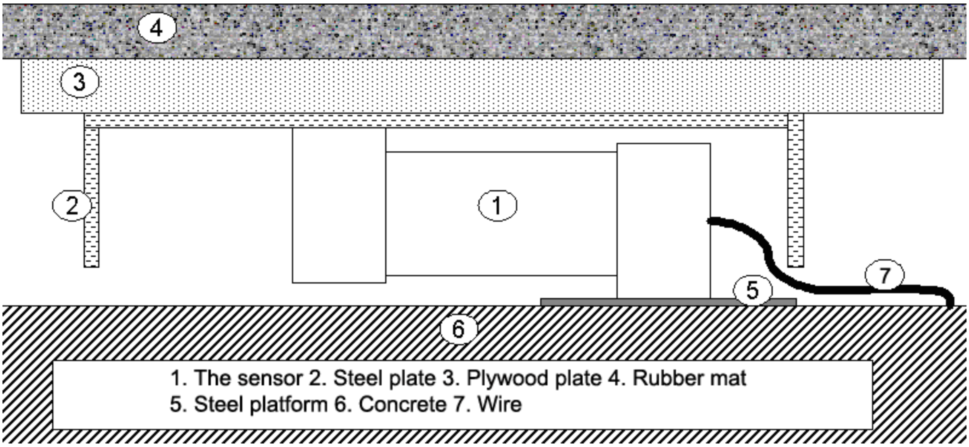

Figure 2. The structure of scale platforms.

Figure 3. The user interface made with TestPoint.

in one scale is always connected with a decrease on another scale measuring the load of the neighbouring leg.
After one year of more or less constant measurements, data have been gathered from around ten thousand milkings. The final analysis of all measured data was performed with a MATLAB program which can look for suitable criteria for automatic detection of problematic cases. These cases were then compared with the observations made by a veterinarian.

Results

Typical data for a cow that developed a hoof disease is given in Figure 5. White line disease and a sole ulcer were detected on the left hind leg during a veterinary inspection on 12.8. Symptoms of pain can be seen from the measured data 14 days before the inspection and clear lifting of the affected limb starts 10 days before the detection of hoof disease. The kicking frequency of the left

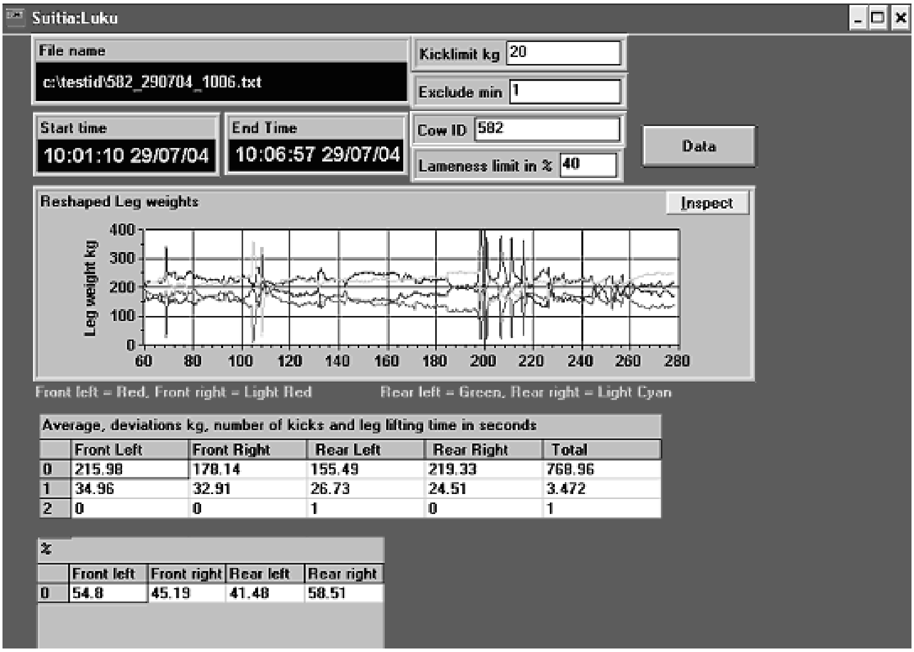

Figure 4. The user interface of the preliminary statistical analysis of one milking. The peaks in the graph are due to kicks.

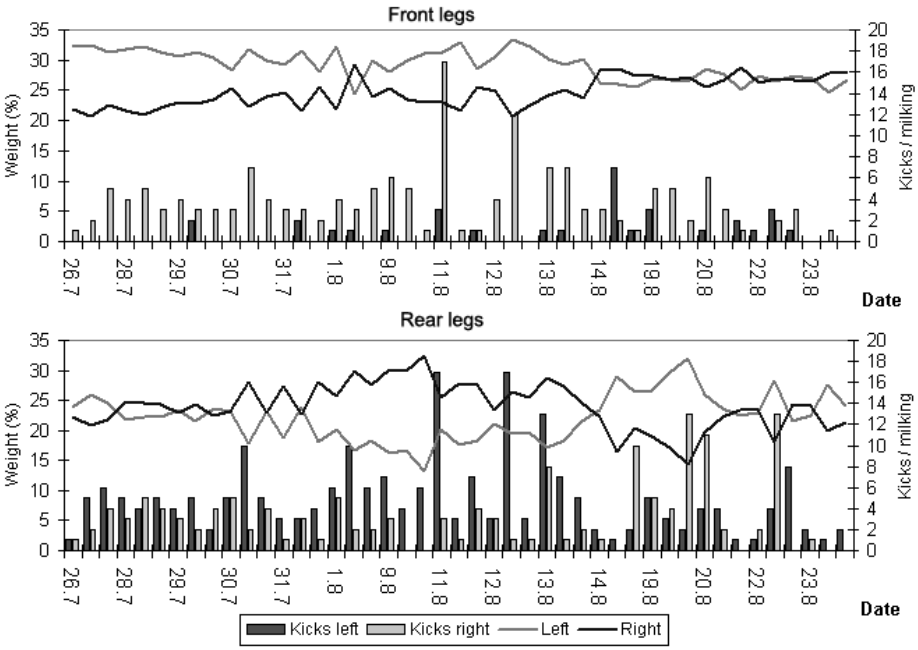

Figure 5. The relative leg weights and the number of kicks during successive milkings of cow number 637.

hind leg increased at this time. The hoof was treated and the leg weights of the cow returned to normal in 10 days.
Useful information about the herd can also be extracted from the data. The weight distribution between the front and rear legs was calculated for 32 Holstein cows. The average weight distribution of front legs was 53.3 ± 0.2 % of the total weight. The weight distribution is shown in Figure 6. The weight of cows ranged from 544 kg to 749 kg and the mean weight was 652 kg.

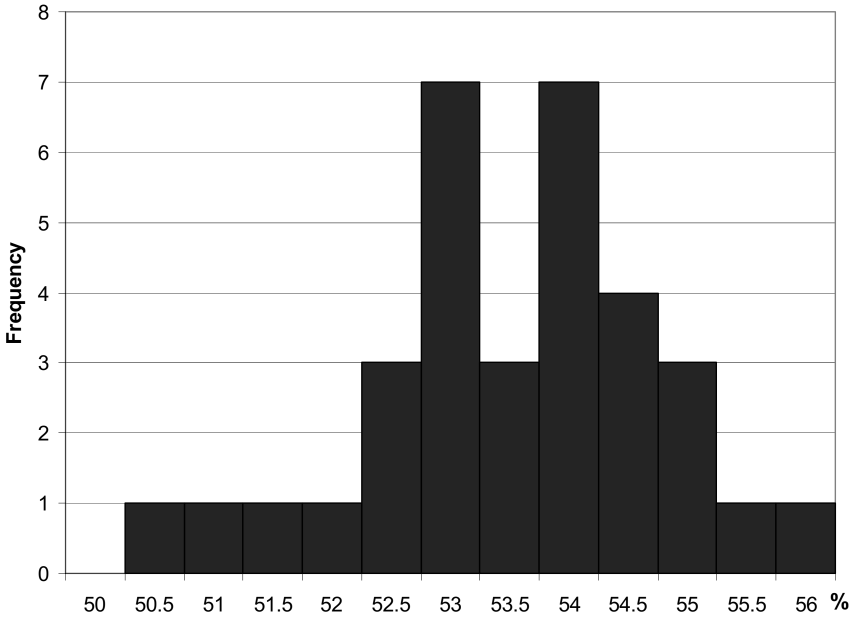

Figure 6. The weight distribution on front legs of 33 cows.

Discussion

After one year's experience the system functions as expected. However, the scales are under constant and severe load and the fixing of the transducers and platforms has been problematic. This is due to the point loading of the cow's leg; the transducers are not designed for very concentrated point loads but for a larger load area than a hoof. Not all the measurements were successful; this is due to the different sizes of cows. This already presented problems when designing the platform sizes. Cows can also put their legs outside the platform or they sometimes lean on the robot chassis, resulting in lower weights than normally. Apart from these shortcomings the system can give reliable information about leg health and step and kick behaviour.
In addition to hoof disease and lameness detection the system automatically gives a lot of useful basic data. Figure 6 shows that the weight distribution differs a lot from one cow to another and the mean values of the inspected cows are different from the 60% on the front legs and 40% on the hind legs that is given in literature (Vermunt, 2004). This may be due to the fact that the weight distribution depends on the breed of the cow or that the weight distribution has changed in the course of years when cows have been bred to produce more and more milk. This naturally increases the weight on rear legs.

Conclusions

The system has operated as it was designed to do, with the expected limitations. The step and kick behaviour of a cow can be seen from the data, i.e. a calm cow can be separated from a restless cow. The number of kicks can be calculated from curves and a quantitative measure of restlessness can be figured out. It opens the possibility for milking robots or automatic feeding stations equipped with an automatic weight measuring system, incorporating automatic alarm messages for suspected hoof diseases and other leg problems.

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Survey of the sustainability aspects of Automatic Milking Systems (AMS) in organic dairy production

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Abstract

The objective of this survey was to assess economic, ecological and societal sustainability aspects when introducing automatic milking systems on organic dairy cattle farms. The assessment is made in close relation to the stakeholders that have been determined. This assessment is based on current available knowledge which does not differentiate between organic and conventional management. Net farm income on conventional dairy farms introducing AMS does not increase significantly, neither is this expected for organic AMS farms. The time saving effect results in social but not economic advantages. Introduction of AMS on conventional farms in combination with grazing, results in a small increase in fossil energy use per kg milk, and an increase in eutrophication per ha farm area due to less efficient use of total grazing area. Similar results are to be expected for organic AMS dairy farms. Introduction of AMS does not result in animal health problems for conventional farms, and is not expected to result in problems for organic farms. Concerning cow welfare, the relation between use of AMS and grazing required in organic production is essential. Milk quality decreases due to the introduction of AMS at conventional farms, and might have a similar effect at organic farms. Farmers', consumers' and other defined stakeholders' perceptions of the selected sustainability aspects have hardly been investigated. Conventional farmers express satisfaction when asked after having invested in AMS. It is crucial to communicate with stakeholders about the different aspects of innovative technology and even more important to organic consumers that show major concern for product quality, ecology and animal welfare.

Keywords: AMS, sustainability indicators, organic dairy, pasture grazing

Introduction

The general hypothesis of this study is that introduction of innovative technology, such as AMS, can contribute to sustainable development of organic dairy production in Denmark and the Netherlands, without compromising basic organic principles (Anonymous, 2004). An assessment of sustainability aspects concerning AMS on organic farms is presented here. This assessment can create the basis for more applied research, involving the actual practice of this new technology on organic farms. Organic dairy farming in Europe is, after having grown extensively the last decade, under pressure. Decreasing milk prices force dairy farmers to rationalize, specialize and cut costs. One way of rationalizing is the use of modern technologies. Implementation of new technology, especially when developed within the integrity of organic values and principles, is believed to be important for the future of organic farming. However, new technologies like the automatic milking system can be rejected for economic, ecological or societal reasons. Factual information on organic application of new technologies in terms of economic impact, consequences for management or effect on product quality is missing. This can lead to rapid rejection, based on prejudice that organic agriculture is incompatible with large farm units (big herds, many acres) or high-tech solutions. Therefore scientific studies are required to analyze the potentials for the organic sector.

Materials and methods

This survey is based on a standardized framework to monitor sustainable development, described by staff members of the Animal Production Systems group at Wageningen University, The Netherlands (van der Zijpp, 2001).

1. Identification of stakeholders and description of the research case and problem areas.
2. Determination of the relevant economic, ecological and societal (EES) issues and the definition of goals.
3. Translation of the selected issues into quantifiable indicators for sustainability.
4. Analysis of the contribution of the indicators to sustainable development and monitoring of the indicators.
5. Communication of the results to the stakeholders, review of the process and evaluation of the results on basis of the original problem definition.

The sustainability aspects presented are based on a literature review. In literature, no information was found on organic dairy farms using AMS (Meijering *et al*., 2004). Hence, literature found on introduction of AMS on conventional farms was used and interpreted to assess economic, ecological and societal consequences on organic farms. Literature and information gathering was concentrated on the situation in The Netherlands and Denmark. Steps 1, 2, and 3 are presented in this paper. The succeeding steps, including a qualitative participatory research on stakeholders' perceptions, are in progress.

Results and discussion

Identification of the stakeholders and description of the research case and problem areas

Both the interest groups that influence functioning of the AMS, as well as those that depend on its functioning are relevant. Figure 1 shows an overview of the registered stakeholders. Stakeholders often have different interests and therefore validate sustainability aspects differently. This should

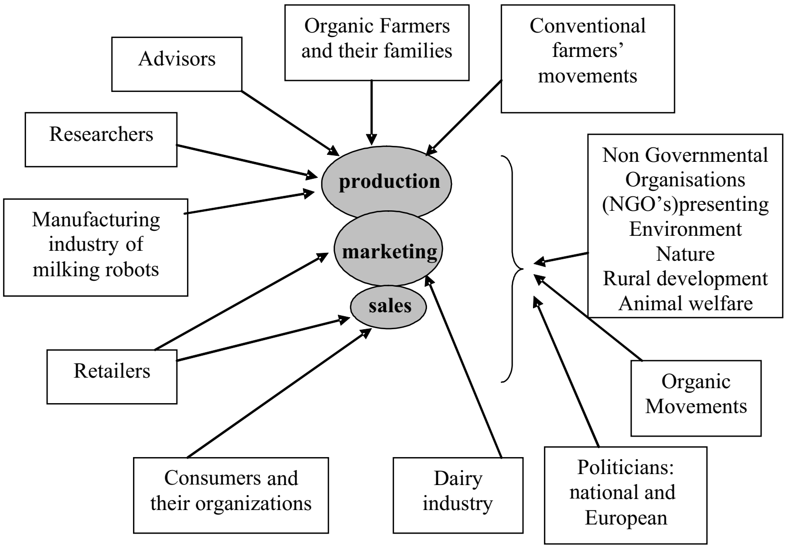

Figure 1. Stakeholders concerning AMS use in organic milk production.

be taken in account, not only when prioritizing them, but also when analyzing the sustainability indicators (SI) and when disseminating them (van der Zijpp, 2001).
AMS are being implemented in organic dairy farming without a scientific assessment. In Denmark 8% of the 630 organic dairy farms have started with AMS, in the Netherlands this is 1.6% out of 310 farms

Determination of the relevant EES issues and definition of the goals

The selection of economic and societal issues is based on numerous socio-economical studies (Mathijs, 2004; Meskens *et al*., 2001; Meskens and Mathijs, 2002). The selection of ecological issues is based on Life Cycle Assessments (Audsley *et al*., 2004; de Boer, 2003). These studies have thereafter been related to the literature and knowledge on organic principles, standards and norms (Anonymous, 2002; Anonymous, 2004; Benbrook and Kirschenmann, 1997; Alrøe and Kristensen, 2000; Alrøe and Kristensen, 2004; Verhoog *et al*., 2003).
When defining the goals it is possible to try and define absolute or relative measures of sustainability. Relative measures in this study below will be in comparison with the organic dairy farming without AMS, and in comparison with conventional farming. The selection of the issues was partially made to match these goals. Absolute measures for sustainability are difficult to define, and therefore related to the general principles and standards of organic agriculture.
Economic: The financial situation of the farm and the sector as a whole.
Ecologic: The use of natural resources, eutrophication (nitrogen and phosphorus), global warming, acidification, and biodiversity. *Societal: A*nimal health and welfare, landscape, farmers' attitudes, consumers' attitudes, product quality, work quality, institutional, national and European constraints and society's attitudes towards organic agriculture.

Translation of the selected issues into quantifiable indicators for sustainability

Economy:
The goal of an economic analysis based on measurable indicators is to validate the economic sustainability of investing in an AMS on an organic dairy farm. Indicators that can be quantified are: net farm income, full time employee/cow/farm, and fixed costs/variable costs in the situation before and after.
Usually implementation of new technologies is assessed as an influence on net farm income after investment (Pedersen, 2003). In the case of AMS there are some data from farms having worked with the AMS for some years, besides theoretical calculations. Models indicate (de Koning and Rodenburg, 2004) that milk yield increase and labour saving are important factors in the net income. Until now the facts have shown that the milk yield increase is limited. According to French data it is 3-9% , and a Dutch study shows a range from -16%-+35% with an average of 5% (de Koning and Rodenburg, 2004).
On the time saving account there are limited data, but an average of 10% is recorded (de Koning and Rodenburg, 2004), with significant variation from farm to farm. Lower costs are only achieved if the labour can be reduced in practice (laying off employees) or if the production can be increased proportionally. In practice it shows that not many farmers actually reduce the number of employees, simply because they don't have them.
Danish data show that on average 41% labour time is saved, with a range from 27% to 70% (Rasmussen, 2000). Most labour was saved with the one box AMS.
The total costs not only depend on the initial costs of the automatic milking unit, but also on the maintenance costs, which can be rather high. An economic study made in Denmark shows that out of 41 registered farms with AMS, only 17 managed to achieve a positive net income (Nielsen and Vestergaard, 2003). The main reason for farms having negative consolidation is high financial

expenses due to high capital costs due to high mortgage and debt. There was a tendency that the farms with the most cows had the worst financial results, and the younger farmers the best results. In organic agriculture the relation between feed-stuff prices, milk yield and the net income is different, which calls for further study. The time saving aspect of the automatic milking could give the organic farmer the option to find alternative income sources and to increase animal welfare. The demand for grazing however can easily result in extra work , such as having to fetch the cows, that don't come voluntarily.

It has been documented that organic dairy farms in general have a better or at least the same financial position as their conventional counterparts (Jørgensen and Pedersen, 2004; Nielsen and Vestergaard, 2003; Water, 2002). This could decrease the risk of too high debts when investing. Decreasing premiums for organic production and increasing percentage of organic fodder, is recently undermining their financial situation.

Ecology:

Sustainability aspects (natural resources, eutrophication, global warming, acidification and biodiversity) are selected as important because they are relevant to the organic principles and highly relevant in society. Of the natural resources only direct energy and water use are mentioned in literature (Rasmussen and Pedersen, 2004a). Research concluded that a regular check-up of the installation could save a lot of water and energy. Later measurements done on farms, showed that especially energy use is higher than in normal parlour milking and dependent on the robot make (Rasmussen and Pedersen, 2004b). Possibly the indirect energy use also increases because of the use of more concentrates.

Eutrophication strongly depends on stocking rate, rules for spreading manure and grazing regime. Stocking rate and maximum amounts of minerals per ha are part of the organic standards in DK and NL. Net surplus of nitrogen on organic dairy farms as a whole, is low; in DK 124 kg N ha^{-1} versus 195 kg N ha^{-1} in conventional dairy farming (Kristensen *et al*., 2003). This nitrogen can either volatilize (N_2O or NH_3) or leach (NO_3). Organic farms with AMS, however, will be tempted to let their cows graze mainly at fields near the farm. Fields further away cannot be grazed easily and might only be used for silage production. This can lead to very high disposition of urine and faeces on a small area causing extreme losses of nitrogen.

The farm balance of phosphorus directly depends on the amount of manure imported and the amount of concentrates used. The data on farms with AMS have shown an increased use of concentrates. No data on organic AMS farms have been found. Surplus of phosphorus is not expected to be higher, normally there is no or very little net surplus of phosphorus on organic farms (Hviid, 2002).

Greenhouse gases from agriculture cause about 24% of the total greenhouse effect, divided as follows: 3.5% from CO_2, 5.9% from CH_4 and 14.8% from N_2O. A recent Danish study shows that these figures are extremely inaccurate (+/- 25%) (Pedersen and Olesen, 2002). CO_2 production in agriculture mainly results from combustion of fossil fuels (22%), from production and transport of concentrates (30%), and artificial fertilizer and pesticides (21%) (de Boer, 2003). The large percentage caused by N_2O is mainly from the use of fertilizer, manure and slurry in crop production. This is only for a small part caused by organic dairy production; the larger part is due to massive swine-slurry applications and artificial fertilizers. A very slight decrease in the volatilization of nitrous oxide can be expected, because of the shorter time the dairy cows will be grazing. No effect is estimated for the milk yield increase.

The methane production of the animal herd in Denmark is mostly influenced by the amount of animals (de Boer, 2003) .

Acidification is for 78-97% caused by ammonia volatilization. In dairy systems only 20% of the nitrogen input in the system is returned in the products produced. Of the nitrogen ingested, 75-95% is excreted and 80% of this return in the urine. Here as much as 20% can be lost through

volatilization (Jarvis *et al*., 1988). The acidification of the atmosphere will be somewhat less, if introduction of AMS results in a decrease of grazing.
Biodiversity is a sustainability issue but the goals are not defined. If grass pastures with the implementation of AMS will be used increasingly for cutting, this will undoubtedly decrease the biodiversity of flora and consequently fauna. Studies have shown that diversity of grass land gives milk a higher quality (Baars, 2001) .

Society:
Indicators of societal aspects are often difficult to quantify and of extreme importance to organic farming. In this survey the societal indicators that have been quantified (animal health, welfare and product quality and some farmers' perceptions) are reviewed.
The following measurable indicators on animal health were found: body condition (Dearing *et al*., 2004), lameness (Grove *et al*., 2004), teat condition (Neijenhuis *et al*., 2004), milk leakage (Persson Waller *et al*., 2004), fertility (Dearing *et al*., 2004), udder health (Poelarends *et al*., 2004) ,and infection risks (Zecconi *et al*., 2004). The problem in most of these investigations was, that the influence of management often was greater than the influence of the AMS. Automatic milking units seem though to have a slight positive influence on teat condition on the longer term, and do not result in health problems at a well managed farm. There are no indications that this will be different for organic dairy farms.
The welfare aspect is more complex as there is discussion about which indicators can define welfare. In Denmark a group of researchers carried out a health and welfare assessment protocol, which can be used in the process of validating the effects of AMS (Hindhede *et al*., 2004). Welfare is negatively influenced when grazing decreases. Organic standards prescribe grazing and this will imply forced grazing on AMS farms. This might lead to forced cow traffic, longer waiting times, aggression amongst dominant cows, fewer visits to the milking unit, feeding with more concentrates, or high stocking rate. Much more research is needed on optimizing the management concerning the grazing (Heutinck *et al*., 2004).
Physical product quality indicators like: total plate count (TPC), a measure for bacterial presence; somatic cell count (SCC), a measure for the inflammatory cells in the udder of the cows; freezing point (FP), a measure for the amount of water in the milk; free fatty acids (FFA), a measure for the damage of the fat globules, and the susceptibility for lipolysis and taste, are easiest to investigate. Literature shows that the first 6 months after milking with AMS the levels for TPC and SCC are higher; thereafter they stabilize at the original level. There is a big difference between the farms investigated. The FFA level remains too high and this is not clearly understood (de Koning *et al*., 2004). In several countries research programs aim to investigate, and possibly improve this quality aspect. The FFA can also influence the taste and storage stability. These milk qualities are not expected to be different on organic farms.
Indirectly influenced physical qualities of milk, like amount of antibiotics in the milk or the amount of CLA (Conjugated Linoleic Acid), Vitamin E and anti oxidants have also been measured. They are greatly influenced by the time the cows graze. High contents also are considered positive quality measures. The higher residues of antibiotics are results of bad management (Rasmussen and Justessen, 2004).
The socio-economical research done on farmers' satisfaction using AMS give reason to conclude that they are positive, especially considering free time disposal (Meskens and Mathijs, 2002). This motive is not expected to be different among organic farmers.

Conclusion

From the selected issues quantifiable sustainability indicators (SI) are presented. To validate the net farm income, time saving effect, and total costs too little "organic" data on AMS have been

analyzed. Use of models with "organic" data and direct on-farm registrations would be necessary. Ecological indicators like eutrophication, influence on greenhouse gasses, acidification and biodiversity are all dependent on the practice of grazing. There is a tendency to decrease grazing when using AMS in organic herds, even though rules prescribe it. To validate the indicators registration of grazing days and hours per year, the area used for grazing and the amounts of supplement roughage and concentrates fed, is necessary. The use of fossil energy tends to increase when using AMS.
The social indicators, milk quality, animal health and welfare that can be measured, show that grazing has an important role. Animal welfare and milk quality aspects are key motives to buy organic products. Considering the attitudes of consumers, farmers, NGO's and authorities, the aspect of grazing is therefore chosen as main focus in all group and individual interviews following this survey. No clear conclusion can be made at the moment if AMS use on organic farms positively or negatively influences the total sustainability of organic dairy farming. The analyzed measurable indicators show some negative tendencies for milk quality, animal welfare and eutrophication problems. Especially the animal welfare and eutrophication problems are linked to the amount of grazing. In terms of positive effects the time saving and job satisfaction seem the most important. The latter is indeed a very important indicator for sustainability of the sector.

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Working time studies in conventional and automatic milking systems with one or two AMS units

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Abstract

Time studies were made on four farms with conventional milking (tandem parlour 2x3), four farms with one AMS unit and four farms with two units. From this study, it is possible to make estimations of expected labour savings when investing in an automatic milking system (AMS) and the big scale advantages when investing in two AMS units. The conclusion of this study is that working time can be approximately 2.4 minutes shorter per milking cow and day in a single AMS farm when compared to a conventional stable of the same size. Work concerning cleaning, feeding and AMS was reduced by 0.4 minutes per milking cow and day when comparing single and double AMS farms.

Keywords: Automatic milking, working time, labour, AMS

Introduction

When farmers change their systems from conventional milking to an automatic milking systems (AMS) it is stated that there is a considerable difference in the amount of work as well as an alteration in work tasks. Therefore, the present study evaluated the indicated differences in working time and working tasks between conventional and automatic milking systems.

Materials and methods

Twelve farms were studied during the stall season 2003, four farms with conventional milking in a parlour (2x3 tandem), four farms with one AMS unit and four farms with two AMS units. The herd size varied between 45 and 61 milking cows for the conventional farms, from 48 to 59 and 86 to 103 milking cows for the AMS farms. All farms were family farms without full-time employees. The selection of farms was made together with local counsellors. The aim was to select farms that were representative of Sweden. All the AMS farms had forced cow traffic. The farms were selected so that key factors such as size, age of the farm, labour situation and degree of mechanisation were as similar as possible. All AMS farms had to have more than one year of experience with the system to eliminate "starting" problems.
Working categories were defined to be able to measure and compare working time between farms and systems. The following categories were defined: conventional milking, cleaning of cubicles, feeding, AMS, young cattle and other. All categories were divided further.

Time studies

During the study, farmers were observed during a whole working day in order to cover all daily working tasks. Duration and sequence of all work concerning cows and all other cattle was measured manually with a timer and registered at the same time in a protocol. When two working tasks were done simultaneously, the time was distributed evenly, with 50% given to each task. An

example of this multitasking is when the cubicles are cleaned at the same time as the cows are fetched for milking.
Farm data and factors affecting the time study were noted during the practical study. For example, non-daily working tasks, their duration and how often these tasks were done.
At the AMS farms, an alarm-list for the past month was analysed together with each farmer. The number of alarms during working hours and non-working hours were counted and an approximation was made of the amount of the time spent on each alarm.

Statistics

The data were analysed by PROC GLM according to SAS (SAS Institute, 1996).

Results

Milking in parlour

The milking work was divided into the following sub-works: preparing before milking, driving cows to and from milking, milking, cleaning the parlour/pen and cleaning the milk equipment. The distribution of these tasks is presented in Table 1. All conventional farms milked twice a day. In all farms, the cubicles were cleaned at the same time as the cows were fetched for milking. Therefore the time was evenly divided as stated above.

Table 1. Milking in conventional parlour, minutes/milking cow and day.

Farm	No. of milking cows	Preparing before milking	Driving to/ from milking	Milking	Cleaning parlour/pen	Cleaning milking equipment	Total
1	45	0.3	0.5	2.8	0.4	0.2	4.3
2	47	0.3	0.5	3.1	0.2	0.2	4.3
3	61	0.1	0.2	3.7	0.4	0.2	4.6
4	56	0.1	0.2	3.1	0.4	0.2	4.0

AMS work

The AMS work consumed 1.1 to 1.8 minutes per milking cow and day (mpmc) at the single AMS farms whilst the double AMS farms consumed 0.5 to 2.9 mpmc. The sub-works that varied the most within the AMS category were "waiting to help a cow at milking in AMS" (0-1.3 mpmc) and "Cleaning AMS" (0.2 -0.8 mpmc), Figure 1. The category "Other" concerns work related to daily service and maintenance such as, supervision of the vacuum pump/compressor, changing the milk filter, filling of teat spray and detergents, etc. Again, the time was divided equally when the cubicles were cleaned at the same time the cows were fetched for milking.
An alarm-list for the past month was analysed together with each farmer, the number of alarms and time spent on each alarm was estimated. Alarms that the AMS could manage itself and alarms pre-set by the farmer are not included in the data. An example of a pre-set alarm can be "cow trapped" when a cow is kept in the AMS station after milking for treatment. The alarm frequency for each farm is presented in Table 2.

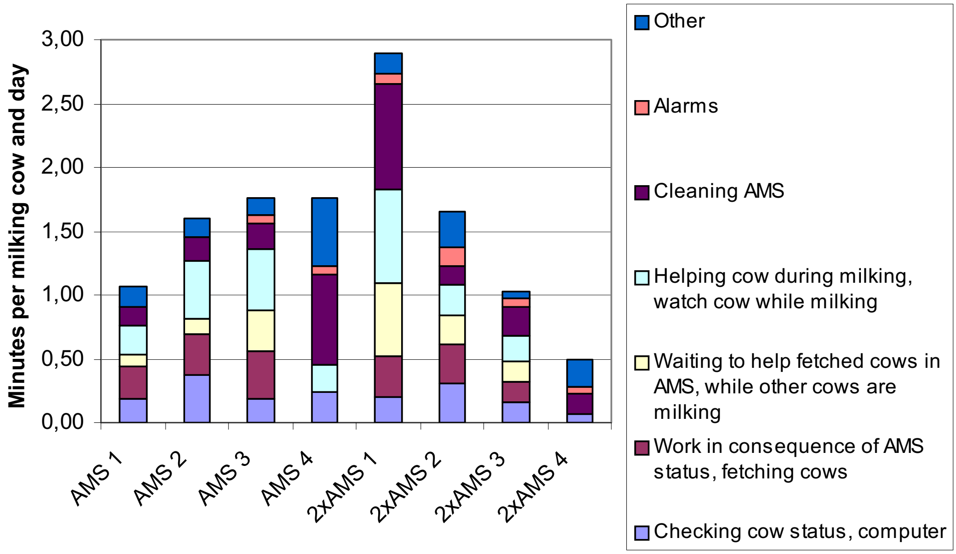


Figure 1. Work related to AMS, minutes per milking cow and day.

Table 2. Alarm frequency (number/month) and point of time for the AMS farms.

	AMS1	AMS2	AMS3	AMS4	2xAMS1	2xAMS2	2xAMS3	2xAMS4
No. of alarms/month	5	4	7	9	13	24	12	10
Working hours (no.)	1	1	1	4	10	15	8	6
Non-working hours (no.)	4	3	6	5	3	9	4	4

Cleaning and littering of cubicles

The conventional farms consumed on average 0.44 mpmc for cleaning and littering the cubicles, whereas the AMS farms consumed 0.89 mpmc for single AMS farms and 0.54 mpmc for the double AMS farms. There was no significant difference between systems for these working tasks. The distribution between cleaning and littering is shown in Figure 2. Cleaning of cubicles was often done at the same time as cows were fetched for milking in the parlour or in the AMS. Again, in these cases working time was evenly distributed.

Feeding of silage and concentrates

The feeding work consists of loading, transportation, foddering and cleaning of the feeding trough. All stables used feeding stations for foddering concentrates. All AMS farms gave a small portion of concentrates during milking.
The feeding work can be divided into two main working tasks, preparing/loading and foddering. The distribution between these two tasks is shown in Figure 3.

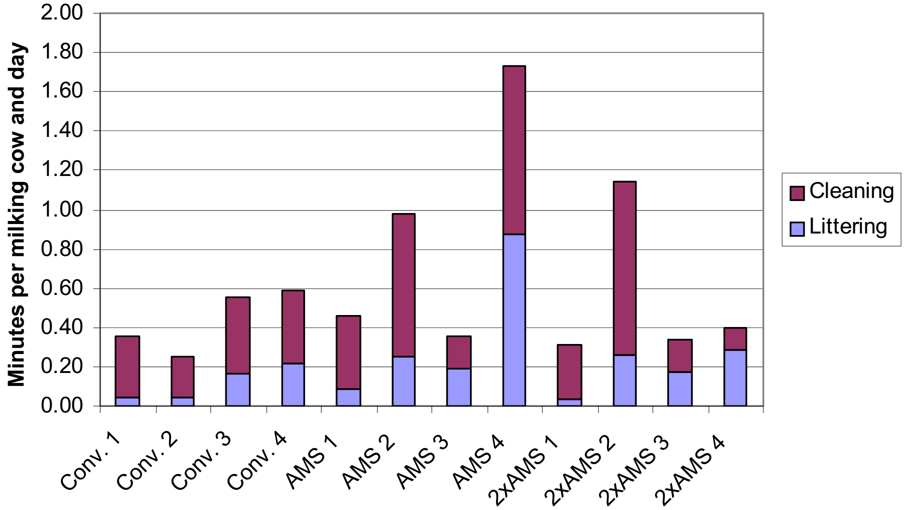


Figure 2. Time spent for cleaning/littering of cubicles (minutes per milking cow and day).

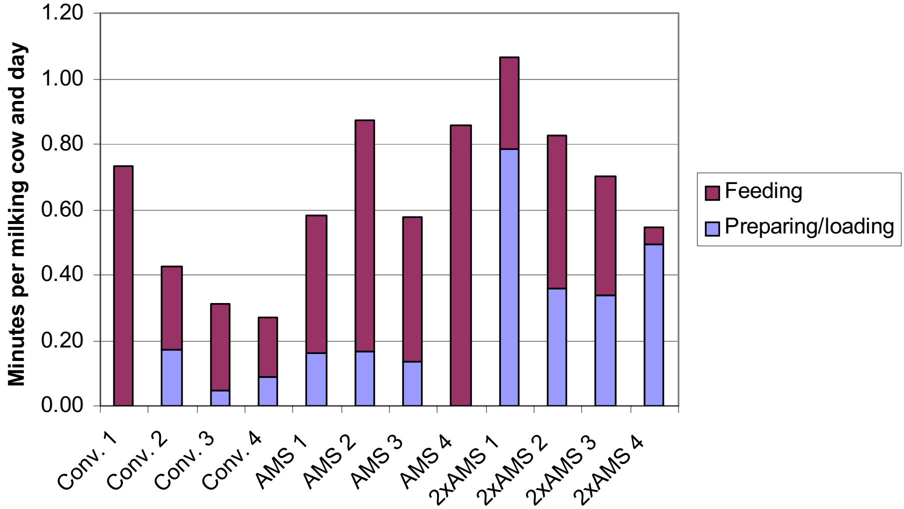
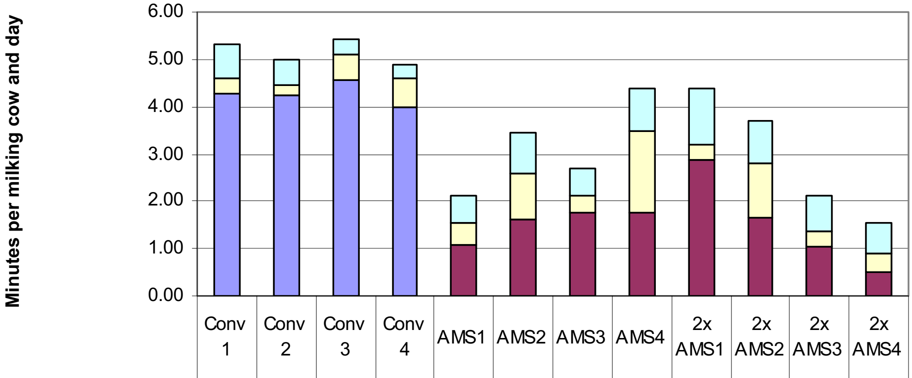


Figure 3. Time for preparing/loading and foddering (minutes per milking cow and day).

Feeding work was significantly higher ($p<0.05$) for AMS farms when compared to the conventional farms. Foddering frequency was higher for AMS farms. Silage was fed on average 2.75 times per day at the double AMS farms, 2.25 times at the single AMS farms and 1.25 times a day at the conventional farms.

Comparable work

The categories milking, AMS, feeding and cleaning/littering of cubicles are the foremost working tasks that can be used for calculation of labour savings. These categories are presented and displayed in Figure 4.
There was a significant difference ($p<0.05$) between conventional and automatic milking when comparing this overall work. No significance was found when comparing single and double AMS farms.



	Conv 1	Conv 2	Conv 3	Conv 4	AMS1	AMS2	AMS3	AMS4	2x AMS1	2x AMS2	2x AMS3	2x AMS4
Feeding	0.73	0.51	0.31	0.29	0.58	0.88	0.58	0.90	1.18	0.87	0.76	0.66
Cleaning/littering	0.31	0.21	0.56	0.59	0.45	0.98	0.36	1.73	0.31	1.16	0.34	0.40
AMS	0.00	0.00	0.00	0.00	1.07	1.60	1.76	1.76	2.89	1.65	1.03	0.49
Milking	4.29	4.26	4.56	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4. Minutes working time per milking cow for the categories milking, AMS, feeding and cleaning/littering of cubicles.

Discussion and conclusions

When the categories milking, AMS feeding and cleaning/littering of cubicles are compared between farms with parlour milking (tandem 2x3) and automatic milking with one AMS unit there is an average saving in labour time of 2.4 minutes per milking cow and day. This verifies the results of Rasmussen (2002) who reported a reduction of work time of 127 minutes for single AMS farms (2.3 minutes per milking cow for a herd with 55 milking cows).
Time for AMS work, feeding and cleaning/littering of cubicles consumed on average 274 minutes per day at the double AMS farms. This also verified the work by Rasmussen (2002), which reported 291 minutes for similar work.
All AMS herds have some cows that are less suited for being milked automatically. If the farmer removes those cows, the work with fetching cows and helping cows at milking would decrease dramatically. From an economic point of view this is not always the best solution, since either the farmer increases expenses through buying new cows or loses income due to less milk. This is clearly shown in farm (2xAMS 1), as at the time of the visit it had eight cows that did not fit into the system and could not be milked automatically. The farmer did not have any possibility to get rid of these cows through economic means. He chose to milk those cows “manually” in the AMS unit in the morning and in the evening. If those eight cows were replaced with new cows, the AMS

work would be reduced to the same level as the other double AMS farms (from 1.3 to 0.5 mpmc). Data for AMS work from this farm has not been used when calculating labour savings.

Work concerning fetching cows to the AMS and helping cows during milking in the AMS varied between 0 and 1.63 minutes per cow and day. The highest value is explained in the paragraph above. Two of the AMS farms did not have to fetch any cows for the AMS station. These two parameters varied the most between farms and have a great importance on the farmer's opinion about how the system works.

Two of the AMS farms had extremely high labour time for cleaning the AMS. At AMS 4, the farmer and his employee completed the same cleaning work within a few hours. Co-ordination at this farm would reduce the cleaning work by 50 %. At 2xAMS 1, the peat litter in the cubicles caused a lot of dust that soiled the AMS unit heavily. Because of this the AMS was cleaned twice a day. If the peat was replaced with another type of litter the work would be reduced to the same level as the other double AMS farms, from 0.8 to 0.2 minutes per cow and day.

A large amount of time spent on the AMS work consists of supervision of cows. It can be difficult to specify how much time this work really demands. An alarm often interrupts other work and causes extra working time due to transportation to/within the stable. Labour time increases with the number of alarms, for both the AMS- and other work. Danish research (Rasmussen, 2002) shows that 73 % of the farms have less than three alarms per week, which is similar to the results in this study.

In this research only tandem parlours 2x3 have been studied. The working time for milking would have been different if other parlours had been investigated. This is shown by Keller (1994) who found an efficiency of 44 cows an hour for a 2x3 tandem parlour and 59 cows an hour for an 2x4 tandem parlour. In big herds, the size (Smith *et al*., 1998) as well as type of parlour (Jakobsson, 2000) affects the milking capacity.

The length of time to clean the cubicles varied between 0.12 and 0.88 (average 0.4) and 0.05 to 0.88 (average 0.2) for littering. These values correspond well with other research (Persson, 1995; Elinder and Falk, 1983).

The average time for work concerning cleaning of the cubicles increased by 50 % in AMS stables compared with parlour stables of the same size. This expected increase could not be explained statistically. One motive for an increase is that the regular health and oestrus check-up in conventional stables is often completed at the same time as milking, whereas in AMS stables it is often completed when cleaning the cubicles. Another is that there is a higher demand on the cleanness of the cubicles in AMS farms to ensure the cows are clean, thereby minimising the risk of transmission of infections and contamination of the bulk milk.

Working time concerning cleaning of the cubicles was reduced by 30 % per cow in double AMS farms compared to single AMS farms, this difference could not be explained statistically. A decrease in cleaning work was expected since there are large-scale advantages for this working task when the number of cows increases.

At two of the farms, AMS 4 and 2xAMS 2, the work concerning cleaning of the cubicles was extremely high. AMS 4 had problems with mastitis and according to the local veterinarian the cubicles were cleaned and littered four times a day. The farm 2xAMS 2 had old sand cubicles which had been converted to cubicles with rubber carpets. The high rear edge of the sand cubicles were still left and made the cleaning work very heavy and time consuming.

Values for cleaning from these two farms have not been used when calculating labour savings, because these discrepancies are due to the building solutions rather than type of milking system.

Feeding work increased from 0.43 to 0.79 minutes per cow and day when stables with conventional and automatic milking systems were compared. This can be explained with more frequent feeding in the AMS farms. The number of feeding occasions increased with the AMS and number of AMS units. One explanation for this is that three of the double AMS farms had high yielding cows or

heifers on both sides of the feeding trough and could therefore not get enough silage out in just two feeding occasions per day.
When stables with one and two AMS units were compared there was no difference in working time per milking cow for feeding work, although some large-scale advantages were expected. This can however be explained; when the farmers invested in an AMS they wanted to keep their investments as low as possible and therefore they invested in relatively cheap and time consuming feeding systems. Many of the AMS farms have plans to invest in a more mechanised and rational feeding system.

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Feeding technology and feed quality

The feed level controlled mash feeder vs. conventional tube mash feeder: Performance and eating behaviour of young weaned piglets

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Abstract

The objective of the research was to examine the performance and eating behaviour of young weaned piglets with regard to the feeding system. A force-ventilated compartment with two identical pens was used. Both pens (25 piglets/pen) were equipped with one conventional tube mash feeder (TF). Nine rearing periods of five weeks each were analysed. All piglets were weaned at the age of 21 days and fed with the same food. In one of these pens (reference group - RG) the TF was used exclusively. The other pen was used for the experimental group (EG): During the first three rearing periods in this pen, the feed level controlled feeder (FLCF) served as the exclusive feeding system (EXP1) in the first two initial weeks of rearing. In the next three rearing periods the FLCF as well as TF were activated (EXP2); during rearing period seven to nine, feed from two FLCFs were available in the first two initial weeks. From the third week piglets in EXP1, EXP2 and EXP3 were fed with the TF.
Compared to piglets in the RG, piglets housed in the EG gained significantly more weight after two and five weeks of rearing. Concerning the average number of piglets at the trough no significant differences could be detected between the RG and the EG. In comparison to the RG, significantly more piglets in EG attempted to get some food but were not able to eat because of occupied feeding places. In EXP2 the majority of the piglets preferred to eat at the FLCF. In EXP3 one of the FLCFs was much more frequented than the other. Although both FLCF were identical, piglets preferred to eat together at the same feeder.

Keywords: feed level controlled feeder, piglet, performance, behaviour

Introduction

It is the goal of balanced piglet feeding to exhaust the large growth potential of the piglets optimally until the end of the rearing phase and to avoid feeding-related losses. The weaning phase of the piglets is a physiologically caused stress situation (von Borell *et al*., 1997). The most important stress factors in this phase include the separation from the mother, transport, new dominance fights, the struggle with the pathogen pressure of the new environment as well as the change in feeding from mother´s milk to solid feed (King and Pluske, 2003). The weaning weight and the weight gain of piglets immediately after weaning influence their growth until the end of their fattening period (Pluske *et al*., 2003). Most of the piglets take in their first meal already some hours after weaning; however, some piglets clearly need up to 54 hours longer (Brooks *et al*., 2001). During nursing time, piglets suckle at intervals which are given by sows (Brooks and Burke, 1998). After weaning piglets miss this stimulus to eat together at regular intervals (Brooks and Tsourgiannis, 2003). They have to relearn water and feed intake and to differentiate between hunger and thirst. Liquid feeding systems for weaned piglets are often valued since these systems satisfy the water demand and the consistency of this feed more likely reminds them of sow's milk (Brooks *et al*., 2001).
Especially in early weaned piglets, the feed level controlled mash feeder is intended to provide a smooth transition from mother's milk feeding in order to mitigate those weaning problems. In this

contribution, the effects of the feed level controlled mash feeder with regard to rearing performance and eating behaviour is compared with the conventional tube feeder.

Animals, materials and methods

Feeding technique

The tank of the feed level controlled mash feeder (FLCF; PreMixer, Euro Feed Systems GbR, Essen i. Old., Germany) had a capacity of 30 l. The diameter of the trough bowl was 25 cm (Figure 1).
A sensor which protruded into this trough bowl served as an overflow protection. When the sensor registered feed in the trough bowl, the mixing cycles were interrupted until the trough was eaten empty. Up to three piglets were able to eat at the trough simultaneously. In the feed level controlled mash feeder, the mixing time and the mixing cycles could be set in 1 to 30 minute intervals. Per minute of mixing time, an auger transported 23 g of feed to the trough bowl, where it was mixed with warm water shortly before being discharged. The water was warmed by the heat radiation of the motor of the control unit. The consistency of the feed was steplessly adjustable from dry to liquid. In this trial, the set mixing time and the mixing cycle were two minutes. Feed was dispensed as viscous mash.
The trough bowl of the tube feeder (Lean Machine, Big Dutchman, Germany) had a diameter of 40 cm. The tank held 80 l. When the piglets moved the metering bar of the tube feeder, feed fell into the trough bowl, where the animals were able to mix it with water from the trough spray nipples to obtain mash. At this tube feeder, the animals were fed ad libitum. Up to six piglets were able to eat at the same time.
During the first 14 days of the rearing phase, the piglets in both pens got a pre-starter (17.5 CP, 15.0 MJ ME, 1.5% lysine). As of the third week, the animals were fed a starter (18.03 CP, 13.52 MJ ME, 1.23% lysine).

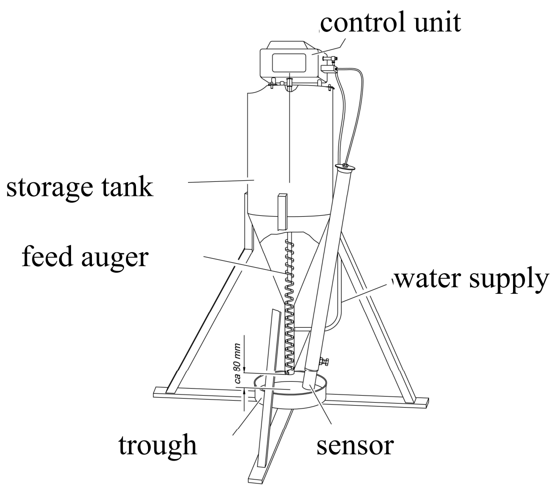


Figure 1. Schematic view of the feed level controlled mash feeder

Housing condition and experimental setup

For this study, a force-ventilated compartment with two identical pens was used (Figure 2). Pen size was 5.8 m^2. The perforated floor consisted of plastic gratings. Both pens were equipped with a tube feeder.

One of those pens was used as the experimental pen: In the first three rearing periods, a feed level controlled feeder served as the exclusive feeding system in the first two weeks; the tube feeder was switched off (Experiment 1, EXP1) (Table 1).

In the next three rearing periods the feed level controlled feeder as well as the tube feeder were activated in the first two weeks of rearing (experiment 2, EXP2). In experiment 3 (EXP3) which lasted from the seventh to the ninth rearing period, piglets were fed with two feed level controlled feeders during the first two initial weeks, the tube feeder was switched off. In EXP1, EXP2 as well as in EXP3 piglets were fed with the tube feeder from the third to the fifth week of rearing. The reference group (RG) was fed with the tube feeder during the entire rearing phase of five weeks.

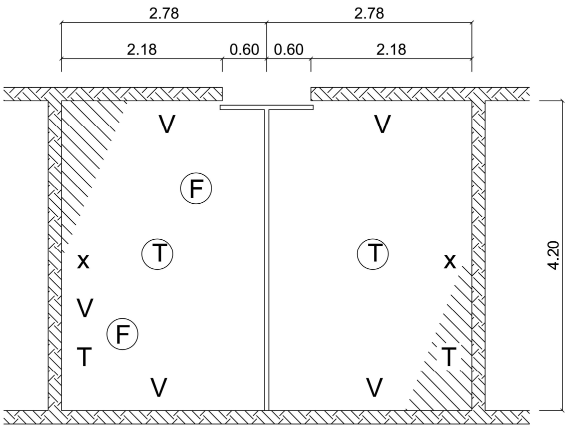


Figure 2. Ground plan of the rearing compartment (measurements in m).
F, Feed level controlled feeder; T, tube feeder; V, video camera; T, drinker; x = measuring point for air temperature and air humidity

Table 1. Design of the trial. FLCF, feed level controlled mash feeder; TF, tube mash feeder; AFR, animal-feeding place-ratio; SD, Standard Deviation

Rearing period	Group	Feeding system (first two weeks)	AFR	Avg. weaning weight (SD)
1-3	EXP1	1 FLCF	8.4:1	5.31 kg (0.79 kg)
	Reference	1 TF	4.2:1	5.31 kg (0.81 kg)
4-6	EXP2	1 FLCF and 1 TF	2.7:1	5.55 kg (0.88 kg)
	Reference	1 TF	4.2:1	5.60 kg (0.94 kg)
7-9	EXP3	2 FLCFs	4.2:1	5.87 kg (1.08 kg)
	Reference	1 TF	4.2:1	5.94 kg (1.08 kg)

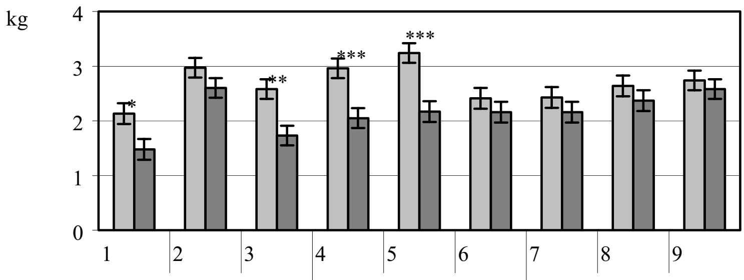
Animals, data collection and statistical evaluation

Data of nine rearing periods was collected. In both pens piglets were housed in groups of 25 animals with a balanced gender ratio. The piglets were breeds of PIC sows, which were mated with a stress resistant Pietrain boar. The weaning of the piglets and the placement to the rearing compartment took place 21 days after birth. Each piglet was weighed and rated on the day it was brought into the stall, thereafter at two and five weeks. Four piglets of the reference group (one piglet each in rearing period 1,5,6,8) and one piglet of the experimental group (rearing period 8) were removed from the compartment because these animals lost a considerable amount of weight and were in danger of starving. These animals were replaced with piglets of the same age, whose data were not considered in the evaluation. Both the feed level controlled mash feeder and the tube feeder were filled manually. The feed quantity used was registered by both feeding systems. The behaviour of the piglets was recorded on video tapes during the whole trial. Eating behaviour was analysed with the time sampling method in a 2-minutes interval on six selected day over a 24 hour period. Additionally, focal piglets in EXP2 and EXP3 were observed continuously. In the assessment of the video recordings, the number of animals at the trough (snout in the trough bowl) and the number of animals in the trough area were considered.
Analyses of variance of performance data as well as of behaviour data were carried out with the program package SAS 8.01. If the data were normally distributed the procedure “glm” was used. Data which did not show a normal distribution had been evaluated with the procedure “npar1way”. For statistical evaluation of the performance data, which was normally distributed, the effects of feeding group and repetition as well as the covariable weaning weight were taken into consideration (t-Test). Behaviour data had been logarithmically transformed into a normal distribution in order to compare the behaviour of the piglets of the experimental group and the reference group. Variance analytical calculations were done considering the effects of feeding group, rearing period, day time as well as observation day (t-Test). Behaviour of piglets depending on the feeding automats within EXP2 and EXP3 was not normally distributed, statistical calculations were done with the procedure “npar1way”. The effect of the feeder was taken into account (Wilcoxon-Test).

Results and discussion

Performance

Feeding piglets with feed level controlled feeder as an exclusive feeding system or in combination with the tube feeder in the first two weeks of rearing, followed by feeding them with the tube feeder the next three weeks led to significantly higher weight gain after two weeks. During this time piglets of the experimental group gained on average 0.53 kg more weight than animals of the reference group. From the third until the fifth rearing week, all groups were fed with the tube feeder. During this period, no significant differences between the weight gain of the piglets of both groups were able to be detected. When the entire five-week rearing phase was considered, a significant advantage (0.84 kg) of the experimental group over the reference group was observed. In all nine rearing periods, piglets of the experimental group gained more weight during the first two initial weeks compared the animals of the reference group (Figure 3). The Least Square Means of weight gain after two weeks in rearing period 1 and 3 (EXP1) as well as in rearing period 4 and 5 (EXP2) were significantly higher. In EXP3, no significant differences could be established between the experimental group and the reference group. In rearing periods 1-3 piglets in the EXP1 gained on average 0.62 kg more weight, in rearing periods 4-6 piglets of the experimental group (EXP2) showed a 0.74 kg higher weight gain and piglets in rearing periods 7-9 gained on average 0.23 kg more weight in the initial two weeks compared to the reference groups.



	EXP1			EXP2			EXP3		
experimental group	2.13	2.97	2.58	2.96	3.24	2.41	2.43	2.64	2.74
reference group	1.48	2.6	1.73	2.05	2.17	2.16	2.16	2.37	2.58

rearing period

Figure 3. Least Square Means and Standard Errors of weight gain after two weeks of rearing depending on the feeding system and rearing period. * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$ (t-Test)

From the third until the fifth rearing week, all groups were fed with the tube feeder. During this period, no significant difference between the weight gain of the piglets of all groups could be detected (weight gain 3rd-5th week). In this period piglets in EXP1, and EXP2 gained more weight with 0.69 kg, 0.50 kg, respectively, than piglets in the reference group. However, piglets in EXP3 gained less weight by 0.30 kg compared to the reference group. When the entire five-week rearing phase is considered, a advantage of the EXP1and EXP2 over the reference group can be observed. Piglets gained 1.34 kg (EXP1), 1.25 kg (EXP2), respectively, more weight. But, this advantage of the experimental group was not found with piglets in EXP3, they gained 0,09 kg less weight compared to the reference group. The piglets were subjected to the same housing conditions with the exception of the feeding technique in the first initial two weeks. Obviously, the reason for higher weight gain in these first two weeks of rearing had to be due to the feed level controlled feeder. Food fed by the feed level controlled feeder was always freshly prepared and was served warmed in the trough. On one hand it could be possible, that piglets prefer warm food compared to cold food. One the other hand it could be feasible that piglets take in more food if the mash is always freshly provided, compared to food for which piglets have to "work" in order to dose it into the trough and there mix it up by themselves.

Feed consumption

After two weeks of rearing, piglets of the experimental group gained significantly more weight compared to piglets of the reference group. Furthermore in all rearing periods, the feed consumption per piglet was significantly higher in comparison to the reference group (Table 2). On average, piglets of the experimental group consumed 0.85 kg·piglet^{-1} more feed than animals of the reference group. However, no significant differences were detected concerning the feed conversion. To obtain 1 kg weight gain, piglets of the experimental group consumed 1.41 kg and animals of the reference group consumed 1.33 kg of feed.

Table 2. Least Square Means (LSM) and Standard Error (SE) of feed consumption, weight gain and feed conversion in the initial two weeks of rearing depending on the feeding system. a,b, LSM within one criteria with different letters are significant different ($P < 0.05$; t-Test).

		Experimental group		Reference group	
		LSM	SE	LSM	SE
Feed consumption	[kg·piglet^{-1}]	3.73^{a}	0.10	2.88^{b}	0.10
Weight gain	[kg·piglet^{-1}]	2.67^{a}	0.09	2.15^{b}	0.09
Feed conversion	[1:]	1.41^{a}	0.05	1.33^{a}	0.05

Behaviour

The eating behaviour of the piglets was observed over six days. The feeding technique differed between the groups on the first three observation days (2nd, 9th and 14th day of rearing). On the first observation day, the average number of piglets at the trough was slightly lower in the experimental group compared to the reference groups. On this day the number of piglets in the trough area and the number of piglets at the trough were on the same level (Figure 4). On observation days 2 and 3, the average number of piglets at the trough was on a slightly lower level in the experimental group compared to the reference group. But on these days, the average number of piglets in the trough area was significantly higher in the experimental group compared to the reference group. In the experimental group, significantly more piglets tried to reach the trough bowl but failed because of occupied feeding places.

Choice of feeder

Piglets in EXP2 could choose whether they ate at the feed level controlled feeder or at the tube feeder. On the first observation day no significant difference between the number of piglets at the

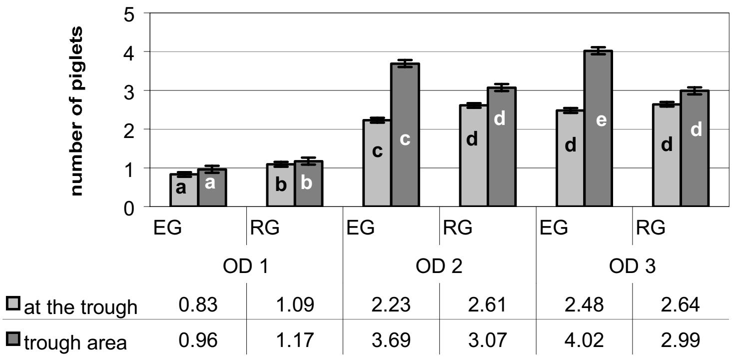


Figure 4. Least Square Means and Standard Error of the number of piglets at the trough and the number of piglets in the trough area depending on the rearing groups and observation day (OD). EG, experimental group; RG, reference group; OD1, 2nd day of rearing; OD2, 9th day of rearing; OD3, 14th day of rearing; a,b,c,d,e, LSM within one criteria with different letters are significant different ($P < 0.05$; t-Test).

trough of each feeder could be determined (Table 3). On the second as well as on the third observation days, the number of piglets at the trough was significantly higher at the feed level controlled feeder compared to the tube feeder, although the tube feeder had twice as many feeding places as the feed level controlled feeder. Also on the second as well as on the third observation days, the average number of piglets which stayed in the trough area of the feed level controlled feeder was 3.29, 3.65 respectively, whereas the number of piglets in the trough area of the tube feeder was only 0.57, 0.26, respectively. It seems that that piglets preferred food from the feed level controlled feeder. They would rather put up with displacements than eat at the tube feeder. Though both feeders were available for the piglets, they almost exclusively ate at the feed level controlled feeder, so that the actual used animal-feeding-place-ratio was not 2.7:1 but rather 8.4:1

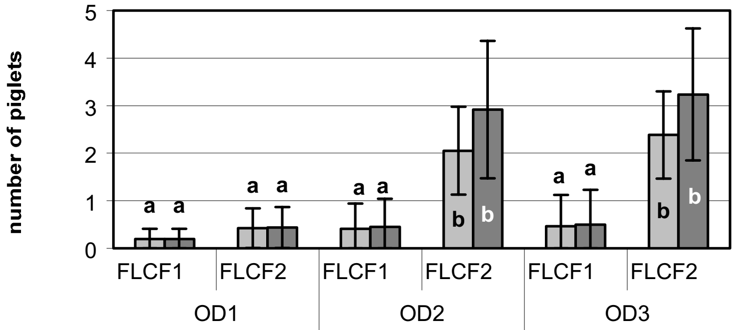
In EXP3 two identical feed level controlled feeders (feed level controlled feeder 1 and feed level controlled feeder 2) were available for piglets of the experimental group, so that the animal-feeding-place-ratio was the same in the experimental and in the reference group. On the first observation day both feed level controlled feeders were rarely frequented (Figure 5). On observation day 2 and 3 the majority of the piglets preferred to eat at feed level controlled feeder 2. Although both feed level controlled feeders were identically built (operativeness was controlled) and the positions of both feed level controlled feeders within the pen were interchanged with each other between the rearing periods, piglets favoured the feed level controlled feeder 2. Even though all feeding places at the feed level controlled feeder 2 were occupied, piglets which tried to get feed rarely attempted to get feed at the feed level controlled feeder 1. It seems that piglets favour to eat together at one feeder, and due to the distance between both feeders, they did not try to eat at the other one. As in EXP2 piglets preferred to eat at one feeder, so that the actual used animal-feeding-place-ratio in EXP3 was not 4.2:1 but rather 8.4:1.

Table 3. Average number and standard deviation of piglets at the trough and piglets in the trough area within EXP2 depending on the feeding system. a,b,c, Means within one criteria with different letters are significantly different (P<0.05;Wilcoxon-Test); SD, standard deviation; OD1, 2nd day of rearing; OD2, 9th day of rearing; OD3, 14th day of rearing; FLCF, feed level controlled feeder; TF, tube feeder

		At the trough		In the trough area	
	FLCF	TF	FLCF	TF	
OD1	mean	0.48^{a}	0.55^{a}	0.56^{a}	0.57^{a}
	SD	0.37	0.62	0.47	0.64
OD2	mean	1.73^{b}	0.55^{a}	3.29^{b}	0.57^{a}
	SD	0.57	0.62	1.40	0.64
OD3	mean	1.98^{b}	0.26^{a}	3.65^{b}	0.26^{a}
	SD	0.73	0.29	1.96	0.29

Conclusion

Feeding piglets with the feed level controlled feeder in the first two weeks of rearing, followed by feeding them with the tube feeder the next three weeks leads to significantly higher weight gains compared to feeding piglets with the tube feeder during the entire rearing period of five weeks.



	OD1 FLCF1	OD1 FLCF2	OD2 FLCF1	OD2 FLCF2	OD3 FLCF1	OD3 FLCF2
at the trough	0.19	0.42	0.41	2.05	0.46	2.38
in the trough area	0.19	0.44	0.45	2.92	0.50	3.23

Figure 5. Average number and standard deviation of piglets at the trough piglets in the trough area within EXP3 depending on each FLCF and observation day.
a,b,c, Means within one criteria with different letters are significantly different ($P<0.05$; Wilcoxon-Test); FLCF1, feed level controlled feeder 1; FLCF2, feed level controlled feeder 2; OD1, 2nd day of rearing; OD2, 9th day of rearing; OD3, 14th day of rearing

After the two initial weeks of rearing, piglets fed with the feed level controlled feeder gained more weight and consumed more feed, but feed conversion of the experimental group und the reference group were alike.
More attempts to get to the trough failed with piglets fed with the feed level controlled feeder because of occupied feeding places. Piglets preferred to eat at the feed level controlled feeder (EXP2). They rather put up with displacements than eat at the tube feeder which was also available. Piglets preferred to eat together at one feed level controlled feeder (EXP3), although empty feeding places were available at an other feed level controlled feeder.

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Precision protein and energy feeding of dairy cows during transition time

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Abstract

The objective was to evaluate precision feeding of protein and energy to the individual cow during the transition time from calving to lactation establishment.
Dual channel, computer-controlled self-feeders (CCSF) supplied daily concentrate allocations of protein and energy based on dry matter intake (DMI), as calculated with a model that used daily milk yield (MY), body weight (BW), days in milk (DIM), and milk composition as inputs.
In the first stage of the trial two groups of cows received two different precision rations and the control group a total mixed ration (TMR). In the second stage, the better precision ration was fed to one group, and TMR to a control group. All performance parameters were measured until 7 weeks after calving in the first stage and up to 20 weeks after calving in the second. The MY, BW and body condition (BC) records favored precision feeding over TMR: MY exceeded 44 kg/d vs 41.3 kg/d; BW fell by less than 8% vs more than 10%, post-calving; and average BC score declined for 7 vs 11 weeks, and from 2.9 to 2.7 vs 3.1 to 2.4.
In the second phase the same trend was demonstrated despite a lower performance of both groups. It is concluded that precision agriculture principles can be applied to protein and energy feeding management for dairy cows.

Keywords: Transition time, precision livestock farming, protein, energy, lactation, dairy

Introduction

Transition time is a very sensitive period during which cow lactation is initiated. It is characterized by rapid changes in milk yield (MY), body weight (BW), and dry matter intake (DMI) that demand rapid physiological adaptations. Mismanagement during this period, especially in protein feeding (NRC 2001), could impair the entire lactation. Advanced technologies in the dairy industry raise the possibility of applying "precision agriculture" principles in dairy farming. Precision management of nutrition in dairy farming can be defined as matching protein and energy feeding to the basic production units, i.e., the individual cows, according to a general feeding strategy that includes responses to physiological capacity and actual performance. Performance-recording sensors, on-line modeling capabilities, and technology for real-time management response facilitate the application of precision livestock management to protein feeding by supplying every cow in a group with amounts of protein and energy in accordance with its actual performance. This can prevent nitrogen load as DMI increases (Maltz and Silanikove, 1996), and can save on expensive feed.
Precision livestock farming in general, and in the dairy in particular, depends on several requirements: a) sensors for on-line performance measurements; b) on-line performance data acquisition; c) on-line data analysis, supported by modeling to evaluate performance parameters for which sensors are not available; d) decision making based on a general strategy and adjusted to match actual performance; e) execution (preferably automatically) of decisions.

Sensor data often need processing into a format that has a physiological and managerial meaning, but this information would clearly still be useless unless action can be based on it either to sustain or to change the situation. For example, when cows are fed a total mixed ration (TMR) that provides each cow in the group with a ration suitable for an "average cow" (NRC 2001), nothing can be done for any particular cow whose recorded performance calls for an increase or reduction in protein. In the present study we tried to use a precision management technique to execute a general strategy of feeding energy and protein during the transition time, not on the basis of averages, but individually to each cow in the group according to her actual performance. For energy it is a similar strategy to that of feeding TMR until peak production, i.e., the increasing need for energy as lactation proceeds is achieved by increasing the DMI. For protein we decided to meet the nutritional needs and physiological capacity (Maltz and Silanikove, 1996) by feeding high levels of protein immediately after calving and reducing the level gradually as lactation proceeded and DMI increased.

The objectives of this study were to use advanced technologies during transition time to achieve precision in protein and energy feeding to the basic production unit in the dairy, i.e., the individual cow, in accordance with her performance and production potential as well as nutritional and physiological needs.

Methods

The study was performed in the experimental dairy of the Volcani Center; it used Israeli Holstein cows that were milked thrice daily at 8-h intervals.

The facilities and settings to execute precision farming in this study were:

- Sensors: Milk meters, walk-through scales positioned on the outlet path from the milking parlor.
- Data acquisition: daily MY, BW, concentrates consumption (energy, and protein), visits to CCSF; weekly, milk composition.
- On-line data analysis and modeling: stage of lactation, DMI,
- Individual concentrates allocations that were based on a general strategy and were adjusted in accordance with actual performance.
- Execution of decisions: dual-channel, computer-controlled self feeders (CCSF) that distributed the two kinds (energy and protein) of pelleted concentrates, separately in each channel.

In the first phase, 36 multiparous cows were grouped in clusters of three, according to lactation number, calving date, and previous year's MY. From each cluster, cows were allocated randomly into one of three groups. The nutritional strategy and rationing provision for each group were as follows:

1. Group 1 (GR1). Daily ration energy density of 1.765 Mcal/kg DM net energy for lactation (NL) until peak production. After peak production, the ration energy density was adjusted according to the weekly milk composition test. The protein density was 28% of DM after calving and was reduced gradually to 17% when the maximal DMI was reached. Forage was supplied in the feeding lane, and all concentrates were supplied via the CCSF (CCSF operation, see below).
2. Group 2 (GR2). Daily ration energy density of 1.765 Mcal/kg DM NL. The protein density of 19% of DM after calving was reduced to 17% after 28 days (Spahr *et al*., 1993). Forage was supplied in the feeding lane, and all concentrates via the CCSF.
3. Group 3 (GR3). Daily ration energy density of 1.765 Mcal/kg DM NL. The protein density was 17% of DM throughout. The ration was supplied as TMR in the feeding lane.

For GR1 we tested the feasibility of a new concept of feeding a high-protein-density ration after calving and decreasing the protein density as DMI increased (Figure 1). For GR2, energy and protein were in accordance with NRC (2001) recommendations.

For groups 1 and 2, the daily ration of concentrates (energy and protein) was supplied through the CCSF, equally divided among six "feeding windows" (FWs). Three FWs "opened" at the times of return from milking, and the other three between these times, so that each FW lasted for about 4 h. Feed not consumed in one feeding window was divided equally among the next six FWs. The CCSF, operating, calibrating and control, and recording software (AfiFeed), as well as all other sensors and equipment used, were produced by S.A.E. Afikim (Kibbutz Afikim, Israel). The cows were observed closely after calving; all of them started to use the CCSF within 2 days.

The CCSFs were calibrated weekly and every time the containers were filled with a new batch of concentrates, to ensure a supply rate of about 300 g/min (± 20 g) of both concentrates (energy and protein) together. Cows could enter either CCSF to receive their concentrates allocations, and no preference was shown for either of the two CCSFs.

During the first 10 days after calving, as a precaution, the energy and protein concentrates for all cows were allocated by calculating according to predetermined DMI levels: 10 kg/d for days 1-3, 12 kg/d for days 4-5, 13 kg/d for days 6-7, 16 kg/d for days 8-9, 18 kg/d for day 10. MY and BW were measured daily, and BC weekly on a scale of 1 (very thin) to 5 (obese). The measurements were done for 12 weeks after calving, by the same trained person.

The DMI was calculated daily from the daily MY and BW measurements and the periodical milk composition by a built-in model, according to Halachmi *et al*. (1997). This model was checked externally, twice weekly, against the NRC (2001) DMI model and concentrates allocation decisions were taken according to the following equations:

$$\%Protein = ((DMI- DM_{(Con.)} * (E+P))* P_{(For.)}.1+E* DM_{(Con.)}* P_{(Energy)}+P* DM_{(Con.)}* P_{(protein)})/DMI \qquad (1)$$

$$NEL_{(Ration)} = ((DMI- DM_{(Con.)}*(E+P))* E_{(For.)}+E* DM_{(Con.)}* E_{(Energy)}+P* DM_{(Con.)}* E_{(Protein)})/DMI \qquad (2)$$

Where:

%Protein (%) - Percentage of protein in the daily full ration (in this study, initially 28% for cows in group 1, and gradually reduced to 17% as DMI increased towards its peak; initially 19% for cows in group 2 for 28 days after calving and then reduced to 17%)

DMI (kg) - model-calculated DMI (NRC, 2001, Halachmi *et al*.,1997)

$DM_{(Con.)}$ (fraction) - The fraction of dry matter in protein and energy concentrates. (In this study it was 0.9 in both; if there were different values, each of the concentrates would have to be multiplied by the appropriate value)

E (kg) - Energy concentrates allocated

P (kg) - Protein concentrates allocated

$P_{(For.)}$ (%) - Percentage of protein in the forages fed in the feeding lane (11.1 in this study)

$P_{(Energy)}$ (%) - Percentage of protein in E (10.2 in this study)

$P_{(protein)}$ (%) - Percentage of protein in P (39.4 in this study)

$NEL_{(Ration)}$ (Mcal/kg DM NL) - Daily full ration net energy density (1.76 NL)

$E_{(For.)}$ (Mcal/kgDM NL) - Energy density of forages fed in the feeding lane (1.5 in this study)

$E_{(Energy)}$ (Mcal/kgDM NL) - Energy density of E (2.0 in this study)

$E_{(Protein)}$ (Mcal/kgDM NL) - Energy density of P (1.91 in this study)

After E and P were calculated, it was confirmed that their combined value (equation [3]) did not exceed 40% of DMI.

$$\%Con = ((DMI- DM_{(Con.)}*(E+P))/DMI*100 \quad (3)$$

Where: %Con is the percentage of daily allocated E+P in the daily calculated DMI (<40% in our present study)

In the second phase (which is still in progress), only the ration of GR1 was used, and comparison was with the same control group (GR3). Cows were allocated to one of these two groups according to lactation number, calving dates, and previous year milk production. For reasons not related to the experiment, several cows from the precision-feeding group left the herd, and that is why the numbers of cows presented in the two groups are unequal (see below). Also, there was a failure in the walk-through weighing system at the beginning of this stage, and that is why the numbers of cows within groups regarding MY and BW data are unequal.

Results and discussion

All the cows consumed the full daily allocation; they usually visited the CCSF in every FW, and to miss two FWs was very rare. An example of one cow in Group 1 is presented in Figures 1 and 2. The performance (MY and BW) data from which DMI was calculated for concentrates allocations, are presented in Figure 1. The values calculated with equations (1), (2) and (3) are presented in Figure 2. In general, energy density was kept as close as possible to 1.765 Mcal/kg DM NL, and the total concentrate percentage below 40% of DMI. It can be seen that when performance data were missing (BW on days 74-79 after calving) or suspected to be unreliable (BW on days 80-85 after calving), the concentrates allocations were left unchanged (Figure 1). Nevertheless, the aims of the general strategy of feeding protein and energy concentrates were achieved satisfactorily (Figure 2). The protein level gradually declined from 28% after calving to

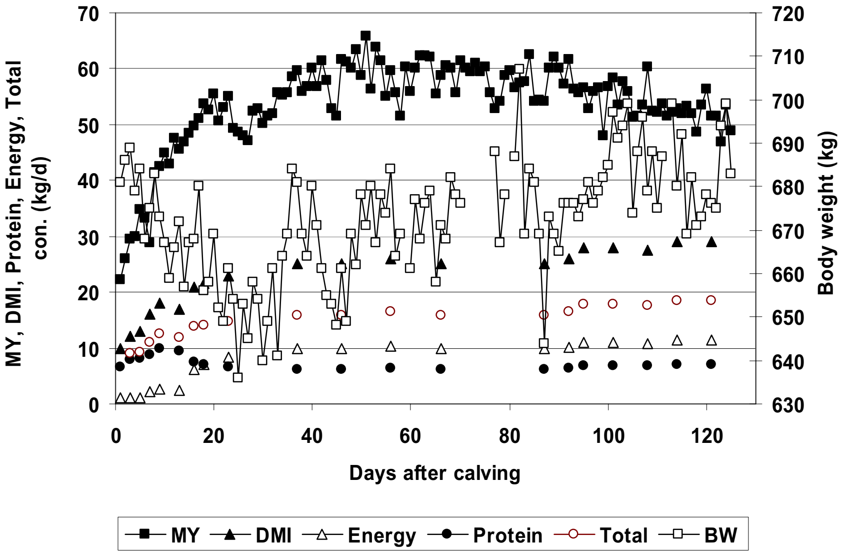

Figure 1. Daily milk yield (MY), model-calculated dry matter intake (DMI), protein concentrates allocation (Protein), energy concentrates allocation (Energy), total concentrates (Total con.), and body weight of one cow (2059) for which the protein rationing strategy involved gradual reduction from 28% after calving to 17% as DMI increased. Ration energy density was kept as close as possible to 1.765 Mcal/kg DM NL, and total concentrate percentage below 40% of DMI.

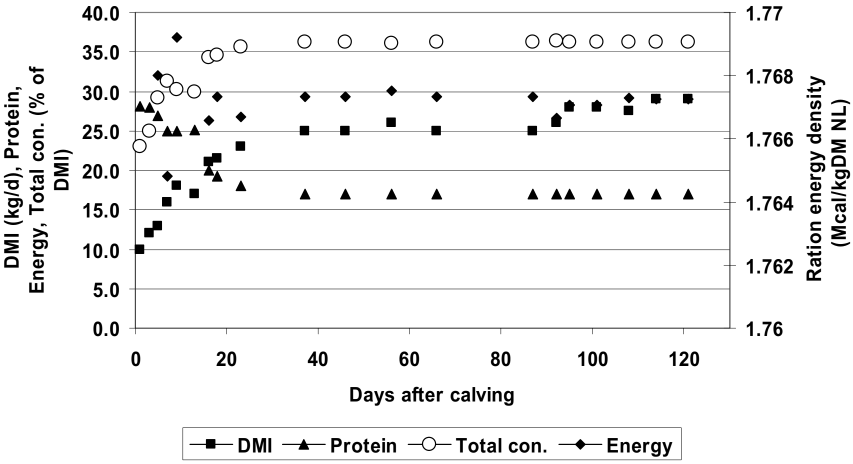

Figure 2. Model-calculated daily dry matter intake (DMI, kg/d), protein concentrates allocation (Protein, % of DMI), energy concentrates allocation (Energy, % of DMI), total concentrates (Total con., % of DMI), for one cow (2059) for which the protein rationing strategy involved gradual reduction from 28% after calving to 17% as DMI increased.

17% just before 40 days after calving, when DMI reached its peak, and the percentage of total concentrates did not reach 40% of DMI (Figure 2). However, the NEL of the daily ration rose above the intended value of 1.76 Mcal/kg/DM NL, which causes a small decrease in the milk-fat content of the precision-fed cows.

In summary, it can be seen that the first stage results for the various groups show that in MY, BW (Figures 3) and BC (Figures 4) precision management was superior to TMR feeding in general, and particularly so for the high and gradually reduced protein feeding (GR1). GR1, 2, and 3 cows started lactation weighing 617±48, 602±56, 606±42 kg (average ± SD), respectively and with BCs of 3.00±0.20, 2.86±0.15, 3.14±0.29, (average ± SD) respectively.

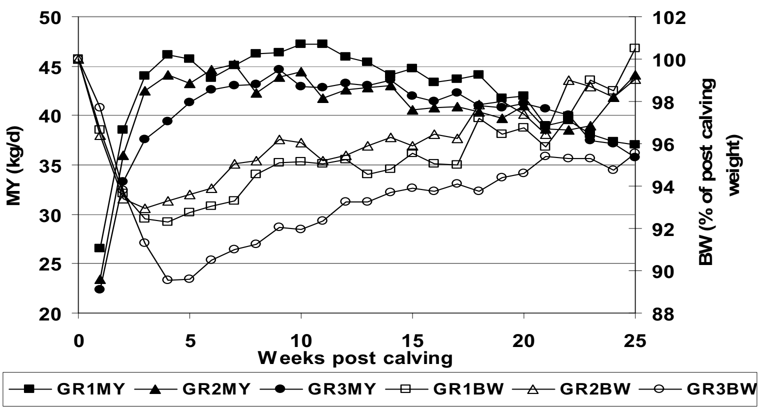

Figure 3. Average milk yield (MY) and body weight (BW) of cows fed energy and protein concentrates individually in a precision-management method, via computer-controlled self feeders (GR1, n=9; and GR2, n=9), compared with cows fed a total mixed ration (GR3, n=9).

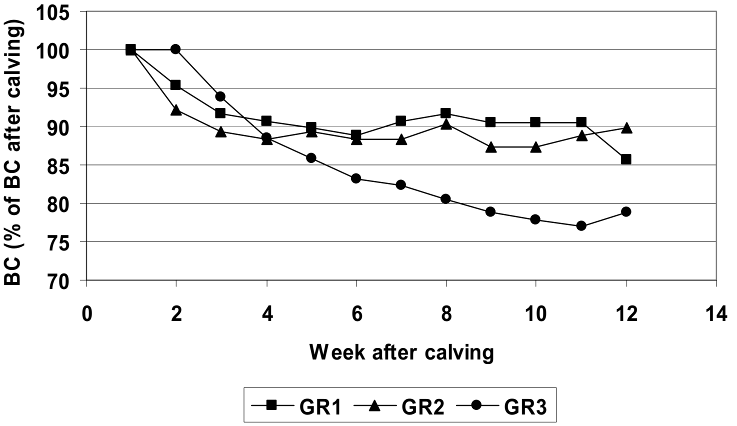

Figure 4. Average body condition (BC) of cows fed energy and protein concentrates individually in a precision-management method, via computer-controlled self feeders (GR1, n=9; and GR2, n=9), compared with cows fed a total mixed ration (GR3, n=9).

The second phase results (work still in progress) presented here, unlike those of the first phase, were obtained with summer calvers, and this may account for the lower MYs exhibited by cows of both groups (Figure 5 and 6). Nevertheless, the trend found in the first phase was repeated: precision-fed cows increased production more rapidly (P<0.05) (Figure 5) and lost less weight (Figure 6) than TMR-fed ones.

Previous attempts to operate precision feeding using CCSF (Maltz *et al*. 1991; Maltz *et al*. 1992) always fell short of the expected breakthrough. Firstly, this was due to lack of individual performance (i.e., BW and DMI) data, and secondly because of the inability to apply the nutritional strategy individually to each cow, and when the latter was achieved (Morag *et al*. 2001) it operated only for energy and not for protein. It seems that we are now very close to overcoming these

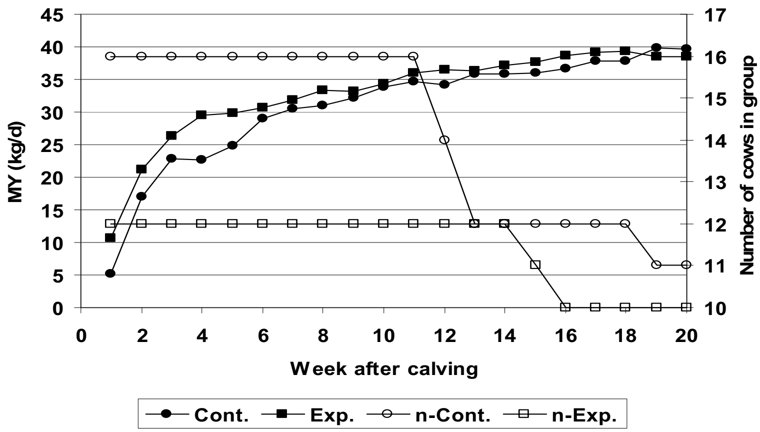

Figure 5. Average milk yield (MY) of cows fed energy and protein concentrates individually under a precision-management method via computer-controlled self feeders (Exp.) compared with that of cows fed a total mixed ration (Cont.). The differences during the first 5 weeks are significant (P< 0.05)

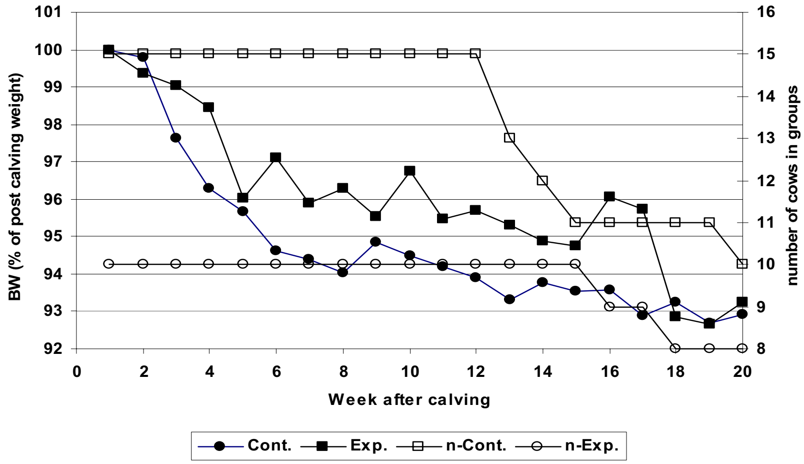

Figure 6. Average body weight (BW) of cows fed energy and protein concentrates individually under a precision-management method via computer controlled self feeders (Exp.) compared with that of cows fed a total mixed ration (Cont.).

obstacles. On-line milk composition analyzers (Schmilovitch *et al*. 2000) that can be used for the DMI model improvement, may even improve the results presented in this study.
The two equations, (1) and (2), with two unknowns (E and P) used in this study, can easily be incorporated into any herd management software that records MY and BW, from which DMI can be calculated by a model (NRC 2001 or Halachmi *et al*. 2004). Close control of this system is essential. The CCSFs must be calibrated frequently, and leftovers in the CCSF must be checked according to a daily routine. Above all, the whole process must be carried out automatically, so that the manager does not have to spend time in analyzing the data, and making and executing decisions. Once the strategy is set, it is incorporated into the herd-management software and executed automatically throughout lactation.

Conclusion

Precision agriculture principles can be applied to the feeding of protein and energy to dairy cows, and the on-line milk composition sensor enables a complete system for use in precision dairy feeding. However, effects such as calving season, parity and other environmental and managerial factors require further research before precision feeding can be fully applied to dairy cows.

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Computer-controlled milk feeding of calves; the effect of precise milk allocation

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Abstract

The aim of this study was to investigate the effect of precise individual milk allowances on calves' performance at weaning. One hundred and fifty four calves were fed with milk by a computer-controlled feeder. A new real-time algorithm embedded in a software application was developed; it calculates the individual milk allocation for a calf that approached the milk feeder, according to the calf's previous feeding behaviour. The logic behind this dynamic feeding regime is (1) that a calf that has missed meals should be compensated in order to maintain its energy balance. For instance, if a calf were ill and therefore had not consumed its entire allocation, the system should supply this calf with more energy (milk) on the subsequent day, so that it can fully recover from the illness. (2) Mild illness cannot be easily observed automatically, therefore the system uses calf feeding behaviour as an indication of illness. Two indexes of performance were utilized in this study, health and body-weight gain. The results were: daily weight gain was 691 g/day (SE 36) in the control group (CG) vs. 771 g/day (SE 36) in the experiment group (EG). The average body weights (BW) at weaning were 76 kg (CG) and 82 kg (EG). The kosher status (an indicator of health) of the best experimental group was 75%, whereas only 57% of the calves in the control group were classified as kosher. It can be concluded that under the circumstances of this study the application of precision management to the feeding of individual calves by a computer-controlled milk feeder has a potential for achieving a higher daily weight gain and improving calf health.

Keywords: calf, health, feeding behaviour, computer-controlled milk feeder

Abbreviations: EG = experiment group; CG = control group; SE = standard error (standard deviation/ square root[n]) ; BW = body weight

Introduction

The current trend in dairy production is toward group housing of calves and use of computer-controlled milk feeders (Jensen, 2004). Little attention has been focused on the way these systems are managed. Some important aspects have been investigated: Jensen (2003), Lidfors (1993) and others listed by de Passille (2001) investigated the cross-sucking phenomena; Jensen (2004) measured the influence of grouping density (i.e., the number of calves per drinking stall) on animal drinking behaviour; others such as Weber and Wechsler (2001) suggested mechanical improvements such as a feeder with a closed stall, like the one used in our present system, except that in our case the gate is pneumatically operated. Other studies considered fitted housing systems (Bøe and Havrevoll, 1993), feed diets (Brosh *et al*., 2000) and several additional aspects of computer-controlled milk feeders. However, although computer-controlled milk feeding systems have been commercially available for many years, the present principal author did not find any published consideration of milk allocation based on the behaviour of the individual calf. The

hypotheses of the present study were: (1) husbandry and nutrition in early age may influence a calf's health and growth; (2) energy intake and therefore energy compensation via the feed are affected by individual parameters such as calf weight, age, breed and health.
Therefore, the aim of this study was to develop a new real-time algorithm, embedded in a software application, to calculate the individual milk allocation for a calf approaching the milk feeder, according to the calf's previous feeding behaviour.

Material and methods

Animals, housing, and feeding

In order to avoid seasonal effects, all treatments were performed simultaneously in parallel. One hundred and fifty four male calves were selected randomly for the trial but, on arrival at the research farm, were allocated to pairs, matched in age and weight. One member of each pair was allocated to the control group (group 1, feeding regime 1) and the other to one of the experiment groups (treatments), numbered 2 to 4 and receiving feeding regimes 2 to 4, respectively. The pairs and groups were virtual, with their members designated only in the computer, so that the farm workers could not know which calf belonged to which group; only the farm nutritionist and the principal author, who set the feeding parameters in the computer, could know if an animal belonged to a specific group. Thus, the experimental design included 'double-blind randomization' which means that - as should be the case - all the calves received the same handling from the farm workers and were subjected to the same climatic conditions, management practices, etc. The research was conducted at the Israeli Northern Research Center, Newe Ya'ar, which belongs to the ARO. The calves were Holstein-Friesians, born on the neighbouring farms. After birth, all calves were moved to individual straw-bedded indoor pens and fed milk from buckets. They were fed colostrum until d 5, after which it was gradually replaced with whole milk. All the calves were 1 wk old when they were transferred to our research institute in a light vehicle with closed sides, and they were then equally familiarized with their automatic drinking machine. In Newe Ya'ar, the calves were assigned to one of two treatments until they were gradually weaned off milk between days 57 and 65. The control group received milk according to the currently used age-dependent feeding regime (regimes 1, referred to in Figure 1 as the 'control group'), i.e., gradual increase up to 6 litres by day 10, and gradual decrease down to a zero milk quota by the age of 57 days. The experiment groups received milk according to the calves' feeding behaviour, i.e., according to their Individual Dynamically updated Allocation, IDA. IDA means that if a calf hasn't consumed its accumulated allocations of milk, the system compensates it with 1.5 additional litre/day in the following days. For example, if a calf was slightly ill (as in a mild case of diarrhoea or pneumonia) and drank 3 l less milk than its accumulated allocation, it will be allowed 2 litres more as soon as it feels better. Technically speaking, the IDA algorithm will allow one and half litre per day in addition to the calf's regular daily allocation until the animal has received its allowed accumulated quota (from birth to date). The calves in the experiment groups 2-4 were fed according to IDAs based on regimes 2-4 (Figure 1). The calves in Groups 1 and 2 were identical (the same age and the same weight) when they arrived at the research farm. Regimes 1 and 2 were identical but regime 2 used IDA. Regime 3 used IDA, calculated for lightweight calves that were not ready for larger amounts of milk until a few days later, when their rumens were further developed. Thus, feeding regime 3 included a sort of "phase delay", reaching its peak later. Regime 4 used IDA adapted for heavier calves that were able to accept the peak allocation earlier. The powdered milk concentration was 125 g/litre in all groups. All the calves were kept in the same cowshed, exposed to the same environmental conditions and treated in the same way.
In addition to the milk replacement the calves were offered concentrates and hay ad libitum from d 12 and throughout the experimental period.

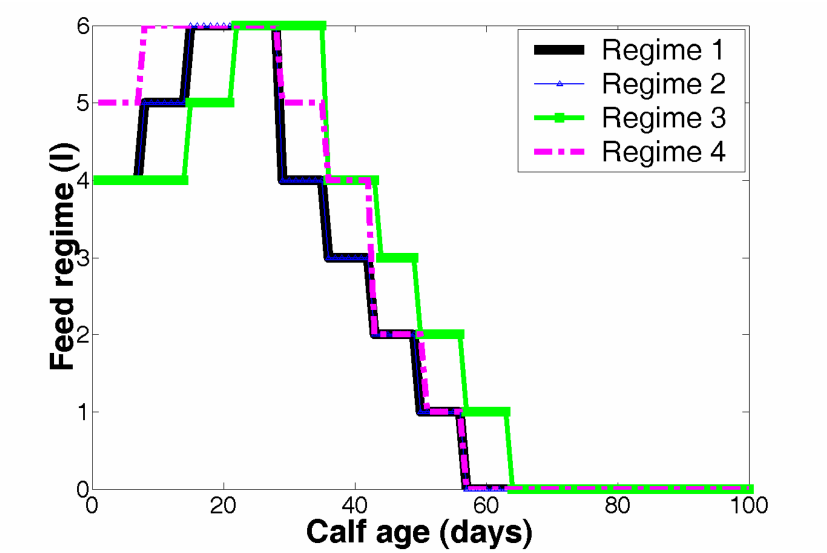

Figure 1. Feeding regimes used in our study. Regime 1 was for the control group (no IDA algorithm applied), regimes 2-4 were for the experiment groups, with the newly developed IDA algorithm applied. Regimes 1 and 2 were identical; regimes 3 and 4 were for initially lighter or heavier calves, respectively.

The experimental cowshed had two straw-bedded pens (6 × 25 m each) each with room for more than 30 calves. However, the number of calves per pen never exceeded 25 at any given time. Each pen had one milk-feeder stall with one teat, connected to the computer-controlled unit (Shimon Ben Cnaan; Gavish, Israel) that was located between the two pens. A feeding stall floor is placed on an electronic weighing scale, connected to the feeder's computer. When a calf enters a stall and his 4 legs are on the stall's floor (guided by a pneumatic gate) and his ID number has read by the RFID antenna, its weight with the ID number are sent to the feeder computer. The accuracy of this 'built in' scale is 0.1 kg, calibrated weekly during the experiment period. The weighing scale is sold by the feeder producer (Ben Cnaan, mentined above) who also provides all the necessary maintenance for both, the drinking machine and the electronic scales. Each stall had a pneumatically operated gate that protected the sucking calf from displacement and gently ejected it when it had finished drinking. The calves were assigned to treatments in groups of around 20 calves per feeder stall. After weaning all the calves were combined into one group and were treated identically until they were slaughtered at the age of 1 yr.

Data collection and statistical analyses

Data were collected via the computer-controlled milk feeder. The computer program that controlled the milk feeder divided each 24-h period into two feeding sessions. The feeding sessions of the individual calves started between 0100 and 1500 h. The calves were assigned at random to each feeding group (regimes 1-4 in Figure 1 above). Within its feeding session, each calf was offered one-half of its daily milk allowance, i.e., 1.5 L; it could take its first milk portion when a new feeding session started but at least 120 min had to pass before it could take its second portion. If a calf consumed 0.2 L of a portion or less, the intake was not recorded, and the calf was allowed to receive the whole portion later. If a calf consumed more than 0.2 L but less than the whole portion the remainder could be consumed later in the session. Had the calf not consumed its ration

within its feeding period, a maximum of 1.5 L would be transferred to its next feeding period. The data collected from the computer-controlled milk feeder unit were logged into a separate computer; these data included the time of the beginning and end of each rewarded visit, i.e., one in which the calf obtained milk, including time spent ingesting milk (defined by the presence of milk in the mixer bowl), and the milk intake. Data obtained on days when the feeder was out of order were deleted from the data set.
Body weight was measured during the weaning period and when the calves were 1 year old.

Results

Data Collected via the Computer-Controlled Milk Feeder

The frequency of IDA use can be estimated from Table 1, which shows that a calf needed additional milk around 10 times during its weaning period. There was no statistically significant difference among treatments.

Table 1. Actual number of days on which the calf used the additional milk.

Group	Days	Feeding regime (Figure 1)
1	0	1 (control group)
2	11.95 (SE=0.35)	2
3	9.26 (SE=0.29)	3
4	10.26 (SE=0.26)	4

The average numbers of visits (rewarded and unrewarded) per calf per day did not differ significantly between CG and EG: 8.4 (SE = 0.043) and 8.4 (SE = 0.039), respectively. However, heavy calves visited the feeder more often than medium- or light-weight calves: 9.78 (SE=0.21), 8.50 (SE 0.080), and 7.76 (SE=0.082) visits/day, respectively, but this could have been a result of the social hierarchy in the herd.
In Figure 2 it can be seen that heavier calves visited the drinking machine more often, probably because they were better able to force their way to it, and no effects of IDA treatments on milk drinking behaviour were found. The average number of visits per calf per day ranged from 10.0 (regime 3) to 12.3 (regime 2), which was not a significant difference (according to the t-test, $\alpha = 0.05$). Calves at the left-hand tail of the distribution curve did not visit the feeder often enough, whereas those at the right-hand corner might have visited too often, so blocking the feeding stall.
Actual milk intakes are compared with the planned regime in Figures 3-5. It can be seen that there was wide variation among the calves: sometimes a calf did not consume its quota and needed extra milk in real time; in other cases an extra milk allocation was not necessary (Figure 5, right). The wide variation among individuals suggests that individual treatment is needed, but that it should be applied automatically every day, in accordance with the calf's current status and previous performance, without human involvement in the real-time decision process. Therefore, the IDA was developed in the course of this study, and was embedded into the drinking machine software.

BW Gain

Daily weight gains were 691 g/day (SE = 36) in the control group (CG) and 771 g/day (SE = 36) in the experiment group (EG). The average body weights (BWs) at weaning time were 76 kg and

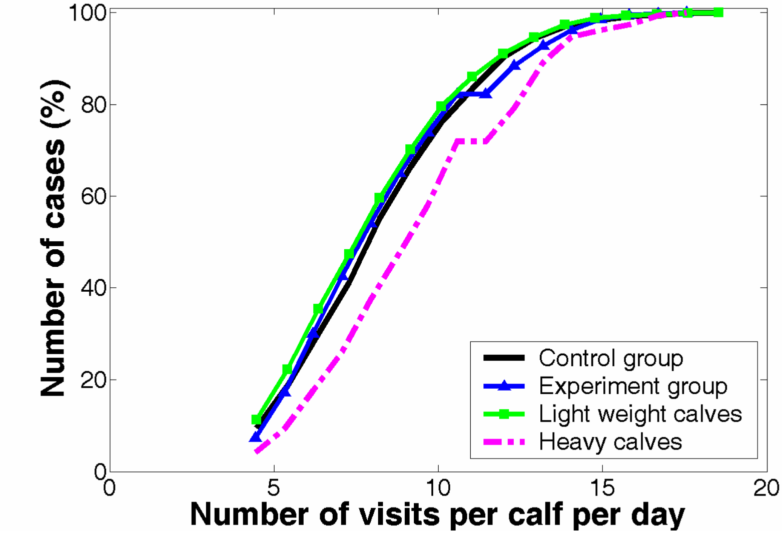

Figure 2. Animal behaviour as expressed in the number of voluntary daily visits per calf to the automatic drinking machine. Calves in group 1 (control group, upper left corner), group 2 (upper right corner), group 3 (lower left corner) and group 4 (lower right corner) were exposed to feeding regimes numbers 1-4 respectively.

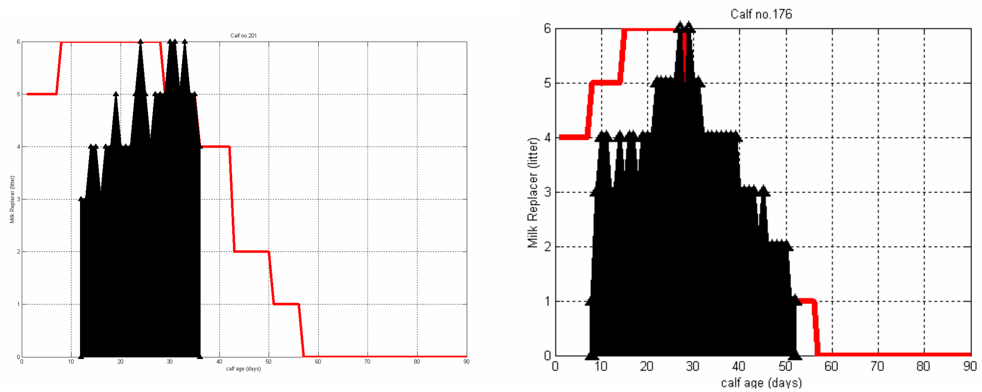

Figure 3. Left: a calf that has not reached its accumulated milk allocation and received compensation. Right: A calf that has not reached its accumulated milk allocation but was not compensated (a calf from the control group).

82 kg in the CG and EG, respectively, and the final BWs were more homogeneous in the EG than in the CG (SE 1.7 and 2.4 kg, respectively). The ages at weaning were 60.4 (SE 1.5) and 64.2 (SE 1.09) days in the CG and EG, respectively, which reflects the milk distribution permitted by the behaviour-based feeding algorithm during the last weaning days of those calves that had not consumed their entire share. Heavy calves (BW > 44 kg on entering the system) grew faster than medium-weight (initial BW 40-44 kg) or light-weight calves (initial BW < 40 kg): *821 (SE 51), 794 (SE 72) and 723 g/day (SE=54), respectively. These findings are in agreement with previously published results. Table 2 summarizes the results mentioned above.

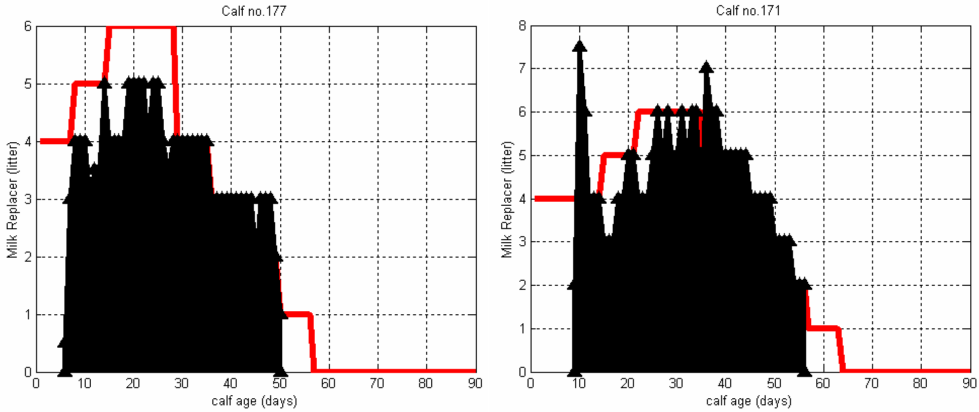

Figure 4. Left: A calf that reached its milk allocation after 30 days. Right: A calf that mistakenly received too much milk on day 10, became ill and recovered.

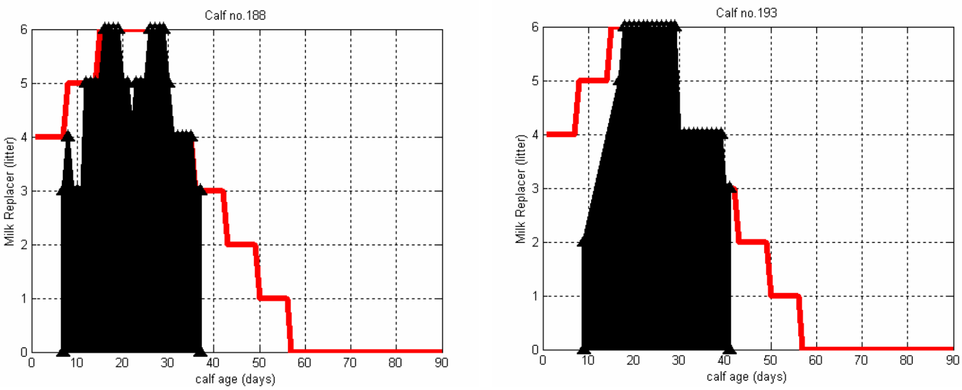

Figure 5. Left: A calf that was in stress and recovered. Right: A calf that took its milk allocation as planned.

Table 2. Average weight gain, body weight and weaning duration.

	Weight gain (g/day)	Body weight at weaning (kg)	Age at weaning (days)
Control group	691 (SE 36)	76 (SE 2.36)	60.4 (SE 1.5)
IDA Treatments			
Experiment group	771 (SE 36)	82 (SE 1.74)	64.2 (SE 1.09)
Heavy[1] calves (44kg<BW)	821 (SE 51)		
Medium[1] weight (40<BW<44kg)	794 (SE 73)		
Light[1] weight (BW<40kg)	723 (SE 54)		

[1]measured on arrival at the research farm

Health evaluation

Not enough health problems occurred during the drinking period to enable a statistically valid conclusion to be reached regarding health improvement during weaning that could be attributed to the proposed new feeding methods. However, an indication of lung diseases can be derived from the kosher status of the calf. Immediately after slaughter the kosher inspector blows into the lung to inflate it (like a balloon). If the lung is without holes and the lung's parts to not adhere to each other, then the calf is certified as "kosher meat". In this way, we can express calf health (lung problems at an early stage) according to a parameter that is measured in every commercial slaughter house (in Israel). For example, if a calf had mild pneumonia when it was 2 weeks old, this might not be detected by the farmer or by the local vet, but since the lung had already been injured, the calf might not be classified as kosher when it is slaughtered one year later. Table 3 presents the kosher results of each group. It can be seen that the preferred regime was number 4. Regime 3 was not significantly different from the control group.

Table 3. Kosher status of each group. Kosher status indicates whether the calves had lung problems at an early age.

Group	Kosher rate (%)	Feeding regime (figure 1)
1	0.57	1 (control group)
2	0.66	2
3	0.56	3
4	0.75	4

Discussion

The assumption behind this trial was that a calf has individual nutritional requirements that depend upon its weight (30-50% diversity), age, heath status, and history. The commonly used regime is based on the calf's age and does not take into account its pattern of body weight increase, decrease and fluctuation, or of reduction in its milk intake because of heath problems, being pushed away by stronger calves in the herd's hierarchy or for any other reasons. A regime that is based only on age prevents heavier calves with more advanced rumen development from fulfilling their genetic growth potential. Such a regime also depresses the growth of lighter calves, because their ability to consume milk develops a few days later than average, by which time the milk allocation has been gradually reduced. Furthermore, in accordance with the minimum requirements of energy and minerals, 25 kg (125 g/L) of milk powder should be provided by the age of 50 days, but under the age-based regime less then the 25 kg minimum will usually be provided, and in some cases the amount provided might not be enough to built their rumen capabilities and to develop their immune system properly. Therefore in the light of the present study, we propose a sophisticated feeding regime which: (1) is individual, based on the dynamic response of each calf, with additional milk provided on an individual basis as needed; (2) provides more milk at an early age to heavier calves; and (3) provides more milk to lighter calves at a later age, to allow later weaning.

Conclusions

The results showed that applying precision management to the individual calf, by feeding it via a computer-controlled milk feeder, offers the potential for achieving higher daily weight gain and improving calf health. Further research, involving a variety of environmental conditions and different breeds is suggested, as well as incorporation of the daily fluctuations of calf body weight into the model.

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Protein reduced, sensor-controlled feeding of fattening pigs

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Abstract

The aim of the work presented was to develop a sensor-based control technique for optimal feeding of fattening pigs. In a fattening trial (624 animals) protein utilisation was modified by varying lysine supplementation. Specific sensors recorded feed intake, pig growth, pig environment and liquid manure data. A new approach in this context is the application of a manure sensor based on near infrared spectroscopy. Dependent on gender, higher levels of lysine supplementation led to a lower feed intake, a better feed conversion, a shorter fattening period and a tendency to higher lean meat percentages in the carcass. The relationship of lysine intake and fattening traits can be depicted by the manure nitrogen and ammonium contents.

Keywords: fattening pigs, feeding control, manure sensor, NIR

Introduction

The objective in pig fattening is to produce carcasses with high lean meat levels, of a well defined quality, as efficiently as possible. The efficiency of production is essentially determined by the utilisation rates of the applied nutrients in accretion of body tissue, particularly with regard to protein. A process control technology for the feeding has to ensure an optimum in feed protein utilisation by the animal. The challenge is to anticipate at any time and under any circumstances the correct level of protein and energy supply, with respect to the actual state of the process. In this regard control loops for feeding have to be defined.

At the beginning of the pig fattening it is only roughly possible to estimate the nutritional demands for the entire fattening period. Temporal and environmental changes lead to alterations in metabolism and nutritional needs. Finding the right level of supply is confronted by a fundamental trade-off between overfeeding energy and specific nutrients and not fully utilising genetic growth potential. If the animals are oversupplied with protein beyond the level of utilisation, undesired environmental pollution in form of enhanced N- and NH_4-discharges increases. It also increases feed costs. On the other hand, if the animals are supplied insufficiently with protein and energy, the risk of losing valuable growth capacity is given. This is unwanted from an economic point of view.

The difficult task to identify parameters and measurable signals of the actual state of the system poses a challenge. Relevant data has to be recorded continuously with adequate sensors. Algorithms have to anticipate future developments in order to detect unwanted trends and to take corrective action prior to the appearance of undesired effects.

From a systemic point of view pig fattening is determined by several factors. Most of them are under limited control. One of the most important controllable factors affecting growth and body tissue properties is the feed (DLG, 1991). Even more than crude protein supply, the level of essential amino acids is a restricting factor - with lysine as the most limiting. To quantify input-utilisation-output, lysine seems suitable to systematically vary the utilisation and accretion of protein.

Nitrogen retention in the carcass in terms of protein accretion is determined by the amounts of essential and non-essential amino acids in the diet (Jackson, 1998). Excessive protein that is not utilised by the animal will be excreted via urine as urea. Changes in protein supply level and utilisation will mainly show up in different volumes of urine and altered contents of urea. Waterlow (1999) described a linear relationship between serum amino acid concentrations and rate of urea production. In manure, the urea will be converted very quickly to NH_3, where it is dissolved in an ammoniacal complex, dependent on pH and temperature. Since the nitrogen content of the faeces is quite constant, it has to be tested, whether the NH_4-N-concentration in relation to the total-N-concentration in manure is suitable as an indicator for the protein utilisation.

Materials and methods

The presented pig fattening experiment aims to provide data to analyse interrelationships of available and recordable parameters in practical pig fattening in order to develop an automated feeding control loop. For this purpose established sensors, as well as a new manure-sensor has been applied. After data collection, it is aimed to perform multivariate statistic tests, to find functional correlations that give indication on how to specificate a feeding control system for the pig fattening in future.

In this experiment different concentrations of lysine in feed rations have been used in a fattening trial. They were then analysed with reference to fattening performance and manure composition. While the influence of lysine in relation to nutrient utilisation and optimal growth is already well explored, the novelty of this approach is to include manure into the complete system analysis.

The animals were supplied with feed by a sensor controlled liquid-feeder (Bio-Feeder, HölscherandLeuschner/Germany). This system feeds the pigs according to their feed intake behaviour. The basic amount for each meal is derived from an age dependent feeding curve. While feeding, the emptying speed of the trough is monitored by trough sensors. With the aid of two electrodes in the trough, the electric resistance is measured. The more feed is extracted from the trough, the higher the resistance rises. This change is evaluated electronically with specific fuzzy logic algorithms. The program identifies and evaluates the feed intake behaviour within a specific time window after feeding start and calculates/batches upon this basic information the succeeding meal, which than is increased/decreased in 4% steps. These adaptations of the amount fed in each meal take place in a corridor of +/- 20% of the feeding curve. The actual feed intake was recorded for each meal.

Lysine was added to the basic ration of cereals and soybean meal with a micro-injector according to the specifications for each trial group. The growth processes and changes in the single animal live weight during fattening were monitored at regular intervals with an animal scale. A set of climate sensors (temperature, humidity) measured and collected on an hourly basis the climate data of the stable.

Manure data was measured with a new near infrared (NIR) manure sensor, developed at the Institute of Agricultural Process Engineering/University Kiel. The manure-NIR-Sensor is a flow-through measuring system, consisting of a diode-array spectrometer (Zeiss CORONA 45 NIR) with a range of 960 to 1690nm, a flow-through cell and a pump. The liquid manure sample (1l) flows through the measuring cell in a layer of 3mm between two glass plates (silicate) and is irradiated with near-infrared light. The measurement mode follows the principles of transflexion. For this purpose the cell is backed with a ceramic disc opposite the measuring head, along with the light source and the diode-array detector. The calibration of the recorded spectral data with reference data from the laboratory is performed with PCA (principal component analysis) and PLS (partial least squares regression). The manure-NIR-sensor was used in this project for measurements of DM, NH4-N and total-N in manure.

A total of 624 crossbred German Pig x Pietrain castrated males and gilts were stalled in conventional housing with slatted floors (Hölscher&Leuschner/Germany). The housing was compartmented into 48 pens for groups of 13 animals. Two pens were always connected by a double trough. The smallest observation unit was determined by the feeding valve and consists of 26

animals in a double pen. The animals were allotted into homogeneous groups according to age, weight and gender. The trial groups were randomly distributed over the stable. The fattening in the range of 35 to 110 kg live weight was divided in 5 observation periods of 3 weeks. Within the fattening periods (fp1 - fp5) the basic diet was kept constant, but it was decreased stepwise in crude protein from one period to the next. Within the fattening period, lysine was added in 4 levels to the basic ration. The 4 trial groups (tg) were defined as tg1 = lowest lysine supplementation up to tg4 = highest lysine supplementation (Table 1).
Three repeated observations for each trial group and gender were carried out. Each double pen was equipped with a manure collecting funnel.
The first of the 3-week fattening observation periods was used for adaptation. The following 2 weeks were used for manure collection and observations. After collecting and homogenizing the manure, 11 samples were taken and analyzed with the manure sensor. At the start and end of each fattening period the individual live weight of each animal was recorded.

Table1. Lysin levels.

	g/kg food (88 % dry substance)				
tg	fp1	fp2	fp3	fp4	fp5
1. low supplementation	9	8	7	6.5	5.5
2. middle supplementation	10	9	8	7.5	6.5
3. high supplementation	11	10	9	8.5	7.5
4. very high supplementation	12	11.5	11	10	8.5

Results and discussion

Data for the fattening trial are shown in Table 2, were the effects are given according to trial group and gender. As can be seen in Table 2, there are significant differences in levels of feed intake, feed utilisation and average daily gain between genders and between trial groups within gender. Only 4 fattening periods are considered in the results, because some pigs reached their final weight at the beginning of the fifth period and were slaughtered.
The feed intake was higher for barrows compared to gilts, averaging a difference of about 0.344 kg for the entire fattening from 35 to 110 kg live weight. Not considering the gender, the animals of the trial groups with the lowest lysine supply level (tg1) consumed on average 0.29 kg more feed than the ones with the highest lysine supply level (tg4).
Differences in the feed utilisation in terms of kg feed/kg weight gain can be observed between genders and the trial groups within genders. Averaging all the fattening periods, the barrows in tg 1 needed 2.84 kg/kg compared to 2.68 kg/kg for tg4. For the gilts the feed conversion was better than for the barrows and the differences from tg1 to tg4 were even higher, with 2.75 kg/kg for tg1 versus 2.48 kg/kg for tg4.
Over the entire fattening, the daily gain tends to increase with the increasing lysine supply level, but with differences between the genders. The males showed an average daily weight gain of 871 g, compared to the females with 810 g. The tg4 with highest lysine supply proved superior to tg1 with the lowest lysine supply, by the amount of 51 g.
Differences in the feed intake and the feed utilisation between the trial groups and genders are also reflected in fattening time, as well as in carcass traits. Fattening duration for tg1 was 128 days

Table 2. Fattening production traits for fattening period (fp1 to fp4) for males (m) and females (f), with tg = trial group (4 lysine supply levels), fi = feed intake (kg) fc = feed conversion (kg feed/kg gain), adg = average daily gain (g).

	Fattening period 1			Fattening period 2			Fattening period 3			Fattening period 4		
Tg	fi	fc	adg	fi	fc	adg	fi	fc	adg	fi	fc	adg
M												
1	1.84	2.14	862	2.36	2.59	916	2.66	2.89	922	2.58	3.72	697
2	1.83	2.39	775	2.42	2.47	979	2.73	2.80	976	2.56	3.55	753
3	1.82	2.21	827	2.40	2.52	957	2.71	2.87	949	2.66	3.76	715
4	1.71	2.03	844	2.33	2.36	991	2.67	2.71	987	2.58	3.61	720
F												
1	1.51	2.19	692	2.15	2.58	837	2.47	2.76	896	2.30	3.50	655
2	1.57	2.17	721	2.03	2.17	939	2.30	2.87	806	2.01	3.20	629
3	1.64	2.00	820	2.17	2.20	994	2.45	2.82	869	2.30	3.36	687
4	1.61	2.01	804	1.98	2.19	906	2.37	2.74	863	2.29	2.97	778

compared to tg4 with 123 days. Generally, across all trial groups the gilts needed more time to reach the growth target compared to the barrows. The lean meat percentage of tg4 averaged at 55.8 %, which is 0.5% higher than the lean meat percentage of tg1.

The differences in the feed intake and fattening performance are predominantly caused by the real lysine intake. Figure 1 shows the average daily gain as regression to the lysine intake. Overall, raising lysine intake and improved feed utilisation, the daily gain increases, but this effect is different for males and females.

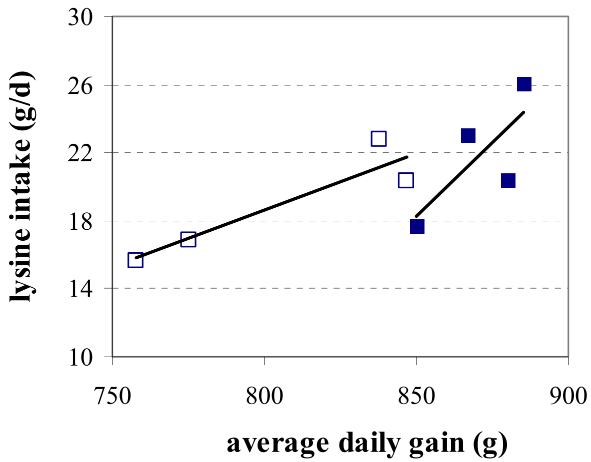

Figure 1. Regression of lysine intake (g/d) and average daily gain (g) for barrows and gilts.

Analysis of the climate recordings in the animal housing shows how the feed behaviour is influenced by temperature. The correlation between feed intake and averaged temperature is 0.3. Temporary colder phases result in temporary reduction of the feed intake. After a phase of acclimatization feed intake raises again. Towards the end of the fattening, the temperatures increased beyond the thermoneutral zone, due to seasonal changes. This resulted in a lasting reduction of feed intake.
N- and NH_4-N-concentration of the manure together with the lysine intake are shown in Figure 2. In all trial groups the trends of the N- and NH_4-N-concentrations follow with a little delay average daily lysine intake. The characteristics in the course of total-N-concentrations are not as clear as for the NH_4-N-concentration alone. For total-N-concentration there is some more variation in the data. The effects are not sufficiently analyzed yet: further experiments are needed.
As can be seen in Figure 3, the protein utilisation (g protein intake/kg weight gain) worsens continuously from the first to the fourth fattening period. Including the manure parameter NH_4-N-concentration, it can be seen that the protein utilisation of the trial group with the highest lysine intake is better compared to the one with lowest lysine level.
In Figure 4, the quotient of N- and NH_4-N- concentration is shown graphically. For the males it decreases continuously from the group with the lowest lysine supply level down to the group with the highest lysine supply level. It can be concluded that the male animals excreted more surplus N in the form of urea, NH_4N, in the manure. As a result of the improved protein utilisation, females excreted more in the form of nitrogen with increasing lysine supply level.

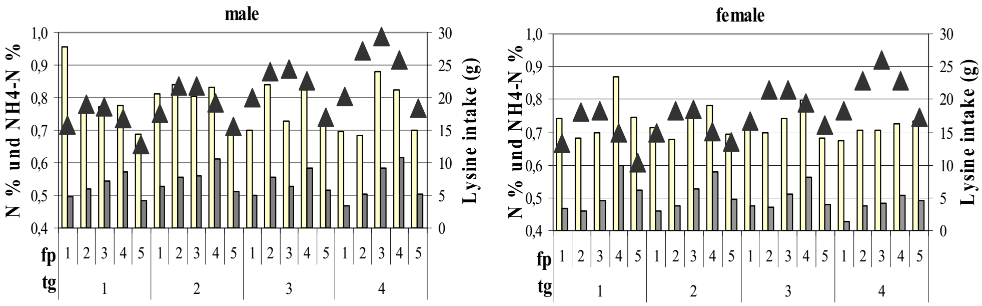

Figure 2. Lysine intake and N-,NH_4-concentration in manure. ▲ = Lysine intake (g); □ = % N in manure; ▮ = % NH_4-N in manure

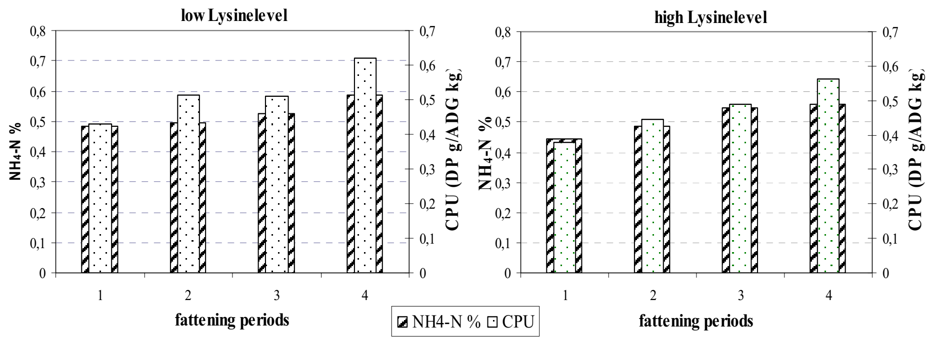

Figure 3. Relationship of crude protein utilisation (CPU) and NH_4-N-concentration for low and high diet lysine levels.

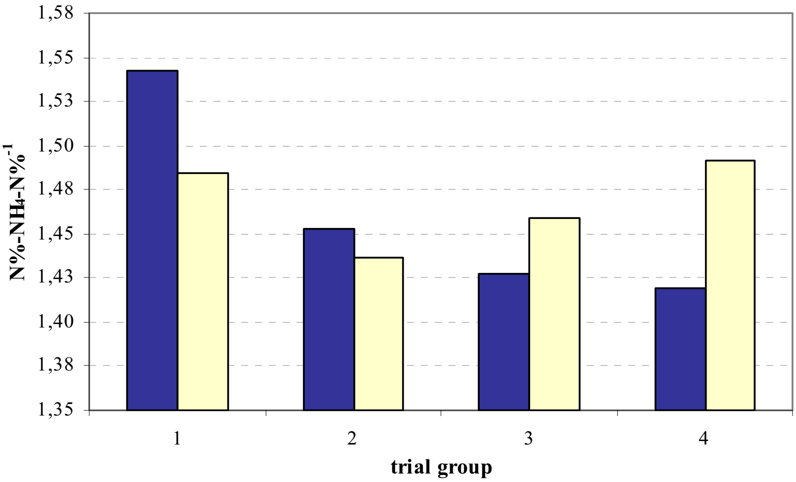

Figure 4. Quotient of N % - NH_4-N $^{-1}$ %. light = female pigs; dark = male pigs.

Conclusions

During the first fattening trial it was already possible to confirm known differences in fattening performance between the genders of the animals, not only with respect to performance, but also with respect to the manure. Feed intake and daily gains were higher for the barrows and the feed utilisation was, as expected, worse than for the gilts. With the variation of the lysine supply it is possible to induce modified rates of utilisation from protein, so that with such a model, exploration and analysis of a complex feed-system can be promoted.
The target of the work reported here was to establish the NIR-spectroscopy for the analysis of pig manure. It can be used for analysis of pig-manure in flowing condition. In relation to a conventional laboratory analysis it is possible to collect data on-line, in real-time mode and nearly unlimited in amount or numbers of samples. The calibration of the NIR-sensor can be continuously evaluated and improved with data from laboratory reference analysis. This makes it potentially possible to integrate the NIR-spectroscopy as an additional sensor in a complex control model in the future.

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Economic response of site-specific management practices on alfalfa production quantity and quality

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Abstract

This study has the objective of comparing and contrasting quantity, quality, and profitability of alfalfa with respect to various management practices under various soil types and examining the response of input and output price changes to returns. Yield and quality results were simulated using Integrated Farm System Model (IFSM) and a mathematical programming model that maximizes net returns was developed. The results indicate that the alfalfa management production practice with no irrigation performed the best. This study generates agronomic as well as economic data that shows the potential to facilitate efficient forage production in a farm system.

Keywords: alfalfa, yield, profitability, soil types, site-specific

Introduction

The economic importance of alfalfa, the United States' (U.S.) third largest crop that brings about 7.1 billion dollars each year (Putnam, 1998), is well known in the agricultural sector. The crop can be used for pasture, hay, silage, green-chop, pellets, and cubes. Its highest yield potential and highest feeding values of all adapted perennial forage legumes makes it a potential cash crop. In addition to its significant economic value and the critical role it plays in dairy and other livestock industries, alfalfa contributes significantly to broader societal goals, such as preservation of wildlife habitat and protection from erosion. It is well adapted to a wide range of soil and climatic conditions and the entire above-ground plant is harvested and used. Alfalfa, an important ingredient in most livestock feeding operations, has gained this prominence because it is high in both crude protein and energy.
Decreasing profits is one reason farmers are looking for ways to reduce their costs. Alfalfa growers make various management decisions that affect profitability, including site selection and preparation, seed variety selection, fertility program, insect and weed control, harvest method and timing, and target market and timing. Many of these management practices affect quantity, quality, price of alfalfa received, and production costs. Price often depends on quality, which in turn is affected by management practices as is quantity. In general, several production systems for alfalfa are interrelated in the production and profit components and affect both costs and returns. Therefore, knowledge of relationships between alfalfa, management practices, and soil types will assist farmers and extension personnel in developing and directing alfalfa production profitably.

Background

Alfalfa crop, one of the most important forage legumes grown in the U.S., has more than 100,000 ha grown in Kentucky (Henning el al., 2000). As livestock industry has been increasing since 1945, alfalfa production has increased only moderately while all other hay production has increased several-fold during this period (Hancock and Collins, 2000). One of the primary objectives of most alfalfa producers is to earn a profit. Many aspects of production and marketing combine to affect both total revenue and total costs. As such, optimum economic results are contingent on considering several factors, including cost of fertilizer and its application rates, cost of irrigation, and harvest costs. Costs of production play an important role as a supply shifter. When expected marginal revenue exceeds expected marginal costs, the stand should be maintained. However, when expected marginal revenue drops below expected marginal cost, one should consider taking it out of the production.

Quantity of alfalfa demanded is largely influenced by its price, prices of other livestock feed, the number of livestock that consumes alfalfa, and the price of various livestock products. The price received is dependent on the prevailing supply and demand conditions as well as time of year since there is a strong seasonal pattern to alfalfa prices. Alfalfa yield is dependent on many of the same factors affecting costs, including weather, an important uncontrollable factor. Alfalfa quality is interrelated with price because hay buyers are willing to pay higher prices for higher quality. Knowing the feed value of alfalfa aids in marketing because alfalfa hay is commonly marketed on the basis of its relative feed value (RFV). RFV has been widely used to ranking forage for sale, inventorying and allocating forage lots to animal groups according to their quality needs (Undersander and Moore, 2002). It is based on the concept of digestible dry matter (DM) intake relative to standard forage. The final index number of RFV is always compared to full-bloom alfalfa, which is considered to have a RFV of 100. While a lower RFV compared to full-bloom alfalfa is considered lower quality forage, a higher RFV generally has a higher monetary value.

A feed with high neutral detergent fiber (NDF) digestibility has a higher value of RFV. Lactating dairy cows will eat more DM and produce more milk when fed forages that have higher NDF digestibility. In contrast, the higher the percentage of NDF (i.e., low NDF digestibility), the less of the forage the animal will eat. Therefore, a low NDF is desirable. The benchmark for high producing dairy cow quality alfalfa is considered to be 20% crude protein (CP) and 40% NDF (Ward and Hutson, 2004). A typical CP content in alfalfa ranges from 10% to 28% of DM (Mader *et al*., 1998). NDF digestibility below 43% is considered as low and above 53% as high (Hoffman *et al*., 2003). Alfalfa growers need an integrated management approach for their alfalfa enterprise. While various studies have been done to evaluate yields, costs and benefits of alfalfa crop (Kanneganti *et al*., 1997; Leep *et al*., 2000; Rotz, 1996), well documented site-specific comparisons of quantity, quality, and profitability of alfalfa with regard to different management practices are lacking.

Objectives

1. To determine site-specific relationships in alfalfa yield and quality.
2. To compare and contrast the profitability of various alfalfa production management systems under various soil types.
3. To use sensitivity analysis to determine how input and product sale prices change the profitability of alfalfa production.

Materials and methods

An economic model with the objective function of maximizing net farm returns above selected relevant costs was developed using mathematical programming. The driven market price of alfalfa hay was based on its premium quality RFV. Alfalfa hay base prices normally vary with supply and demand, however, the market premium for quality has been chosen because it is fairly constant (Jeranyama and Garcia, 2004). RFV has been widely used for years to compare forage varieties, prices, and to assess forage quality. Decision variables included alfalfa production under various soil types (clay loam and loam each with deep and shallow top soils), management practices (variable rate irrigation and fertilizer, no irrigation, and uniform rates), alfalfa sales, and mean net returns. Constraints included limited land, labor, and relevant accounting equations.

The yield results of alfalfa DM, CP, total digestible nutrients (TDN), and NDF were simulated from the IFSM using 25 years of weather data. While agronomic field trials are preferred, such information that allows a series of production strategies under several similar weather data was not available. Relative Feed Quality (RFQ) was calculated from NDF and TDN obtained from simulation results and RFV was obtained from the relationship equation of RFQ versus RFV estimated by Undersander and Moore (2002). Price adjustment in relation to RFV levels was made and the factor was plugged into the price regression equation developed. An analysis to determine the sensitivity of the predicted results to assumptions regarding alfalfa hay and input price changes was conducted. Variable costs, including irrigation cost, were increased/decreased by 2%, 5%, and 10% of the production practices. Alfalfa hay sale price was also increased/decreased by the same percentage changes as variable cost.

Four alfalfa management practices were employed: 1) Variable rates that included variable rate potash and irrigation, 2) Variable rate potash only, no irrigation, 3) Uniform rates, and 4) No irrigation and no potash. Irrigation was included for two levels (low and high) as well as for no irrigation. The simulation model used four soil types (clay loam and loam each with deep and shallow top soils) and variable rate potash (73, 91, 109, and 118 kg/ha). Land for alfalfa crop production was limited to 40 ha for each soil type. As IFSM is not equipped with weather data for Kentucky, the nearest state weather data at Roanoke weather location in Virginia was used. The labor requirements per month, input prices, and input requirements per hectare were taken from the University of Tennessee (2004). The 2004 United States Department of Agriculture (USDA) average price for alfalfa was used (Getz *et al*., 2004). Input operating costs were adapted from O'Brien *et al*. (1998) assuming a 20 year useful life and no salvage value, 8% interest rate and 0.75% insurance rate.

Results and discussion

The alfalfa production practices were analyzed under a risk neutral scenario. The yield obtained is a reasonable estimate compared with the various yields estimated from other research studies. The results for the selected production strategies are presented in Table 1.

The farm that accommodated variable rate management practices provided a mean profit above selected variable costs of US$64,681 and a coefficient of variation (CV) of 32% compared to a uniform rate application management that provided a mean profit of US$67,790 and a CV of 28%. The estimated alfalfa yield was higher for variable rates by 0.27 ton/ha than for uniform rates practices. However, the mean of 80% of the profit maximizing level of uniform rate was higher than that of the variable rates (76%). The farm that practices a uniform rate has a lower CV and a

Table 1. Key economic indicators.

Particulars	Variable rates	V. rate Potash	Uniform rate	No irrigation
Average profit ($)	64,681	84,273	67,790	84,917
CV %	32	26	28	26
Min. profit ($)	29,983	30,362	33,510	31,007
Percent optimum (%)	76	99	80	100
Ave. yield (ton/ha)	12.03	10.4	11.76	10.4

higher average profit with accompanying higher minimum profit than the one with variable rates. These results display superiority of uniform rate management practice compared with variable rate management practice under these circumstances. It indicates that the higher average yield does not always display profit maximization.

When only variable rate potash (K) was used with no irrigation, the farm displayed a higher mean profit (US$84,273), higher percent of profit maximizing level (99%), and a lower CV (26%) than the other two farms (variable rate and uniform rate management practicing farms). Though the average yield for the farm with variable rate K was lower than the other two mentioned farms, the profitability was higher with a high profit maximizing level, indicating that using only K and no irrigation increases profitability. Again, this is an indication that maximum yield does not always lead to optimal profits. The no irrigation management practicing farm had the greatest average profits of all scenarios examined. This, in part, can be explained by the fact that Kentucky receives a lot of rain. The CV of 26% and an average yield of 10.4 tons/ha are similar with the farm practicing variable rate K. While the no irrigation farm has a greater chance of earning a lower minimum profit than a uniform rate farm, it has a greater chance of earning higher minimum profits than variable rate and uniform rate farms.

In considering the CP and NDF values (Table 2), the no irrigation and variable rate potash management practices emerged to have the best quality in relation to NDF. The lower the NDF percent the higher the quality and that is preferred because digestibility is higher. The analysis in this study indicates that the alfalfa management production practice with no irrigation performed the best compared with the other three farming management practices followed by farming practice with variable K. The fact that Kentucky receives a lot of rain throughout the year is an indication that most areas do not need irrigation water, and thus cutting the costs. The quantity of water usage did not have a great impact on the output level.

The sensitivity analysis was conducted by increasing/decreasing variable cost price and alfalfa sale price. Both input and output prices were increased by 2%, 5%, and 10%, and decreased by the same percentages of the production practices. In each case, the average profit in each management practice was positive. However, the no irrigation management practicing farm appeared to perform the best followed by variable rate K management practice (Figure 1 and 2). While the yield in each case remained unchanged as input and output prices were increased/decreased, CV and percentage optimum maximization levels changed with varied levels. In all price changes, the no irrigation management practice had the lowest CV and the highest percentage optimum maximization level followed by variable rate potash. When sensitivity analysis was performed for changes in irrigation cost using the same percentage changes as input and output prices, the average profit, CV, and percentage optimum maximization level remained unchanged. Even with changes in prices, all economic indicators showed positive results. This indicates that alfalfa crop is a promising enterprise and alfalfa farmers have a greater probability of earning profits if they will invest in this crop. However, they need to consider which management practice they should follow in respect to location, weather condition, and soil types. In general, the no irrigation displayed superiority for the profit maximization.

Table 2. Estimated average CP and NDF.

Particulars	Variable rates	V. rate Potash	Uniform rate	No irrigation
Average CP (%)	19	19	19	19
Average NDF (%)	49	46	49	46

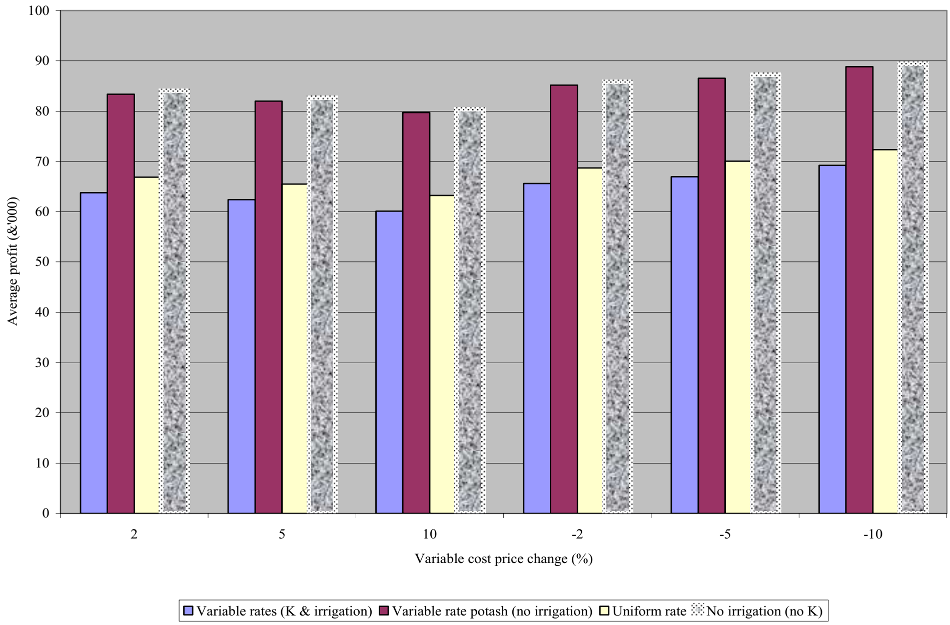

Figure 1. Average profit response to variable cost price change.

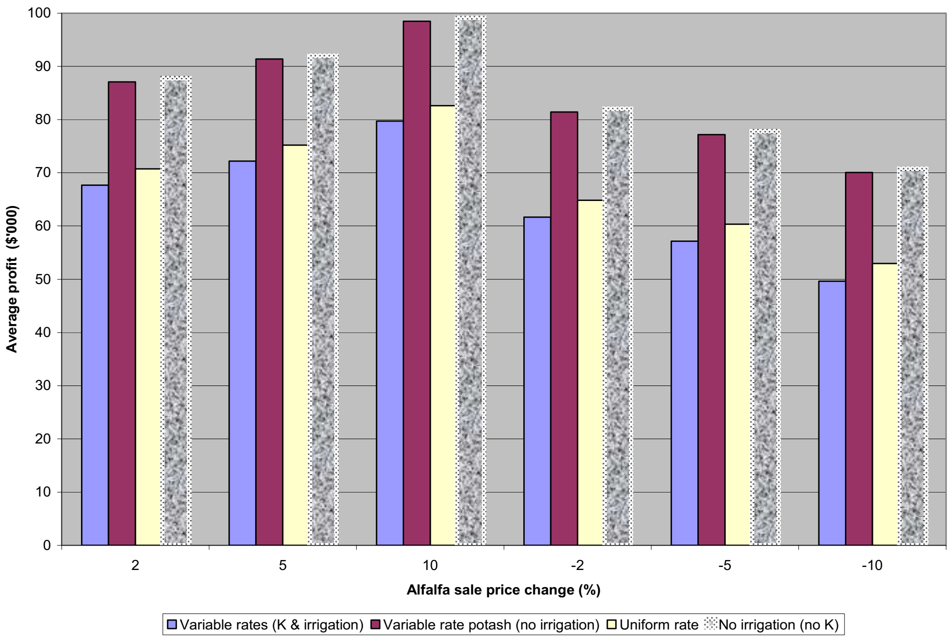

Figure 2. Average profit response to alfalfa sale price change.

Summary and conclusion

Alfalfa crop has the potential for cash market and for intensive grazing. It can be extremely profitable if special attention is given to important management factors. Soil types and management practices as well as variation in alfalfa quantity and quality are some of the factors that can affect net farm returns. This study analyzed profitability of management practices (variable rates, variable rate potash only, uniform rate, and no irrigation) under various soil types (clay loam and loam each with deep and shallow top soils). The yields of alfalfa were simulated from the IFSM using 25 years of weather data. While risk management has long been considered to be an important component of the agricultural producer's decision-making environment, this study used risk neutral management decision. Some risk sources such as fluctuation of yields, price changes, and risks of days unsuitable for fieldwork as a result of weather need to be considered and these are some limitations in this study that need to be considered in future research.

The study employed a mathematical programming model for profit maximization. The results of the analysis indicate that no irrigation management practice of alfalfa crop production is the optimal strategy for profit maximization. However, alfalfa farmers need to consider important factors such as activity location, weather condition, and soil types. In this regard soil testing before planting is very crucial. While variable rate application has the potential to improve profitability and yield, the no irrigation emerged to have higher profits followed by variable rate K management practice. The study had some other limitations. The use of IFSM did not demonstrate a greater impact to alfalfa yield on changes to irrigation water and fertilization levels. Soil mapping is another component that needs to be considered for future research. Depending on soil types and soil fertility level, liming, irrigation, and fertilization (especially phosphorus, potash, and boron) may increase plant population, yield, and quality of alfalfa. Higher alfalfa quality is directly related to increasing profitability because buyers are willing to pay for.

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Image analysis to assess livestock composition

Automatic determination of body condition score of cows based on 2D images

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Abstract

A camera-based method was developed to determine the body condition score (BCS) value of individual cows in an automatic way. Seventy five back-view images of dairy cows (Holstein) were used in developing the algorithm for automatic body condition scoring. The BCS of each new test cow was predicted by comparing the contour of the cow with the contours of the set of reference cows, whose BCS was evaluated by experts. The results are promising because the error of the prediction of the BCS with the camera-based method is on average of the same order of magnitude as the error of the human experts (0.27 vs. 0.25). In this way, automatic monitoring of the BCS of dairy cows, as a part of a precision livestock farming system, might become realistic in practice in the future.

Keywords: body condition score, cow, image analysis, milk production, automatic monitoring

Introduction

Scoring the body condition of individual milking cows is very important for the stockman because it has been demonstrated that the body condition score (BCS) of the animals is correlated, among other things, with important production characteristics such as milk production, fertility, health, etc. (Wildman *et al*., 1982; Pryce *et al*., 2001). In practice, BCS is mostly determined visually (and manually) by experts. As a consequence, body condition scoring is expensive, prone to subjectivity and cannot be performed on a regular basis. Therefore, there is a need to develop methods to monitor the BCS of individual cows in an automatic, more objective, cost effective and a quasi on-line way. One way to do so is by using (cheap) cameras in combination with image analysis techniques. The advantages of such approach are that it does not make contact with the animal, the information in images is very rich and it causes no additional stress (Bloemen *et al*., 1997). The use of image analysis in animal production processes has been demonstrated in several applications reported in the literature for e.g. pigs (Vanderstuyft *et al*., 1991; Schofield *et al*., 1999) and chickens (Chedad *et al*., 2003; De Wet *et al*., 2003; Leroy *et al*., 2003).
The objective of this work was to develop a camera-based system to determine the BCS of individual cows based on 2D images in an automatic way. Such a system could be the basis for a precision livestock farming system.

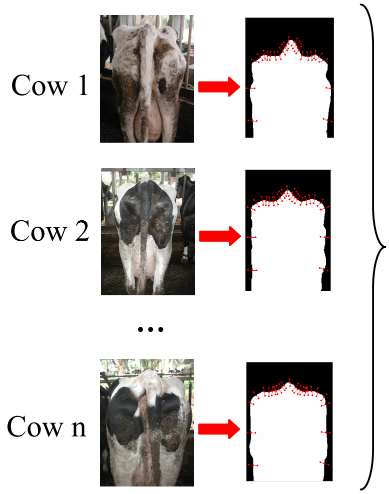
Materials and methods

The animals used were 36 dairy cows (Holstein), housed in the test facilities of the Volcani Center, Israel and were fed a mixed ration of 1.77 Mcal/kg dry feed containing 17% crude protein (as prescribed by the NRC). This ration was administered once a day at 10h30. The cows were milked three times per day at 04h30, 12h30 and 20h30 respectively. 75 back-view images of the cows were

used developing the algorithm for automatic body condition scoring. The images were taken with a digital camera (Nikon E990) once in a week during a period ranging between December 2003 and April 2004. The distance between the camera and the cow was between 1.50m and 2m so that images contained the complete silhouette from legs to tail. Every time an image was taken, a human expert also determined the BCS of these cows using a scoring scale from 1 (very lean) to 5 (very fat) with intervals of 0.25 units.
In order to determine the BCS by using image analysis different steps were made. In the following, each step is described in more detail.

Step 1. Determination of the contour of the back view

Starting from a digital image of the back view of a cow, a binary image was created (background has a pixel value of 0 and the cow has a pixel value of 255) in order to extract the cow from the image. Next, the two-dimensional (2D) xy-co-ordinates of a set of points on the contour were determined (cf. Figure 1). These contour points were taken at consistent locations for all images, corresponding to clear visual features (tail, hips, etc...) and points at equal distances in between. Different numbers of contour points were tried to describe the contour (Eeman, 2003). The presented results in this paper are based on contours of 19 predefined points. In order to compare the contour points of different cows with each other, all the contours had to be transformed to the same reference system by translation, rotation and scaling because 1) not all the images were taken from the same distance, 2) there were differences in postures and 3) there were differences in sizes between the different cows.



$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \\ y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \\ BCS_1 & BCS_2 & \cdots & BCS_n \end{bmatrix} = \begin{bmatrix} Z_{xy} \\ Z_{BCS} \end{bmatrix} = Z$$

data matrix

$$Z \rightarrow \underset{\text{covariance matrix}}{Cov(Z)} \rightarrow \underset{\text{eigenvector matrix}}{V}$$

Figure 1. Construction of the matrix with eigenvectors V based on the data matrix Z with contour and BCS data of a set of reference cows. x_{ij} and y_{ij} are the x-and y-co-ordinates respectively of the i-th contour point of the j-th cow.

Step 2. Construction of an eigenvector matrix

A data matrix (Z) with contour information (xy-co-ordinates of 19 contour points) and BCS values of a set of 39 reference cows was made. By applying principal component analysis, the matrix of eigenvectors V was determined based on the Z matrix (cf. Figure 1).

Step 3. Prediction of the BCS of a test cow

The BCS of each new test cow was predicted by comparing the contour of the cow with the contours of the set of reference cows with known BCS in two steps (Eeman, 2003). First, the contour of the test cow was quantified based on a 2D image of the back-view (cf. Figure 2).

Next, it was assumed that for every cow the vector K_{xy}, containing the measured contour information and the unknown BCS value, could be written as the sum of the average cow of the reference set and a linear combination of the eigenvectors of the matrix V (cf. Eq. 1).

$$K = \begin{bmatrix} K_{xy} \\ K_{BCS} \end{bmatrix} = \begin{bmatrix} x_{1K} \\ x_{2K} \\ \dots \\ x_{mK} \\ y_{1K} \\ y_{2K} \\ \dots \\ y_{mK} \\ BCS_K \end{bmatrix} = \begin{bmatrix} \overline{x}_1 \\ \overline{x}_2 \\ \dots \\ \overline{x}_m \\ \overline{y}_1 \\ \overline{y}_2 \\ \dots \\ \overline{y}_m \\ B\overline{C}S \end{bmatrix} + \begin{bmatrix} dx_{11} \\ dx_{21} \\ \dots \\ dx_{m1} \\ dy_{11} \\ dy_{21} \\ \dots \\ dy_{m1} \\ dBCS_1 \end{bmatrix} p_1 + \begin{bmatrix} dx_{12} \\ dx_{22} \\ \dots \\ dx_{m2} \\ dy_{12} \\ dy_{22} \\ \dots \\ dy_{m2} \\ dBCS_2 \end{bmatrix} p_2 + \dots + \begin{bmatrix} dx_{1r} \\ dx_{2r} \\ \dots \\ dx_{mr} \\ dy_{1r} \\ dy_{2r} \\ \dots \\ dy_{mr} \\ dBCS_r \end{bmatrix} p_r = \overline{Z} + V.X \qquad (1)$$

where x_{iK} and y_{iK} are the i-th x- and y-co-ordinate respectively of cow K; and are average values of x- and y-coordinates respectively; p_j are coefficients.

$$K_{xy} = \begin{bmatrix} x_{1K} \\ x_{2K} \\ \dots \\ x_{mK} \\ y_{1K} \\ y_{2K} \\ \dots \\ y_{mK} \end{bmatrix}$$

Figure 2. Quantification of the contour of a test cow K based on a 2D back-view resulting in the vector K_{xy}.

Equation (1) can also be written as:

$$K_{xy} = \bar{Z}_{xy} + V_{xy}.X \tag{2}$$

$$K_{BCS} = \bar{Z}_{BCS} + V_{BCS}.X \tag{3}$$

The vector with the model parameters X was determined based on eq. (2) by applying the least squares method. The unknown BCS value for each test cow was then predicted by applying Eq. (3).

Results and discussion

The developed method was tested on a test set of images of 32 cows with a BCS, determined by human experts and ranging between 2.25 and 3.50 on a BCS-scale from 1 to 5. The deviation between the BCS values determined by the camera-based method and the human expert was on average 0.27 (absolute deviations ranged from 0.01 to 0.74). The error of two human experts scoring the same cow was in the order of magnitude of 0.25 scale units. An overview of the test results is shown in Table 1.

The first results are promising, since the error of the camera-based system is of the same order of magnitude as the human expert. The advantage of the newly developed system is that it should allow quantification of the BCS in an automatic way and regularly in time without causing additional stress to the animals. One way to implement such a system is to use it on an automatic milking robot, because the robot is visited several times per day by each cow and the cows are standing in a more or less fixed position.

Table 1. Comparison of the BCS values determined by the human expert and by the newly developed camera-based method on a set of 32 cows.

Cow number	BCS by expert	BCS by camera	Absolute deviation	Cow number	BCS by expert	BCS by camera	Absolute deviation
1943	3.50	2.76	0.74	2395	2.75	2.64	0.11
1971	2.75	2.74	0.01	2404	2.75	2.71	0.04
2240	2.50	2.75	0.25	2407	2.25	2.64	0.39
2278	2.50	2.82	0.32	2427	2.50	2.59	0.09
2279	2.50	2.72	0.22	2428	2.50	2.82	0.32
2285	3.00	2.70	0.30	2483	2.50	2.77	0.27
2288	2.50	2.76	0.26	2490	2.75	2.87	0.12
2291	2.75	2.73	0.02	2497	3.50	2.82	0.68
2332	2.25	2.60	0.35	2502	2.25	2.60	0.35
2341	2.75	2.74	0.01	2504	2.75	2.71	0.04
2361	2.25	2.72	0.47	2506	3.25	2.77	0.48
2366	2.75	2.84	0.09	2507	2.75	2.68	0.07
2373	2.50	2.64	0.14	2515	3.25	2.77	0.48
2374	3.25	2.81	0.44	267	2.75	2.76	0.01
2377	2.50	2.86	0.36	275	2.75	2.65	0.10
2391	2.25	2.74	0.49	282	3.25	2.70	0.55
							$\bar{x}$ = 0.27

However, future actions should be undertaken in order to improve the system. A first improvement can be expected in the definition of the contour points. In this research 19 contour points have been used, but the number as well as the position of the individual contour points could be optimised further. A second improvement can be made in the development of the matrix V with eigenvectors by using reference cows with larger variations in BCS values between the different reference cows (ideally ranging over the whole BCS scale from 1 to 5).

Conclusions

A camera-based method was developed to determine the BCS value of individual cows in an automatic way. The results, although preliminary, are promising because the error of the prediction of the BCS with the camera-based method is on average of the same order of magnitude as the error of the human experts employed. Important advantages of the newly developed method compared to the determination by the human expert are that it is more objective, it can be performed in an automatic way and this on a regular basis. In this way, automatic and reliable monitoring of the BCS of dairy cows, as a part of a precision livestock farming system, might become realistic in practice in the future.

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Monitoring live pig weight with a mobile imaging system

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Abstract

Pig husbandry today has to be very efficient to manage the economic demands of finishing pigs. It is important for the farmer to optimize breeding and weight at slaughter in order to reach the weight interval for best payment and delivery increment at the slaughterhouse. To achieve the best economic production, feed consumption, death rate, and time to slaughter have to be minimized. The growth of the herd has to be monitored so that the farmer can control the feeding to reach optimum carcass weight and classification of meat percentage at the slaughterhouse. Ideally, the weight of the pig should be registered daily. Today, it is not possible to complete ordinary weighing daily as it is one of the most stressful, unhealthy, heavy and time demanding elements within pig husbandry.

This paper presents the development of a mobile imaging system for live pig weight estimation in production conditions. The purpose of this project is to investigate if an optical weight estimator can be developed to estimate the individual weight of pigs in the same pen from images containing more than one pig. The optical weight estimator is designed to work in a production environment where transponder feeding is not available. Compared to similar studies, this study concentrates on conditions where several pigs are fed from the same feeding trough at set times, thus a mobile system was used. The adaptability of this mobile system makes it possible to use it in different stable environments.

The optical weight estimator is attached to a carrier and the pigs are monitored during feeding. From the weighing system, pig growth, desired slaughter weight and shape information, as means to assistance in the estimation of meat percentage, can be approximated per pen. To be able to identify pigs ready for slaughter, the farmer has to be present to mark individual pigs that have reached the desired weight. The time for weighing pigs with the optical weight estimator is reduced by approximately 5 hours, from roughly 6 hours to 1 hour for 400 pigs. The relation between area and weight for pigs between 20 and 120 kg was similar to results presented in the literature (r^2=0.97).

Keywords: image analysis, live pig weight estimation, segmentation, shape information

Introduction

To weigh animals without disturbing or moving them is very advantageous. A weighing system based on image analysis reduces the labor demands on the farmer and is less stressful for the pigs. Several research papers on image analysis of pigs and the relation of weight to pig back area have been presented over the years and a selection of them are presented here. Schofield (1990) presented one of the first papers that automatically segmented pigs in images and related the segmented areas to pig weight. He managed to estimate the weight to within ±5% of the actual weight under interactive control. Tillet (1991) presented a model-based algorithm, more suitable for unstructured scenes to locate pigs in images. Another early paper was presented by Minagawa and Ichikawa (1992) who showed a close exponential relationship (r^2=99.9%) between mean central projective image area from above and pig weight.

In an attempt to find the outline of pigs in more complex scenes, Marchant and Schofield (1992) introduced their own version of the snake algorithm first presented by Kass *et al*. (1988). Brandl and Joergensen (1996) covered a higher weight range and included a larger number of pigs than previous studies in their attempts to determine live weight of pigs from image analysis. In their research, Brandl and Joergensen, also identified problems with replication. Panagakis *et al*. (2000) repeated the experiment from Schofield (1990), but with a different image analysis algorithm and for smaller pigs. Similar results were reached. In 1999, Schofield *et al*. presented the first prototype imaging system for production conditions.

In order to find information on pig shape, structured light has also been studied. Van der Stuyft *et al*. (1990) produced topographic exterior shape maps of pigs under experimental conditions and Pettersson (1997) used structured light to estimate pig weight and meat percentage. A recent study using stereo images for capturing pig 3D shape has been successfully developed for research purposes under controlled conditions in order to produce a database of pigs showing shape variations in age, weight, diet and posture (Wu *et al*., 2004).

Many of the above mentioned research projects are based on experimental settings or in loose-housed pig production systems with one single-spaced feed or drinking station in each pen. Camera and lighting are positioned at the feed station where the animal is standing in a rather fixed position relative to the camera.

This paper presents the development of a mobile imaging system for live pig weight estimation under production conditions where individual pigs, in the same pen, can be estimated from images with several pigs. Our system does not require the animals to be in a loose-housed system. Rather, it is designed to work in a production environment where transponder feeding is not available. The pig's weight is estimated during feeding from the same trough at regular intervals, each pen containing approximately ten pigs. The mobility of the system makes it possible to cover all pens in one stable during feeding and makes it very adaptable to use in different stable environments.

Materials and methods

This project was carried out in collaboration with AB Svenska Mätanalys on two experimental farms, of which results are presented from one of the farms due to the larger experimental setting on this farm. In this study, 425 pigs between 20 and 120 kg were studied in a stable with long trough system (wet fed) with 10 animals in each pen. The breed of the animals was YL x Duroc.

Equipment

The idea behind this project was to create a system realistic for non loose-housed production conditions. The camera selected for the project was a compact b/w camera with IEEE-1394 and VGA 656x494 resolution. The camera is equipped with a high sensitivity 1/2" type progressive CCD-array. The camera has frame rates up to 74 frames per seconds and is equipped with a 6.5 mm lens with manual iris.

When moving around in the stable, lighting conditions at the floor level fluctuates with changing distances to the windows and time of the day and year. These conditions are further accentuated in the north when the sun occasionally has a low angle to the horizon. To ensure even light conditions, an external light source is necessary. Several light sources have been tested and a fluorescent tube with high frequency power was chosen. This light provides several advantages: even light distribution over the pigs, a lower light temperature and the high frequency means no interference with the camera system.

Weighing

The mobile image system for live pig weight estimates (containing batteries, lighting, camera, and computer) is placed on a carrier. The pigs are monitored during feeding when they are standing and lined up along the feed trough. The camera and light is positioned over the backs of the eating pigs to acquire images from above. A display on the computer shows when a pig is in an optimal position to estimate its weight from the image and the farmer can decide if this pig is to be measured or not. As a reference, the pigs were weighed with a standard pig scale as well in connection to every weight estimate.
During weighing, the carrier moves around the stable and follows the feeding machine. When a pig to be weighed is located in the center of the image, the farmer selects the image for analysis by pressing a button. The weight is then displayed in a table next to the resulting image. If the pig has reached the desired weight, the farmer can mark the pig immediately with a can of paint. Statistics from the readings are saved in a database, which can be analyzed in the management system of the farm. Since the production system does not use a transponder system, statistics on an individual level are not available at the moment, but can be calculated for each pen.
During normal feeding conditions it only takes a few seconds to feed one pen. For the farmer to be able to keep up with the feeder when using the optical weight estimator a small delay of about 20 seconds per pen has to be applied to the feeding system. This delay allows for the person doing the weighing to have enough time to consider the results. The weight is calculated on the back area disregarding head and tail as suggested by Schofield (1990).

Management system

To suit various stable environments and uses, two different carriers have been tested, a one cart system (Figure 1a) and a one rail system (Figure 1b). Both systems run during feeding when the pigs are eating and standing side by side. The rail system is intended for a future, completely automatic weighing system.
An industrial computer with 2.8 GHz processor and 512 MB RAM was used. A 12.1" touch screen with front panel protection that meets IP 65 was also utilised. The image analysis software was developed by National Instruments LabVIEW 7.1 software with LabVIEW vision development module. The developed software is shown in Figure 2, where an example of the display of the operating system is given. The system keeps track of the pen number so the farmer only has to concentrate on the weighing. A laser dot helps the farmer to identify the pig to be analysed. When

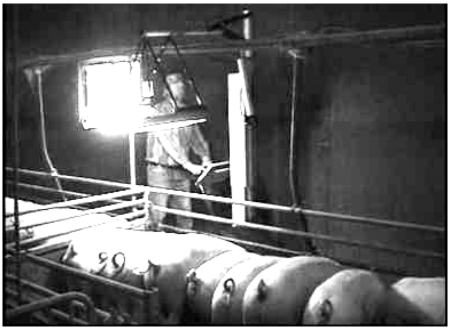
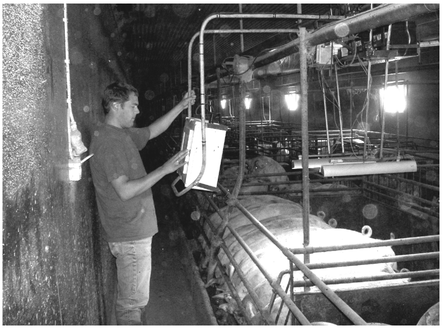
a)  b) 

Figure 1. a) The mobile image weight system is pushed in the inspection walk during feeding. b) As an alternative, rails in the ceiling can carry the system where an arm carrying the display is extended to the inspection walk.

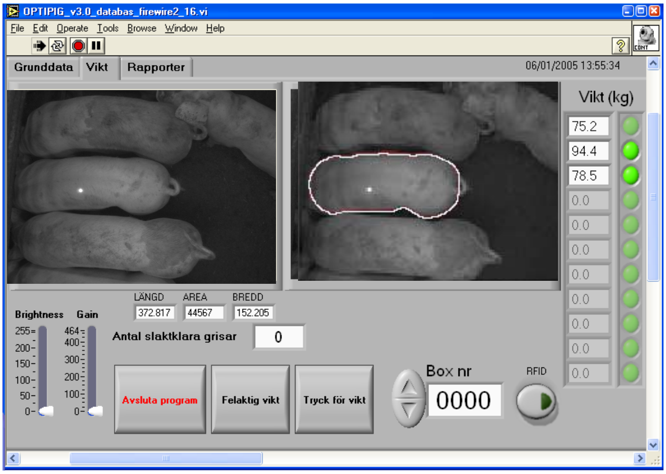


Figure 2. The weight estimating software. On the left, a video image is visible. When the laser dot aims at the pig to be weighed, the farmer presses one of the buttons on the touch screen. The results are shown both as a picture and number.

the dot aims at the pig to be measured, the farmer presses a button on the touch screen. The result is shown both visually and as a numerical value. A red lamp indicates if the pig exceeds the desired slaughter limit.

The image analysis system automatically extracts the contour of the pig and excludes its head from further processing. To calculate weight, a linear regression equation between the area of the pig and weight is used. If the pig has reached target weight, the farmer can quickly mark the pig as he passes. All weight measurements, together with pen-id, farm-id, stable-id, and date and time since the installation of the system are saved in a database, which can provide statistics on pig growth per pen. A RFID-system has been used to keep track of the pens.

Image analysis

From the graylevel images acquired by the camera, gradient information is used to identify possible pig segments. The object most central in the image is selected and investigated further. A check of the selected segment is made to establish whether it is a pig, part of a pig or if it contains more than one pig. If it contains more than one pig a simple separation through erosion is attempted. If this is not sufficient a more complex separation procedure is carried out.

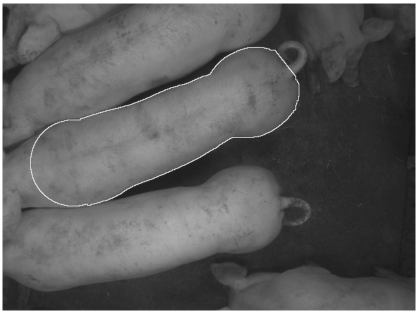
When the object most central in the image is located and considered to be one pig or part of a pig, this segment is considered as an initial region to find the real outline of the pig. Gradient information on or in the vicinity of the initial region is investigated and added to the segment if considered useful in identifying the original pig shape. For further processing to be made on the resulting pig segment, different shape criteria must be reached. Otherwise, the result is disregarded and no weight estimation made.

The next step is to remove the pig head and tail from the segment if necessary. Since the pigs are eating during the imaging process, their heads are held down most of the time. In such cases only an adjustment of the shoulder-line has to be made. The removal of the head or adjustments of the shoulder-line are made according to the widest point of the shoulder. A circle with the same diameter as the shoulder constitutes the front-end point of the pig.

Depending on the position of the pig's tail, the tail may either cause a cavity or protuberance at the back end of the pig. If the tail is held above the back it causes a cavity which has to be filled out. If the tail is directed from the pig back it causes a protuberance which has to be removed.
The position of the tail can be easily identified and this information is then used to make the correct adjustments. When the desired outline of the pig is segmented, the resulting area is then used to calculate the pig weight.

Results and discussion

Pushing the cart at the speed of the feeding machine, with only a small delay between pens, makes it possible to weigh more than 400 pigs per hour. If the correct plan view has been detected, further calculations can be made on pig shape (see Figure 3), however this is not considered in this paper. Preliminary results from the weight estimate have a r^2=0.97 for pigs between 20 and 120 kg, see Figure 4.
Confidence intervals for three predicted weights are for 28 kg (± 1.5), for 85 kg (± 0.6) and for 120 kg (± 1.0). The farmer has the ability to monitor the results in real-time.

a) 

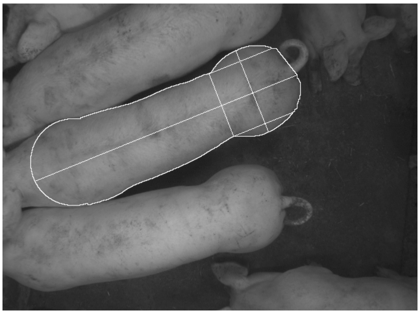
b) 

Figure 3. a) The area of the pig back from above is extracted excluding the pig head and tail from further calculations. b) information about the pig shape can be extracted from the outline.

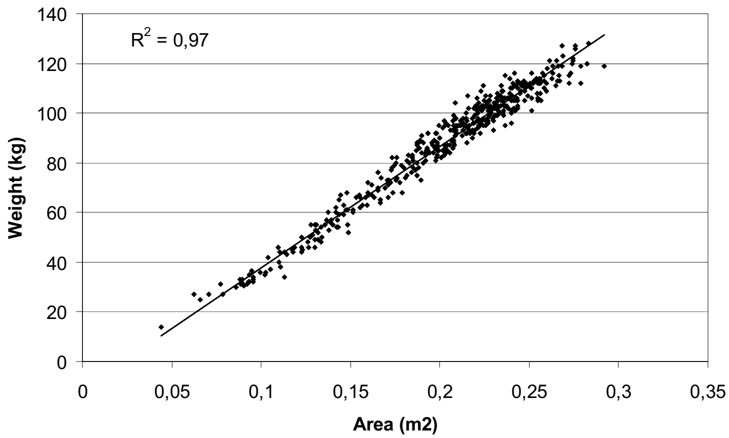
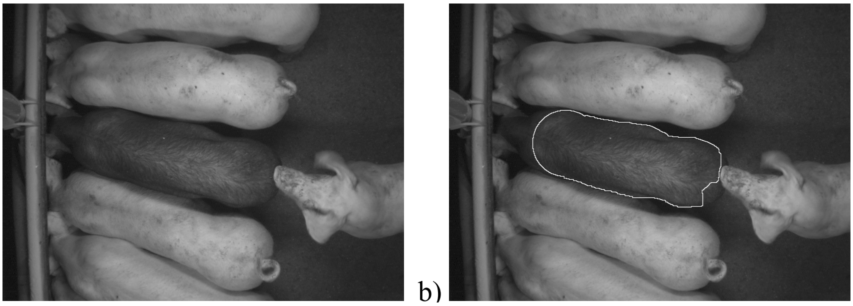


Figure 4. Relationship between pig area (m^2) and manual pig weight (kg).



a) b)

Figure 5. a) Original image, b) attempts to segment a dark pig.

The method has been tested in stables with (although not presented in this paper) and without straw and on pigs with or without dark spots. Some of the pigs in the study were completely dark. The straw conditions do not affect the method at all while the colour of the pig can cause problems. However, given that the farmer has enough time for each pig, both two coloured pigs and dark pigs can be correctly segmented. In Figure 5, an example of an almost correctly segmented dark pig is shown. No parameters are changed in the image analysis system during weighing.

Conclusions

This study shows that it is possible to estimate pig weights using image analysis under the production conditions presented here. The results indicate that this method produces weight estimate in the vicinity of what has been presented in earlier studies made. Further information about the configuration of the pig can be reached if shape information is extracted from the segment. This is not considered in this study, but is interesting to look deeper into.

Acknowledgements

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Improving the accuracy of automatic broiler weighing by image analysis

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Abstract

Flock managers of broilers need on-line information on their weight, uniformity and growth in order to evaluate feed conversion efficiency, occurrence of disease problems and animal welfare. Determining broiler body weight in a continuous manner is done today by one or more portable platform balances in the broiler house. However, the accuracy of the measurements from commercial available balances is still doubtful, especially at the end of the growing period. It was found from literature and field data that heavier broilers visited automatic weighing platforms less frequently at the end of the production cycle, resulting in a systematic under estimation of the average body weight.

The objective of the study presented here was to provide a method that allows improved estimation of the average body weight of a group of broilers by combining automatic weighing platforms with image analysis.

The new system consists of a camera mounted above a weighing platform, providing a top view of animals on and around the weighing platform in an area of about 2.3 m by 2.3 m. The top view images of the birds are used to correct for the bias of results from the weighing platform. The relation between the actual weight and the area of the birds is used to estimate the body weight of all animals within the frame of the camera.

In an experiment over three fattening periods in three different experimental broiler houses, the new method was evaluated against manual weightings every week as a reference. From this analysis it was concluded that the combination of image analysis and automatic weighing provided a better estimate of the actual average body weight of the animals (5% error at the last day of the fattening period) compared to the readings of the automatic weighing only (14.1% error).

Keywords: bird weighing, weighing platform, image analysis, broilers

Introduction

In broiler production, on-line information about weight, uniformity and growth of the birds is needed for the evaluation of feed conversion efficiency, occurrence of disease problems and animal activity. An accurate estimation of average weight and the range of weight distribution throughout the flock can also be of valuable assistance to schedule broiler pick-up and slaughter (Ross and Davis, 1990). In practice, the average weight of the flock is estimated by manual weighing a random sample of birds or, in the best-equipped poultry houses, by automatic weighing. Automatic weighing involves introducing one or more platforms into the broiler house that are connected to a data analysis unit. Feighner *et al*., (1986) reported that the implementation of a computerised weighing system has resulted in a substantial reduction in the amount of time (60 to 65%) necessary for data acquisition and analysis compared to manual weighing.

Some researchers obtained poor agreement between automatic and manual mean weighing. Newberry *et al*. (1985) and Blokhuis *et al*. (1988) found that the average body weights estimated by automatic weighing were lower than the average weights estimated by manual weighing. This

difference was higher in the fifth week compared to week three. Different flocks show somewhat different deviations, varying between 1.5 and 5.5%. Klein Wolterink and Meijerhof (1989) reported that such a weighing system works well with broilers at a young age but in the period of the finishing phase the platforms are visited less frequently.
Although these systems give indications about the relative path of the growth trajectory of the flock, is was concluded by Blokhuis *et al*. (1988) that the measurements still seem doubtful, especially at the end of the growing period.
In our previous studies, the hypothesis was confirmed that heavier chickens visit automatic weighing systems less frequent at the end of the production period, thus generating an error up to 30% in the calculated average final weight (Chedad *et al*., 2000; 2003).
The general purpose of the study presented here was to provide a method to reduce the error in the average body weight assessment to maximal five percent at the end of the fattening period.

Material and methods

The experiments were performed in 3 broiler houses on 3 different locations. At every location, a CCD monochrome camera (Hitachi, KP-M1E/K) was mounted on a metallic frame at a distance of 0.9 m above the floor and was connected to a video recorder (Figure 1). The distance to the floor was similar in the different experiments in order to be able to compare the images of different experiments. It was possible from this height to observe the animals on a surface area of 2.3 m × 2.3 m. The camera was positioned in such a way that the platform was located in the middle of the image. The camera was equipped with a telephoto lens (Cosmicar, focal length of 4.8 mm) to allow the desired area of view to be captured. The measured data from the weighing system were stored on a PC.
Broiler house (I) was illuminated with commonly used TL-lamps (Philips 36 W) and produced an average intensity of 94 lx at the level of the birds (measured at 6 random places in the broiler house). This illumination resulted in a good quality (high contrast) of the recorded images. Besides the good illumination, the floor was covered with chopped straw, which improved the contrast between the animal and the background. The broiler house had a dimension of 11.6 m × 16.2 m with a total of 2900 birds at a stocking density of 16 birds/m^2 (Ross, mixed sex). A commercial weighing platform (Fancom 747) was placed between the feeding and drinking lines in the middle of the house. Food and water were supplied *ad libitum*. Two hundred broilers were manually weighed weekly as a reference. The birds were weighed between 09:00 and 11:00 h a.m.
Broiler house (II) was set to an illumination of 5 lx. This illumination was too weak to extract relevant information from the images. An extra light source (Philips 350 W) was mounted at a height of 2.3 m above the floor and produced a light intensity of 74 lx in the neighbourhood of the platform. The broiler house had a dimension of 15 m × 10 m and was divided into four equal pens with a total of 1500 birds at a stocking density of 20 birds/ m^2 (Ross, mixed sex). In each pen, an automatic weighing system was placed between the feeder- and drink station. The imaging system was placed above one of those platforms. Once a week a sample of 50 animals was taken and weighed manually.
Finally, broiler house (III) was set to an illumination of 99 lx, which produced images of a good quality. The broiler house contained eight small pens with 50 birds each. The birds were kept on wood shavings and occupied 1.5 m × 2.15 m. It was possible to keep 16 animals per m^2. An imaging system was set in one of the eight pens. All animals were manually weighed weekly at 9:00 h a.m.
A conventional lighting schedule 23 h of light and 1 h of darkness was used for broiler house (I) and (III). An alternative lighting schedule was used for broiler house (II). The light intensities were scheduled as follows: d 0-d 1, 20 lx; d 2-d 9, 15 lx; d 10-d 35, 5 lx; d 36-d 37, 7 lx; d 38- d 42, 10 lx. The experiment was designed by the Provincial Service for Agriculture and Horticulture of

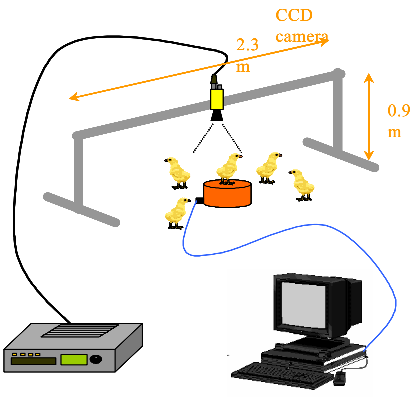

Figure 1. Schematic representation of experimental setup.

Antwerp (Belgium) in order to investigate the production results under different light intensities. In the three houses, the same temperature schedule was followed. Mean air temperature was 30 °C during the first three days. From day 3 on, temperature was set at 28 °C to decrease with 1 degree every three days until the constant temperature of 21 °C was reached at 21 d for the three broiler houses.

In all broiler houses the automatic weighing system consisted of standing platforms with a diameter of 0.34 m connected with a weighing computer (Fancom 747).

Each time a broiler visited the weighing system, the animal was automatically weighed and an image of the animal was collected from which the area of the animal was determined, according to the method described by De Wet *et al*. (2003) and Chedad *et al*. (2003). For each image taken the following steps were made: (i) detect individual birds in the image, (ii) identify the position of each individual bird (on the weighing platform or in the neighbourhood of the weighing platform) and (iii) calculate the visible area of the individual birds (number of image pixels).

To reduce the amount of video data each day, the imaging system recorded 25 images per second at eight different time instants during 10 minutes starting at 09:00, 11:00, 13:00, 15:00, 17:00, 19:00, 21:00 and 23:00. The images were stored on VHS video tape (E 240, Sony) and were digitised on a 486DX/40 PC fitted with a frame grabber (Matrox, PIP-1024B) capable of capturing a 256 × 256 pixel image. Per time instant of 10 minutes, 96 images were digitised, namely 16 images of a single animal within every 2 minutes interval. For each individual image, the area (two dimensional upper view of birds) was calculated from the birds on and around the weighing platform. In the last step, for both categories, the daily average area was calculated based on the 96 images. These images represent the daily data of 48 individual birds on the weighing platform and about 950 birds around the platform.

Figure 2 gives a global overview of the present technique: (1) Determination of the relationship between the surface area (A_b) of birds visiting the weighing system and the weight of these birds measured by the automatic weighing system (W_b); (2) Calculation of the average weight of the flock () based on measurements of the areas of the birds in the neighbourhood of and on the weighing platform (A_{ci}) and the relationship as determined in step 1.

Results

The averages for the surface area and its standard error of the mean for the animals that were on the weighing platform and those that did not are represented in Table 1 for broiler house (I). Camera

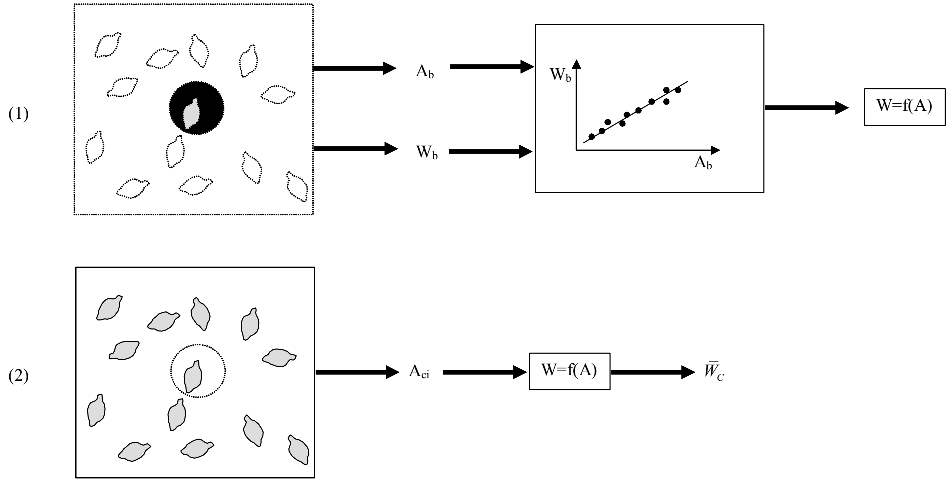

Figure 2. Principle of the calculation of a corrected average weight of a flock of birds by using image analysis in combination with an automatic weighing system.

images were taken from day 15 until day 42. The data of days 19, 20, 27, 28, 35, 39 and 40 are missing due to malfunctioning of the measuring equipment.

Although the difference in visible area between both groups was significant at some of the days in the period from day 15 till day 36, it can be seen that during the last week of the fattening period, the difference became much bigger. As an example, at day 36, the number of visible area pixels of the birds on the scale (1680 ± 12) were not statistically different to those of the birds around the scale (1705 ± 8) (p>0.05). On day 42 however, the average area of the birds on the scale was much smaller than the birds around the scale (2179 ± 58 *vs.* 2857 ± 91, p<0.05).

Similar results were found in the other two houses, as shown in Table 2.

For all 3 houses, there was a significant difference between the visible area of the birds that came up the weighing system, and those who did not, especially from day 36 on. This difference could be attributed to an insufficient number of weights recorded, related to a decrease in locomotor activity of the heavier birds. The number of animals visiting the platform per day decreased from 637 on day 29 to 420 on day 36 and to 385 on day 41 for broiler house (I). For broiler house (II) the number of platform visits decreased from 424 to 326 and further to 170 on respectively day 29, 36 and 41.

Since the weight increases in proportion to the two-dimensional surface area (De Wet *et al*., 2003), it could be concluded that the animals within the selected area around the platform were on average heavier than those which mounted the platform. Consistently, from the data, it is clear that there was a tendency for frequent perching birds to be lighter than infrequent ones after week 5. Hughes and Elson (1977), found a similar result. This also explains the consistently lower average weight generated by the automatic weighing system compared to that determined by manual weighing.

A first option to improve the weight estimate of the birds is based on their two dimensional area as investigated by De Wet *et al*. (2003), so replacing the platform by a camera. However, due to the feather cover, it was found that the correlation between surface area and live weight was not as good as for pigs that have a much more smooth shape. A second option, evaluated in this study, was to use image analysis to correct the estimates of the automatic weighing system in weeks 5 and 6. More specifically, the information of the surface area of birds visiting the platforms and in the neighbourhood of the platforms (or somewhere else in the broiler house), was used to estimate

Table 1. Daily mean area and standard error of the mean of broilers that visited the scale and those, who did not as a function of time in broiler house (I).

Day	Visible area of birds (A) on the balance (Mean number of pixels ± SE)	Number of individual birds on the platform during the measuring period	Visible area of birds (B) around the platform (number of pixels ± SE)	Total number of birds around the platform during the measuring period	Differ-ence in visible area (B - A)
15	628 ± 50	48	607 ± 15[a]	382	-21
16	611 ± 33	42	611 ± 22[a]	412	0
17	630 ± 09	2	616 ± 36[a]	580	-14
18	682 ± 34	36	619 ± 35[b]	372	-63
22	944 ± 45	42	918 ± 25[a]	217	-26
23	912 ± 22	19	946 ± 54[a]	630	34
24	978 ± 26	26	997 ± 52[a]	714	19
25	1062 ± 88	44	1176 ± 61[b]	413	114
26	1077 ± 26	23	1088 ± 35[a]	347	11
29	1034 ± 51	39	1170 ± 48[b]	318	136
30	1091 ± 41	42	1161 ± 18[b]	221	70
31	1432 ± 74	48	1224 ± 09[b]	26	-208
32	1370 ± 56	36	1401 ± 92[a]	340	31
33	1298 ± 87	42	1487 ± 96[b]	486	189
34	1518 ± 24	31	1526 ± 81[a]	517	8
36	1680 ± 12	17	1705 ± 08[a]	312	25
37	1633 ± 15	22	1909 ± 27[b]	228	276
38	1768 ± 47	39	1998 ± 97[b]	214	230
41	2110 ± 21	31	2387 ± 05[b]	106	277
42	2179 ± 58	43	2857 ± 91[b]	240	678

[a]no significant difference, $p>0.05$ (by Student's t-test for paired comparison)
[b]significant difference, $p<0.05$ (by Student's t-test for paired comparison)

the true average size of the birds and so to correct the calculated average weight of the birds using the platform.

The relationship between the measured weight and the area for each bird that used the weighing platform during the monitoring period is shown in Figure 3. Because the visible area of a bird (as measured) is not proportional to its volume or weight, different curve fits were tried, including one where the area was raised to the power 2/3. However, a simple linear curve with a R^2 of 0.95 gave the best fit. To avoid the introduction of an additional error by using predefined curves, in its final application, the slope of this curve is calculated recursively each time a bird uses the scale

The relationship presented in Figure 3 is used as an on-line calibration curve to estimate the body weight of all animals within the frame of the camera based on the daily average area of the birds on and around the weighing platform.

To evaluate the accuracy of this correction technique, the weekly measured manual weight (on days 7, 14, 21, 28, 35 and 42) was compared to (1) the estimated average body weights at the same moment as measured using an automatic weighing system only and (2) using a combination of an automatic weighing system and image analysis, respectively. The results are shown in Table 3.

Table 2. Daily means of the two dimensional visible area's of birds visiting the platform and in the neighbourhood of the platform for broiler houses (II) and (III).

	Visible area of broilers (Broiler house II) (Mean ± SE)		Visible area of broilers (Broiler house III) (Mean ± SE)	
Day	Surface of broilers visiting the platform	Surface of broilers around the platform	Surface of broilers visiting the platform	Surface of broilers around the platform
15	590 ± 12	567 ± 04	576 ± 51	520 ± 23
16	623 ± 44	604 ± 51	602 ± 24	614 ± 51
17	685 ± 17	702 ± 25	656 ± 74	632 ± 47
18	720 ± 41	714 ± 34	670 ± 26	612 ± 12
22	890 ± 72	920 ± 40	726 ± 33	701 ± 36
23	933 ± 32	917 ± 41	820 ± 12	814 ± 44
24	912 ± 29	902 ± 54	852 ± 51	822 ± 15
25	994 ± 31	1040 ± 51	890 ± 54	862 ± 56
26	1056 ± 47	1127 ± 62	930 ± 41	945 ± 41
29	1214 ± 28	1280 ± 43	987 ± 26	944 ± 23
30	1264 ± 54	1278 ± 74	1077 ± 18	999 ± 58[a]
31	1231 ± 25	1302 ± 16[a]	1023 ± 61	1045 ± 78
32	1282 ± 11	1380 ± 23[a]	1156 ± 24	1103 ± 81
33	1350 ± 26	1467 ± 65[a]	1254 ± 41	1198 ± 63
34	1459 ± 24	1540 ± 14[a]	1347 ± 47	1477 ± 71[a]
36	1508 ± 89	1602 ± 58[a]	1401 ± 61	1516 ± 10[a]
37	1556 ± 47	1695 ± 67[a]	1478 ± 76	1656 ± 15[a]
38	1621 ± 78	1720 ± 25[a]	1521 ± 81	1750 ± 66[a]
41	2136 ± 84	2704 ± 47[a]	1888 ± 27	2314 ± 67[a]
42	2235 ± 71	2965 ± 41[a]	1957 ± 63	2465 ± 57[a]

[a]significant difference between visible area of broilers around the platform and area of broilers visiting the platform, $p<0.05$ (by Student's t-test for paired comparison)

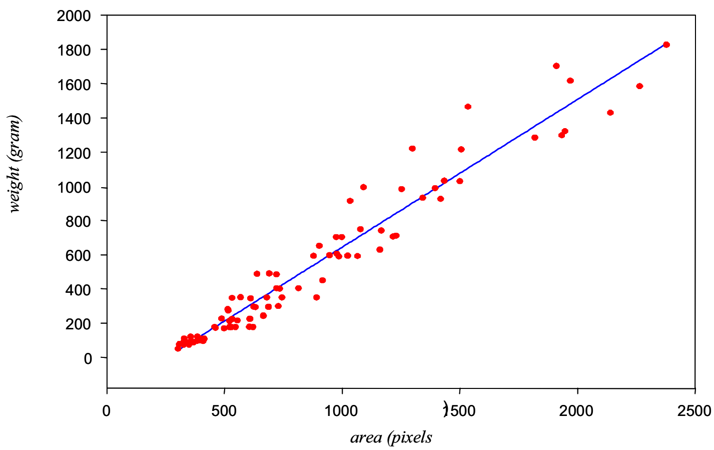

Figure 3. Broiler weight on the weighing platform as a function of the visible area (pixels).

Table 3. The estimated average weight of the animals as determined by automatic weighing (column 2) as well as by automatic weighing and image analysis (column 4) in comparison with the average manual body weight (column 1) at different weeks in the production cycle.

Day	Col 1 Manual weighing (g)	Col 2 Automatic weighing platform (g)	Col 3 Error of automatic balance (%)	Col 4 New algorithm (g)	Col 5 Error of new algorithm (%)
7	140	141	+0.7	138	-1.0
14	296	337	13.8	310	+4.7
21	559	580	+3.7	596	+6.7
28	999	938	-6.1	975	-2.4
35	1477	1445	-2.1	1428	-3.3
42	2140	1839	-14.1	2247	+5.0

Conclusions

From this data, it is concluded that the combination of image analysis and automatic weighing provides a better estimate of the actual average body weight of the animals (maximal 6.7% error) compared to the readings of the automatic weighing only (maximal 14.1% error). Especially at the end of the fattening period (days 42), the error of the automatic weighing system decreased significantly from 14.1 to 5%. Further improvements of the method may be obtained by using more cameras at different positions in the house.

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Emerging technology for assessing the composition of livestock

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Abstract

The value of an animal for breeding, production or slaughter depends on its body composition (the distribution and relative amounts of fat and muscle). Technology to measure or predict these variables would enable the producer to control them by regulating the animal's diet and to improve the selection of animals for breeding, production and for slaughter. This paper examines the progress that is being made in the development of technology for measuring or predicting live animal composition on the farm. This technology includes image analysis, palpation and robotics for sensor placement.

Keywords: livestock monitoring

Introduction

Livestock producers are coming under increasing pressure to supply their customers with products of a given quality, and the price that a producer receives is increasingly determined by the composition of the product as well as the quantity. In the case of meat animals (sheep, cattle and pigs) for example, price usually depends on carcase classification, which includes measurements or subjective assessments of carcase conformation (or shape) and carcase composition (fat content and distribution). Conformation is important because it is an indication of the relative volumes of the various muscles, each of which has a different value. It is also important to control the composition of breeding animals, usually referred to as the animal's condition. For example, in the dairy cow, condition refers to the quantity of fat under the skin of certain areas of the body. It is an indication of body reserves which have relevance to milk production and reproductive performance. Condition in all animals is conventionally assessed visually and by palpation. If technology were available to enable the producer to measure or predict the composition of a growing animal, it would then be possible to control this by regulating the animal's diet and to improve the selection of animals for breeding, production and for slaughter.

Image analysis

Research is being carried out to test the hypothesis that the appearance of an animal is, under some circumstances, related to its composition. For example human assessors are thought to be able, sometimes, to distinguish between fat and muscular pigs on the basis of visual inspection. It seems therefore that some aspects of shape may be related to composition in some animals and that consequently computer-based image analysis offers a promising approach for measuring composition.

Two dimensional image analysis

It has been shown that there is a strong relationship between the live weight and plan view area of a pig measured from images taken by an overhead video camera. Figure 1 shows an example of this type of image. Algorithms for extracting areas from such images have been well established and it has been shown that these can be used to predict pig weight with an accuracy of 5 %

(Schofield at al., 1999). It has also been shown that shape data derived from these images can distinguish between pig types and sexes. With cross validation, canonical variates analysis correctly classified Meishan, Pietrain and Landrace types respectively in 72%, 83%, and 64 % of observations, and neural network analysis in 81%, 81%, and 64 % of observations (White *et al*., 2004). The apparent ability of visual imaging to sort the three commercial pig types into their appropriate groups suggests that the technique may have much to offer with regard to live sorting according to pig shape and conformation. (White *et al*., 2003; Doeschl *et al*., 2004).

There are also indications that the image data can be used to predict pig composition and carcass quality (Fisher *et al*., 2003; Doeschl *et al*., 2003 and 2004). The results of this analysis showed that image and carcass measurements generally led to a similar description of body conformation characteristics for the three pig types, and explain a substantial amount of the variation found in the carcass composition (Doeschl *et al*., 2004).
A similar approach is being applied to the analysis of image of sheep. Scaled images showing the top, side and rear views of two breeds of sheep, with and without wool, have been collected along with conventional records of weight, condition and body composition measured using CT and ultrasound scanning and dissection. Specific areas and linear dimensions derived from these images are currently being processed to determine relationships with the other measurements of

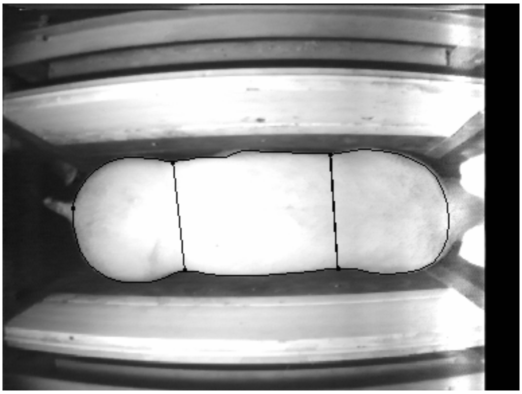

Figure 1. Pig image calibrated to extract plan view dimensions.

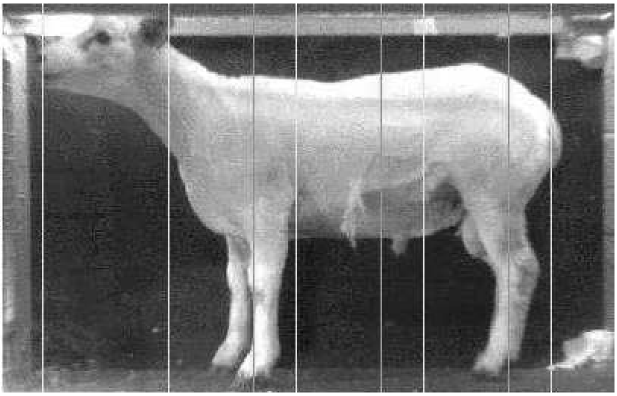

Figure 2. Sheep image calibrated to extract side view dimensions.

composition. Early results indicate that there are significant links between some of these dimensions and the weight and condition of the sheep without wool, and less strong but still significant with wool. Relationships between data derived from the images and from other measurements of composition such as CT scans and carcase dissection are currently being sought.

Three dimensional image analysis

Of the many techniques for 3D measurement, two are reported here: photogrammetic stereo for producing 3D images of pigs, and a structured light technique for measuring the shape of dairy cows. The choice of technique was determined by its scientific interest in the former case and by considerations of potential practical application in the latter case.

In photogrammetic stereo (Faugeras, 2001), two cameras view the surface from slightly different angles. Corresponding features are matched between the two images, and the 3D surface is then constructed by triangulation. Wu *et al*. (2004) developed a 3D imaging system, based on a photogrammetry system known as C3D, for capturing the shape of live pigs. A trial was carried out in which two groups of 16 pigs each were fed different diets (high-lysine and low-lysine) in order to induce differences in fatness. The pigs were imaged at weekly intervals for 14 weeks as they grew from 30 kg to 80 kg. Imaging was performed using 3 stereo pairs of cameras, which captured views from the side, the top and the rear. Example views are shown in figure 3. Initial results (Tillett *et al*. (2004a; 2004b)) indicate qualitative differences in the shape of the back between the two diet groups. Current research has focused on the extraction of quantitative shape measurements. Models were built of 10 pigs (5 from each diet group) for each week of a 10-week period and cross-sections were extracted from half-way along the body. Shape models, in the form of quasi-ellipses, were fitted to the cross-sections, allowing measurements such as height, width and area to be calculated. Figure 4 shows the height-to-width ratios of the pigs, plotted against weight, and clearly shows a difference between the two diet groups.

Structured light imaging techniques are based on the deformation caused to stripes or coded patterns of light projected onto the surface. Laser striping was used to enable the shape of a cow's tail head and back to be measured. These are the parts of the animal that human assessors look at most carefully when assessing the condition score of a cow. An example image is shown in Figure 5. Comparison with the shape, as recorded using a deformable aluminium strip, showed that the r.m.s. accuracy was +/- 2.1 mm in the vertical direction (Figure 6).

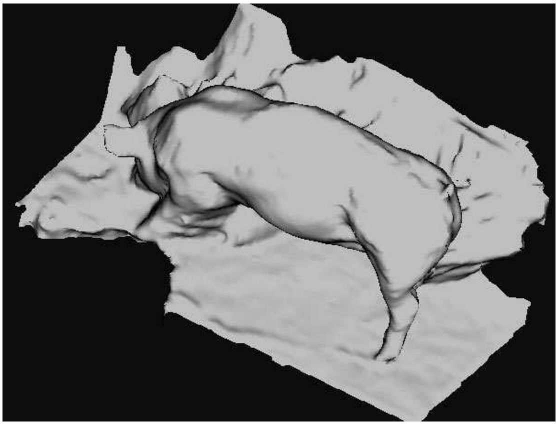

Figure 3. 3D surface recovered from three stereo pair images of the live pig.

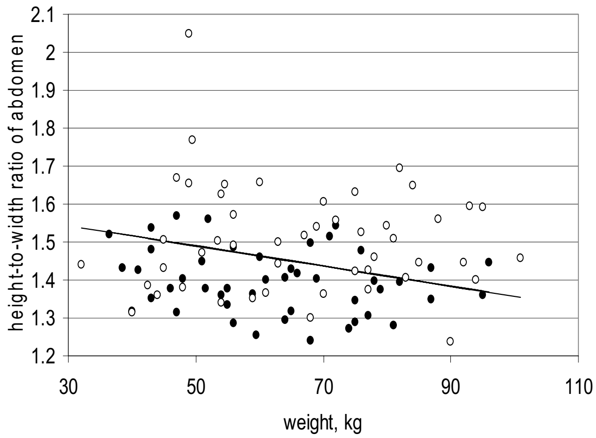

Figure 4. Height-to-width ratio of abdomen cross-sections; ● low-lysine group; ○ high-lysine group; —— canonical variate dividing groups.

Figure 5. Laser stripe illumination to show the shape of a cow's hind quarters.

Two measures of shape as determined by the imaging technique were tested for their correlation with condition scores. The curvatures of the tail head and right buttock were selected because they were likely measures of the "boniness" of the animal. The shape of the back of the cow was modelled well by a series of quadratics, one for each buttock and one over the tail head. An r.m.s. fit of +/- 3.6 mm to the shape was easily achieved for most of the cows. The curvatures of the tail head and the right buttock were correlated with the condition score, but the correlations (55% and 52% respectively) were not strong enough to accurately predict condition scores from the curvatures. However they did indicate that these curvatures were an important component of the condition scoring.

Palpation and ultrasonic sensing

The stockman gains a great deal of information about the composition of an animal by palpation. However, these assessments are subjective and unreliable. It is possible to contemplate, as a longer term objective, the development of devices which would emulate some aspects of manual palpation

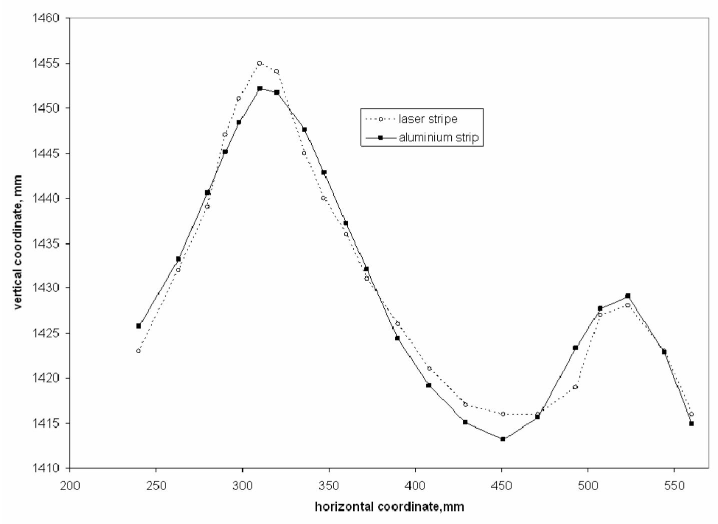

Figure 6. Coordinates along one laser stripe recorded automatically and compared to those measured using a manual method (deformable aluminium strip).

and introduce reliability and objectivity into the process. This would require the development of instrumentation which would enable relevant tactile parameters which are intuitively assessed by manual palpation to be identified and quantified. As a first step a system has been developed for measuring the relationships between stress and strain in live animal tissues. An ultrasonic imaging system, which enables the depths of the tissues underlying the sensor to be measured, has been connected to a load cell which measures the contact force applied by the ultrasonic sensor to the animal. This system therefore enables simultaneous measurements of applied load and the resulting tissue compression. Figure 7 is an example image of a sheep showing the eye muscle. Figure 8 shows an example stress strain plot based on the depth of this muscle, obtained during a single, continuous loading cycle.

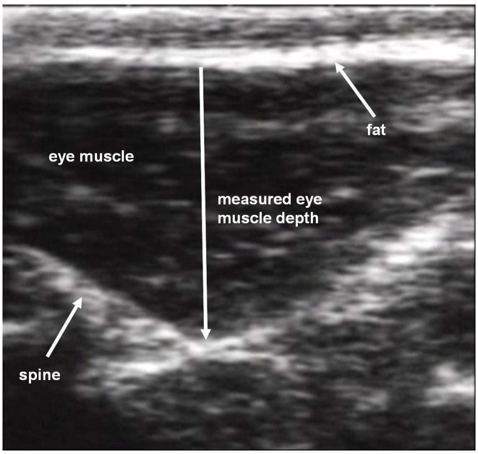

Figure 7. Ultrasound image of sheep eye muscle.

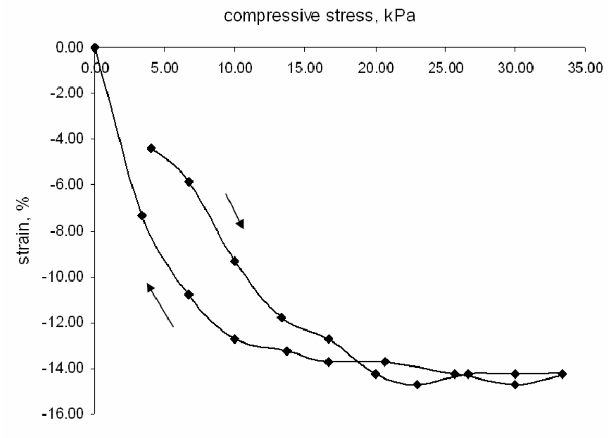

Figure 8. Stress strain plot based on the depth of a sheep eye muscle, obtained during a single, continuous loading cycle

This technique enables a mechanical, tactile property of live animal tissue to be measured directly. Further research is required to establish any relationships between these measurements and other factors such as animal breed, age, conformation, health and the mechanical properties of carcase tissue.

Frequent manual deployment of ultrasonic, or other sensors for measuring animal composition or other variables, is not feasible because of the large amount of labour required. One solution to this is to develop automatic systems. As a step in this direction a vision guided robot has been designed to track a given position (the P2 position used for backfat measurement) on the body of a pig as it stands, loosely constrained, in a feeding stall (Frost *et al*., 2004). The vision guidance system was based on a model which predicted the P2 position from the positions of points on the periphery of plan view video images of the pig. A purpose built, two axis, SCARA (Selective Compliant Assembly Robot Arm) robot with pneumatic actuation was developed. The tracking performance of the combined robot and image analysis system was evaluated by testing the ability of the robot to track recorded images of a pig moving around in a feeding stall, and by its ability to track live pigs in a field trial. The results showed that it should be feasible for a vision guided, pneumatic robot to track a moving pig and place an ultrasonic sensor at a target position on its back at a frequency which would enable useful data to be collected.

Conclusions

This paper demonstrates the progress that is being made in the development of technology for measuring or predicting live animal composition on the farm. It demonstrates the feasibility of gathering information that can be related to the conformation of animals, using image analysis based observation and non-invasive monitoring techniques. The challenge now is to make the connections between data related to a live animal's conformation and its composition.

Image analysis based techniques appear to give promising results with pigs. Measurements from images are useful in the estimation of muscle size, carcass conformation and composition. Results for dairy cows are less clear and indicate that further research is required if a relationship between measured shape and condition score, as subjectively assessed by experts, is to be established. Early results from trials with sheep indicate links between external shape and composition, even with a full fleece.

Ultrasound can provide useful information about the composition of an animal but currently this has a high labour requirement in accurately placing the sensor on each animal. This problem has been addressed by the development of a robotic system that can deploy the sensor automatically. Work in progress is aimed at extracting information on the mechanical properties of tissues in the live animal by observing the deflection of tissues in ultrasound images under applied loads.

Acknowledgements

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Precise management and modelling in livestock systems

A system analytic approach to model animal responses as a basis for precision livestock farming

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Abstract

The objective was to develop a dynamic model combining a data-based with a mechanistic model that predicts the heat loss response of broilers to their thermal environment as a basis for a precision livestock farming system. The advantage of such coupled model is that it combines a compact model structure with physically meaningful model parameters. It was demonstrated that static as well as dynamic responses of heat loss could be modelled with a correlation coefficient of 0.83 up to 0.96. The introduction of such tools to predict animal responses is one way to improve the process management by precision livestock farming.

Keywords: Data-based mechanistic model, dynamic modelling, heat loss, broilers

Introduction

The responses of living organisms to their micro-environment have been studied extensively in order to gain an insight into the underlying homeostatic mechanisms (e.g. Reece *et al*., 1980; Kettlewell and Moran, 2000). This knowledge has been the basis, among others, of modern environmental management systems in livestock production. In spite of the application of modern techniques, this approach does not always result in the expected process performance because it over-simplifies the complex interactions between an animal and its environment. One possible way to improve process management is to integrate on-line measured responses of livestock to their process environment in the process control actions by using modern engineering methods of monitoring and control resulting in a precision livestock farming system (Aerts *et al*., 2000, 2003a and b). An essential part of such control systems, is the availability of a dynamic and reliable process model. Ideally, such a process model should be compact enough to be implemented in the control hardware, but should also be interpretable from a biological/physical point of view. Models coupling a data-based model with a mechanistic model that combine both advantages might offer opportunities for application in precision livestock farming.
In the reported research, the objective was to develop a compact model, combining a data-based with a mechanistic model, to predict the heat loss response of broilers to their thermal environment.

Materials and methods

In order to develop the model, two modelling approaches were used and combined. First, data were measured of heat and mass transfer between broilers and the thermal environment and a dynamic data-based model was developed. Second, a mechanistic model of heat and mass transfer between the bird and the thermal environment was developed. Finally, a coupled model was developed by combining a first order dynamic data-based model with the mechanistic model. In the following, the generated experiments for model evaluation and both models are described.

Model development

Dynamic data-based model:

A single-input, single-output (SISO) discrete transfer function model was used for describing dynamic responses of the bird's heat loss to variations in air temperature. It had the following general structure (Young, 1984):

$$y(k) = \frac{B(z^{-1})}{A(z^{-1})} u(k-d) + \xi(k) \tag{1}$$

where: $y(k)$ is the system output of total heat production in W/kg at time k; $u(k)$ is the system input air temperature in °C at time k; d is the time delay in dynamics between y(k) and u(k); $\xi(k)$ is additive noise, assumed to be a zero mean, serially uncorrelated sequence of random variables with variance σ^2 accounting for measurement noise, modelling errors and effects of unmeasured inputs to the process; $A(z^{-1})$ *and* $B(z^{-1})$ are two polynomials with model parameters.

The model parameters were estimated using a refined instrumental variable approach (Young, 1984). For each data set, the model parameters of eq. (1) were estimated and the resulting models were evaluated by means of the coefficient of determination R_T^2, the Young Identification Criterion and the confidence intervals on the model parameters.

Mechanistic model:

The processes of heat exchange between an animal and its surroundings can be described by appropriate equations. For the development of the mechanistic model of energy and mass transfer, the following assumptions were made: the deep body temperature of the chicken was constant and equal to 41 °C (Wathes and Clark, 1981b); the sensible heat was mainly lost by radiation and convection; heat transfer by conduction was neglected (Wathes and Clark, 1981b; McArthur, 1987); at every moment heat loss equalled heat production; the bird was living indoors and did not receive solar radiation; the convective heat transfer occurred in mixed regime (fair assumption in practice, Wathes and Clark, 1981a).

The sensible heat loss by convection (C) and radiation (L_n) at one hand and the evaporative heat loss (G_e) at the other hand were calculated (in steady state) as:

$$C = \frac{\rho c_p}{r_{aH}} (T_c - T_a) \tag{2}$$

$$L_n = \frac{\rho c_p}{r_R} (T_c - T_e) \tag{3}$$

$$G_e = \left(\frac{1}{A_s}\right)(0.0016)\left(-202 + 471.W^{0.64} + 6.T_a\right) \tag{4}$$

The total heat loss is the sum of these partial heat losses and thus:

$$G_t = \left(\frac{A_c}{A_s}\right)(C + L_n) + G_e \tag{5}$$

where C is the convective heat loss (W/m^2); L_n is the radiant heat loss (W/m^2); G_e is the evaporative heat loss (W/m^2); G_t is the total heat loss (W/m^2) ; r_{aH} is the thermal resistance of the boundary layer (s/m); r_R is the radiant resistance (s/m); T_a is the air temperature ($°C$); T_c is the surface temperature of the feathers ($°C$); T_e is the average radiant temperature of the environment ($°C$); ρc_p is the volumetric specific heat of air ($J/m^3.K$); A_c is the surface area of the feathers (m^2); A_s is the surface area of the skin (m^2).

The resistances r_{aH} and r_R were calculated as described by McArthur (1987).

Coupling of the dynamic data-based model with the mechanistic model:
By combining the dynamic data-based model with the mechanistic model, physical meaning could be given to the parameters of the compact data-based model, resulting in a coupled data-based mechanistic model. This is explained hereafter.
When assuming first order dynamics, as suggested by Aerts *et al*. (2000, 2003), the dynamic response of total heat production to variations in air temperature can be written with a first order transfer function model as:

$$G_t(k) = -a_1 Gt(k-1) + b_0 T_a(k-d) \tag{6}$$

Where $G_t(k)$ and $T_a(k\text{-}d)$ are the time series of total heat loss and air temperature respectively rescaled by subtracting the initial operating points.

When substituting eq. (2), (3) and (4) in eq. (5) and assuming that the radiant temperature of the environment T_e equals the air temperature T_a, the mechanistic model can be written as:

$$G_t = \left[\left(\frac{1}{A_s}\right)(0.0016)\left(-202+471W^{0.64}\right)+\left(\frac{A_c}{A_s}\right)\left(\rho c_p T_c\left(\frac{1}{r_{aH}}+\frac{1}{r_R}\right)\right)\right]-\left[\rho c_p\left(\frac{A_c}{A_s}\right)\left(\frac{1}{r_{aH}}+\frac{1}{r_R}\right)-\left(\frac{1}{A_s}\right)(0.0096)\right]T_a \tag{7}$$

The steady state gain (SSG) of the response of heat production to air temperature, can be written as a function of the parameters of the dynamic transfer function as (Aerts *et al*., 2000):

$$SSG = \frac{b_0}{1+a_1} \tag{8}$$

Since the SSG equals the slope of the steady state relation between heat loss and air temperature, the model parameters of the transfer function model can be written as a function of physical properties:

$$\frac{b_0}{1+a_1} = -\left[\rho c_p\left(\frac{A_c}{A_s}\right)\left(\frac{1}{r_{aH}}+\frac{1}{r_R}\right)-\left(\frac{1}{A_s}\right)(0.0096)\right] \tag{9}$$

Furthermore, the parameter a_1 is linked with the time constant τ of the dynamic response in the following way:

$$a_1 = -e^{-\frac{\Delta k}{\tau}} \tag{10}$$

where: Δk is the measurement interval; τ is the time constant.

So, by combining both modelling approaches the model parameters of a compact and accurate data-based model can be interpreted on the basis of physical knowledge of the system, resulting in a data-based mechanistic model, i.e. a compact data-based model structure where the model parameters can be expressed as a function of physical/biological properties of the system.
By substituting eq. (9) and (10) into eq. (6), the expression for G_t can be written in an alternative way as:

$$G_t(k) = G_t(k-1)+\left(1-e^{-\frac{\Delta k}{\tau}}\right)\left[-\left(\rho c_p\left(\frac{A_c}{A_s}\right)\left(\frac{1}{r_{aH}}+\frac{1}{r_R}\right)-\left(\frac{1}{A_s}\right)(0.0096)\right)T_a(k-d)-G_t(k-1)\right] \tag{11}$$

and finally when working around the initial operating points:

$$G_t(k) = G_t(k-1)+\left(1-e^{-\frac{\Delta k}{\tau}}\right)\left[G_k^* t(k)-G_t(k-1)\right] \tag{12}$$

where G^*_t is the steady state heat loss response defined as in eq. (7).

Experiments

Experiments for evaluation of the mechanistic model:

Two growth experiments (Exp1 and Exp2) were performed with groups of 2900 broilers during a production period of 42 days in a broiler compartment of 48 m x 16 m. Air temperature T_a was measured in the ridge by means of a thermo-couple (accuracy of 0.1 °C). The radiant temperature of the environment was determined based on images of an infrared camera (AGEMA Thermovision 570) taken of the walls, the roof and the litter. The temperature of the feathers T_c was measured by means of the same infrared camera. The compartment was equipped with four weighing platforms (diameter of 0.34 m, accuracy of 1 g) connected to a weighing computer for measuring the average weight of the flock animals every 24 hours. Feed consumption was recorded daily with an accuracy of 1 g. During the growing period, measurements of T_c, T_e and v were performed on day 3, 8, 16, 23, 30, 37 and 42 in Exp1 and on day 3, 10, 15, 22, 30, 37 and 42 in Exp2. The values of the air temperature T_a and average weight W of the animals were registered daily from the process controllers. Air velocity v was measured (accuracy of 2% of the reading) at 0.3 m above the litter and the sensor was positioned to measure the air flow along the middle longitudinal axis of the house.

Experiments for evaluation of the dynamic coupled model:

Data of three experiments (Exp3, Exp4, and Exp5) of dynamic heat production responses to step variations in air temperature (measurement interval of 4.5 minutes) were used. In these experiments, steps (steps up and down) were generated with air temperature. After a step change in temperature, the new steady-state level of temperature was kept constant for at least two hours in order to let the animals reach a new steady-state level of heat production. Magnitude of step changes was fixed at 17°C for air temperature. Light intensity was kept constant at 35 lux. The animals in these experiments were 6 days old (Exp3), 14 days old (Exp4) and 21 days old (Exp5). For more details about the experiments and the used test installation, the reader is referred to Aerts *et al*. (2000).

Results and discussion

Experiments for evaluation of the mechanistic model

Figure 1 shows results of the simulations of the steady state model of broiler heat loss with input data from Exp1. Figure 1a shows the course of the convective C, radiant L_n and total sensible heat losses G_c during the growing process. The course of the total sensible heat losses was characterized by a sharp increase from day 1 up to day 8, a plateau from day 9 to 21 and finally a decrease between day 22 and day 42. Similar results were found by Wathes and Clark (1981c).

The courses of the simulated total heat losses G_t, the sensible heat losses G_c and the evaporative heat losses G_e are shown in Figure 1b. The portions of G_c and G_e to G_t are 60 to 40% in case of G_c and 40 to 60% in case of G_e. This is in agreement with numerical values found in the literature (Reece and Lott, 1982; Curtis, 1983; Chwalibog *et al.*, 1985; Xin *et al.*, 1996).

Experiments for evaluation of the dynamic coupled model

Based on 30 step experiments in air temperature, Aerts *et al*. (2000) found that the response of total heat production (loss) to variations in air temperature can be modelled by assuming first order dynamics. This research also indicated that the time constant of the dynamic response was on average 8.6 minutes for the on-transient and 12.8 minutes for the off-transient. These values were used to evaluate the dynamic coupled model in eq. (12). The following variables were used as input in the dynamic coupled model: air temperature T_a, air velocity v and average bird weight W.

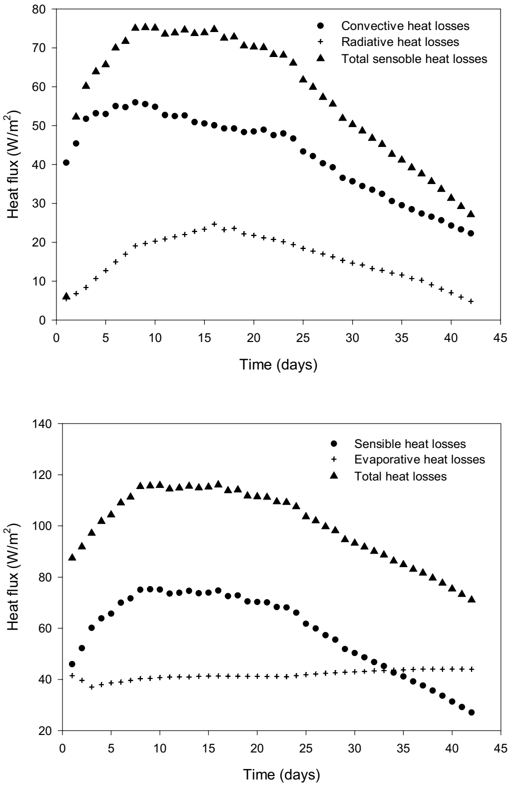

Figure 1. Simulated data for growth experiment Exp1: (a) simulated convective heat losses C, radiant heat losses L_n and total sensible heat losses G_c; (b) simulated sensible heat losses G_c, evaporative heat losses G_e and total heat losses G_t.

Because radiant temperature and coat temperature were not measured, the following assumptions were made: the radiant temperature of the environment T_e equals the air temperature and the coat temperature T_c can be written as a function of T_a, namely:

$$T_c = T_a + 0.7(40 - T_a) \tag{13}$$

The dynamic model was tested on three data sets for animals of different ages (6, 14 and 21 days) and for step up as well as step down responses. In Figure 2 the simulation results for one example are shown. Figure 2a shows the measured total heat loss and air temperature. In Figure 2b the measured total heat loss is compared with the simulated total heat loss. Figure 2c shows the simulated total heat loss and the different simulated partial heat losses (convective heat losses, radiant heat losses, total sensible heat losses and evaporative heat losses). Finally, in the last part of the figure (Figure 2d) the portions of the different partial heat losses in the total heat loss are shown. Table 1 summarises the modelling accuracies for the different experiments in terms of the correlation coefficient r between the measured and simulated heat loss response.
Based on the graphical results as well as the results in Table 1, it is seen that the model for energy and mass transfer between the broiler and the thermal environment succeeds in describing the static as well as the dynamic response of total heat loss (r varying between 0.83 and 0.96). The results

Table 1. Modelling results of the dynamic simulation model expresses as correlation coefficient r between the measured and simulated total heat losses.

Exp. n°	r for step up response	r for step down response
Exp3	0.96	0.85
Exp4	0.89	0.85
Exp5	0.88	0.83

of Wathes and Clark (1981c) showed that for broilers of 10 days old (Ross1, in a cluster), an air temperature of 25°C and a radiant temperature of the environment of 24°C, total sensible heat loss was between 40 and 50 W/m^2. For similar conditions of T_a and T_e and age of birds (6 days old) the simulated total sensible heat loss was nearly 60 W/m^2. An increase of T_a causes a decrease of the portion of convective heat losses C to G_c due to diminishing difference between T_a and T_c (Chwalibog and Eggum, 1989). This has also been observed in the simulations. The calculations of Wathes and Clark (1989c) showed that the convective heat losses C of broilers of 8 days old (T_a and T_e of 24 °C) were 50% of G_c. For similar conditions of T_a and T_e and age of birds (6 days old), the portion of the simulated convective heat loss was also 50%. The simulated evaporative heat

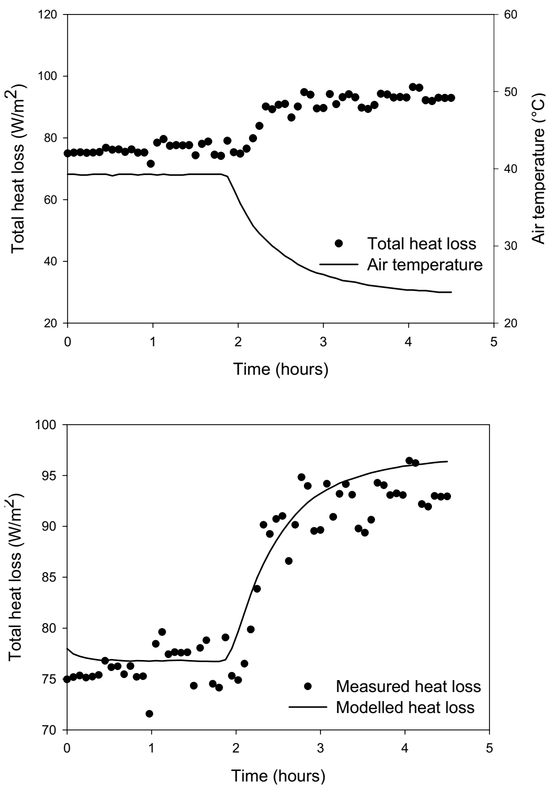

Figure 2. An example of measured and simulated heat losses (total sensible heat loss, convective heat loss, radiant heat loss and evaporative heat loss).

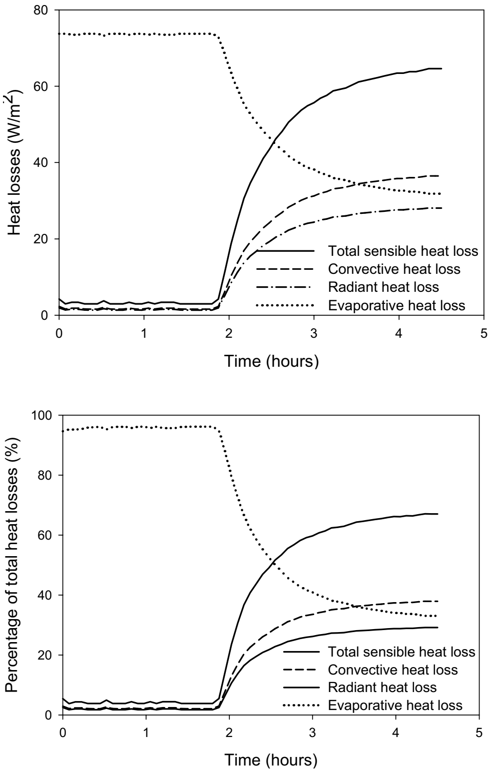

Figure 2. Continued.

losses G_e were 33% to 35% of G_t for T_a varying between 20°C and 25°C. These values are in accordance with the results of Richards (1976) who demonstrated that G_e was 30% of G_t when T_a was 26°C. In case of high values of T_a and T_e (35°C - 38°C), the portion of the simulated evaporative heat losses increased strongly. In Exp4 and Exp5 the portion of G_e in G_t increased until 80%. However, in Exp3 the portion of G_e in G_t increased up to 95%.

Conclusions

The combination of on-line measured information on the animals (weight and coat temperature) and the environment (air temperature, radiant temperature of the environment and air velocity) with compact data-based mechanistic models can be used for predicting animal heat losses in practice. Such models can be used as a basis for control and monitoring of livestock processes. The introduction of such tools for precision livestock farming is one way to improve the process management in livestock production.

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Representation of fat and protein gain at low levels of growth and improved prediction of variable maintenance requirement in a ruminant growth and composition model

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Abstract

We have developed a prediction system for ruminant animal growth and composition, representing body protein in two pools, viscera and non-viscera (muscle). Using sheep datasets, we have included adjustments in the model for protein gain and loss of body fat at near maintenance feeding, and more precisely estimated variable maintenance parameters than current feeding systems. In the model muscle and viscera each have an upper bound (m* and v*, respectively). For muscle m* is genetically fixed; however, v* is affected by energy intake and muscle (protein) mass. Net energy intake above maintenance is used for muscle and viscera gain before its use for fat accretion. Maintenance energy includes a variable coefficient on body weight which results in a lag in change of maintenance requirements after intake changes. Alternatively, heat production may be represented by a regression equation with body protein components. Sheep growth and composition is more accurately predicted with the revised model, and the model predicts sheep empty body weight gain and fat content (± 25 g/d and 2.3%-units, respectively) more accurately than the current Australian feeding system. New additions refine predictions at levels of energy intake at or below maintenance. Limitations identified are imprecise parameter estimates due to lack of longitudinal datasets. The model provides the structure for predicting composition of growing cattle as well, but has yet to be completely parameterized and tested.

Keywords: sheep growth, composition, maintenance, energy

Introduction

Measurements of carcass composition by ultrasound can be combined with computer growth models to improve marketing and quality of fattening animals. Many new selling agreements depend on carcasses meeting specifications, and the ability to sort and manage individual animals require use of a computer projection to predict sale date and carcass specification. For example, several beef cattle feedyards in the United States sort cattle using ultrasound and computer growth software into groups of cattle with expected uniform days on feed, based on optimum profitability based on feed costs and carcass value. However, our computer growth models generally depend on national feeding systems and need improvement.

Most current feeding systems predict retained energy in order to estimate growth rate by using some empirical relationship between retained energy and body weight gain. Composition of growth may be inferred in some of these by assuming protein content of the fat-free mass and energy value of protein and fat gain (e.g. 22.01% of fat-free mass is protein and the energy contents of fat and protein gain are 39.6 and 23.8 MJ/kg, respectively, NRC, 2000). The prediction of retained energy is derived from the feed not used for maintenance or other productive functions. This may be arrived at in different ways. In net energy systems it is

$$NEG = (DMI - NEM_{req}/NEM_c)\ NEG_c \qquad (1)$$

where NEG is net energy for gain (retained energy), DMI is dry matter intake, NEM_{req} is net energy required for maintenance, and NEM_c and NEG_c is net energy concentration in ration dry matter for maintenance and gain, respectively. In metabolizable energy systems it is

$$NEG = (MEI - NEM_{req}/k_m)\ k_g \qquad (2)$$

where MEI is metabolizable energy intake, and k_m and k_g are efficiency of metabolizable energy use for maintenance and gain, respectively. Alternatively, it may be expressed

$$NEG = MEI - HP \qquad (3)$$

where HP is heat production. In the model described in this paper, based on a set of models (Soboleva *et al*., 1999; Oltjen *et al*., 2000), we have chosen to predict growth using an estimate of retained energy as the driver in contrast to our earlier model which used empirical relationships with the ratio of MEI to a reference MEI (Oltjen *et al*., 1986). Therefore, one of our objectives is to improve prediction of retained energy, essentially by estimating maintenance (which may be variable) or HP more accurately. This may require an estimate of visceral mass, since variation in maintenance and heat production is greatly influenced by change in visceral organs such as gastrointestinal tract and liver (Koong *et al*., 1982). Hence, in predicting composition of gain we separate growth into three pools, visceral and non-visceral protein and empty body fat. Thus variable maintenance can be dynamically related to the protein pools in the model. Further, the current version of the growth model contains improved representations of growth at low or near maintenance levels. Previous versions (Soboleva *et al*., 1999; Oltjen *et al*.; 2000) had unidentified parameters for visceral protein growth. Our objective is to describe the revised model, the parameter fitting methods used, and how this new model achieves more accurate visceral mass and variable maintenance predictions.

Model Description

In the original dynamic model (Oltjen *et al*., 2000) viscera and non-viscera (muscle) and each have an upper bound (v* and m*, respectively). For muscle m* is fixed, although the possibility of reaching this level depends on both the current intake and nutritional history of the animal. However, v* is affected by energy intake and depends on previous nutrition. As in previous models (Oltjen *et al*., 1986) net energy intake above maintenance (net energy for gain or retained energy, NEG) is used for viscera and muscle tissue gain before its use for fat accretion. Visceral tissues are more sensitive than muscle to changes in energy intake. Maintenance requirements and heat production are related to energy intake (MEI), but changes in maintenance requirements follow changes in intake with some time delay. This depends on both the magnitude and the duration of the change in energy intake. The model is expressed in terms of energy (kJoules):

$$dm/dt = k_m\ (NEG + c_m\ f_a)\ (1 - m/m^*) \qquad (4)$$

$$dv/dt = k_v\ (v^* - v) \qquad (5)$$

$$df/dt = NEG - dm/dt - dv/dt \qquad (6)$$

where

$$f_a = (1-m/m^*)^{e2} \qquad (7)$$

and

$$v^* = cs_1\ MEI + cs_2\ m \quad (8)$$

Here m is nonvisceral empty body protein (kJ), v is visceral empty body protein (kJ), f is empty body fat (kJ), NEG is retained energy (kJ/d), m* is mature m, and k_m (0.353), c_m (1,340 kJ/d), k_v (0.050/d), e2 (3.4), cs_1 (0.314 d) and cs_2 (0.0416) are estimated parameters. Note that k_m and k_v separate the retained energy into m or v, and are not partial energetic efficiencies. The model parameters c_m, cs_1, and cs_2 allow body composition changes to occur at zero or low retained energy gains. Young animals gain more protein and lose more fat than older ones when feeding is restricted to maintenance levels.
The empty body weight of the animal W in kg is connected to our state variables (m, v and f) by the relationship

$$dW/dt = (dm/dt + dv/dt)/(23{,}800 \times 0.2201) + (df/dt)/39{,}600) \quad (9)$$

where 0.2201 is the protein content of the fat-free empty body.

The energy driving the growth of muscle and viscera is given by the term NEG:

$$NEG = MEI - HP \quad (10)$$

where HP is total heat production, the sum of heat production for maintenance (HP_{maint}) and heat production for gain (HP_{gain}). Heat production for maintenance (HP_{maint}) is estimated:

$$HP_{maint} = \alpha_t\ EBW^{0.75} \quad (11)$$

where

$$\alpha_t = \alpha_0\ (1 + b(MEI_t/MEI_0 - 1)(1-e^{-t/\tau})) \quad (12)$$

which results in a lag in change of maintenance requirements after intake changes from MEI_0 to MEI_t. Here EBW is empty body weight, t is time (days), b (0.116) and τ (20.0 d) are constants; MEI_0 and α_0 are original values of intake and the maintenance coefficient, respectively. The heat production for gain is:

$$HP_{gain} = MEI - HP_{maint} - NEG \quad (13)$$

If one assumes a constant efficiency of feed energy use for gain (k_{gain}=0.043M/D, SCA, p. 49, eq. 1.39, 1990):

$$NEG = k_{gain}\ (MEI-HP_{maint}) \quad (14)$$

or

$$HP = MEI - k_{gain}\ (MEI - HP_{maint}) \quad (15)$$

Otherwise any general form for HP can be used.

We also added the SCA (1990) energy terms for loss of body energy; for MEI < HP_{maint} body energy is used at 0.8 efficiency, so

$$NEG = (K_{maint}/0.8)*(MEI-HP_{maint}) \quad (16)$$

where K_{maint}=0.02*M/D+0.5 (SCA, p. 26, eq. 1.23, 1990) and M/D is metabolizability of the feed.

Fitting the unknown parameters to the data is a simultaneous nonlinear regression problem, given that the set of differential equations is solved numerically. The estimation involves simultaneous regression since the same parameters occur in each of the three equations. This means that the estimation must take account of both the different scales and variances between the three body components, and also the covariance between the residuals of these variables. For example, if fat had a greater variance than muscle or viscera then this would make the fat pool much more influential in determining the parameter values than muscle or viscera unless this greater variance was taken into account in the estimation.

The corollary of least squares parameter estimation for one equation is to minimize the determinant of the residuals for parameter estimation in simultaneous equations. This is also the maximum likelihood estimate when the residuals are multivariate normal. The derivation is given in Bates and Watts (1988).

Initially the parameter estimation was done by solving the set of differential equations numerically using a Runge-Kutta method with adaptive step size control (Press *et al*., 1989) and a continuous parameter genetic algorithm (Haupt and Haupt, 1998) to minimize the determinant of the residual covariance matrix of muscle, viscera and fat. These estimates were used as the starting values for estimation using Markov Chain Monte Carlo (Metropolis - Hastings algorithm, Tanner, 1996). This method also provided estimates of the parameter distributions.

Data obtained by Ferrell *et al.* (1986) studying compensatory growth on intact male Suffolk × Rambouillet × Finnish Landrace lambs were used to test the model

Most parameters were estimated using data obtained by Ferrell *et al*. (1986) studying compensatory growth of intact male Suffolk × Rambouillet × Finnish Landrace lambs. Rams were assigned to gain 16 (H), 5 (M), or -6 (L) kg during period one (42 d), followed by assignments of 27 (S), 16 (H), 5 (M), or -6 (L) kg gain during period two in an incomplete 3 X 4 factorial design with treatments HH, HM, HL, MH, MM, ML, LS, LH, and LM (period one designated by first letter, period two by second). There were four lambs per treatment. Data for visceral protein alone were not available, so v has been defined as the sum of liver, heart, kidney, spleen and gastrointestinal tract protein, and m as the remaining empty body protein for the example presented here. Measurements were made of the initial and final body weight, average daily energy intake, and muscle, viscera and fat weight at slaughter. The dynamic system of three coupled nonlinear differential equations was solved numerically using initial conditions based on the body weight of the animals at the beginning of the trial. We assumed that initial liver, heart, kidney, spleen and gastrointestinal tract weight was 8.15% of body weight, and that v was 16.58% of this sum. To account for the effect of the level of energy intake on maintenance requirements the value of α_0 was adjusted relative to the HH treatment, and initial intake (MEI_0) was set to 19,000 kJ/d. The results from the simulation at day 84 were compared to the measurements made on the animals at this time.

Thee prediction of v* and k_v is based on a dataset including longitudinal observations for viscera for rams and ewes held for long periods of time on constant intakes after various prior nutritional manipulations (Ball, 1996). An equation including both m and MEI best fit the data without an intercept, since it was not significant (P>0.1).

The model simulation of variable maintenance (Figure 1) shows its dynamic nature. Overall, the model shows significantly improved predictions (Figure 2) of body fatness (bias, -0.22, and standard deviation, 2.29 %-units) and empty body weight gain (bias, 21, and standard deviation, 25 g/d) over previous models. However, the maintenance function used is the traditional form adopted by nutritionists and may not be correct, especially in a dynamic situation.

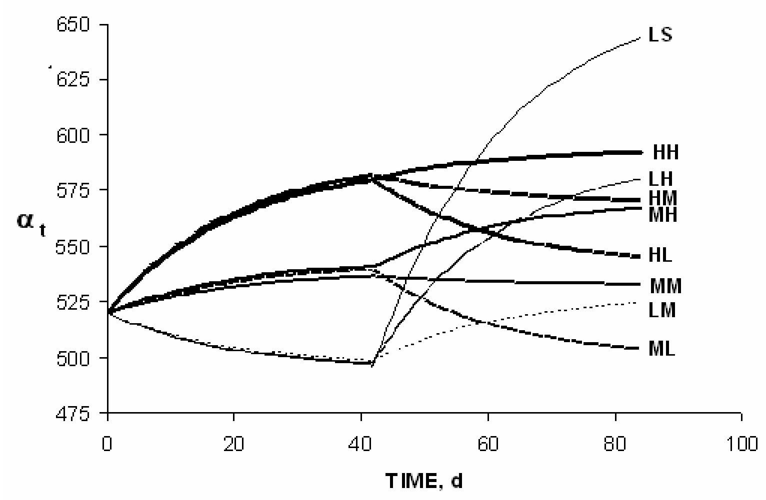

Figure 1. Model predicted maintenance coefficient (α) as a function of time (t) for nine treatment groups of Ferrell et al. (1986).

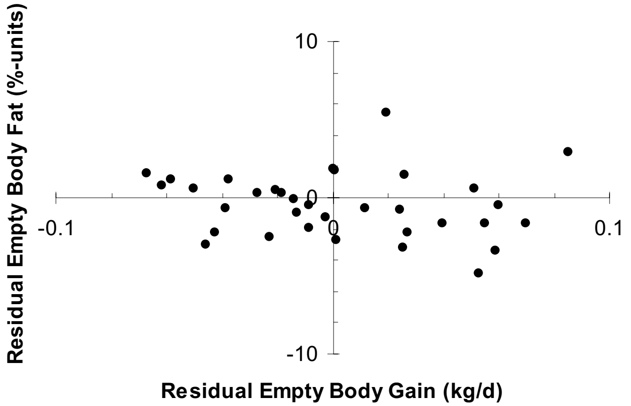

Figure 2. Residual (predicted minus observed) empty body fat and gain for rams fed 84 d (Ferrell *et al.*, 1986).

One of the advantages of the way the model is formulated is that the performance of different functions describing heat production of the animal can be investigated. We tested different approaches to estimating HP and found that an alternative multiple regression equation including muscle protein, visceral protein, and the change in muscle and visceral protein could also be used:

$$HP = b_1\, m + b_2\, v + b_3\, dm/dt + b_4\, dv/dt \tag{17}$$

where b_1 and b_2 were 1.023±0.333 and 10.54±3.40 MJ/(d kg), respectively, and b_3 and b_4 were 60.93±13.80 and 282.7±91.6 MJ/kg, respectively (Oltjen and Sainz, 2001). Heat production per unit protein mass of viscera is about ten times that of muscle. Eisemann *et al.* (1996) found that oxygen consumption of liver plus portal-drained viscera of 450 kg steers was about 7.5 times that of hindquarters tissue on a per unit mass basis. Also, since viscera responds faster than muscle to changing energy intake by the animal, this equation results in more dynamic HP. In any case either traditional net energy concepts or more general functions for HP can be compared to choose the best functional description.

Conclusion

Sheep growth and composition is more accurately predicted with the revised model, and the model predicts empty body weight and fat content more accurately than the current feeding system (SCA, 1990). New additions refine predictions at levels of energy intake at or below maintenance. Limitations identified are imprecise parameter estimates due to lack of longitudinal datasets. The model provides the structure for predicting composition of growing cattle as well, but has yet to be completely parameterized and tested.

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The future role of robotics systems in Precision Livestock Farming

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Abstract

This paper explores the potential for robotics in animal husbandry. New technologies give us the chance to improve animal welfare in cybernetic husbandry systems. The paper discusses first the main developmental trends relating to this, the growing use of expert and decision support systems, smart learning machines, and mobile robots with tracking systems. Then it deals in particular with dairy cows and the progress in autonomous robotic milking systems. To improve robotic milking three different solutions are considered.

Keywords: cybernetic husbandry system, expert system, learning machine, mobile robot

Introduction

In recent years, demand has increased for cybernetic systems in animal husbandry. The term cybernetics is used here in the original sense of Wiener (1961). In his book "Cybernetics or Control and Communication in the Animal and the Machine" Wiener describes the original root of the word cybernetics: the steersman who controls a ship. The steersman has to predict the movements of the machine and tries to guide it. The living being acts and the machine reacts. This is "indeed one of the earliest and best-developed forms of feedback mechanisms" (Wiener, 1961). Cybernetic systems can be feedback mechanisms between machines and living beings, although at the beginning only humans were considered. But with modern technologies animals can follow in these footsteps too. There can be a strong relationship between animal and machine with an overhead control by the farmer. Such cybernetic systems can allow improved animal welfare for large herd sizes. The implementation of milking robots on farms are an important example of these interesting developments. Modern technology means that animals can now be treated more individually. Cybernetic systems enable us to establish higher standards, leading us into an era of what we can call Smart Livestock Farming (SLF). This term can be defined as the incorporation of agricultural husbandry systems comprising an interdependent network of technologies like robotics, artificial intelligence, sensors, learning machines, and knowledge bases that consider economic and ecological aspects as well as ethical issues.

Main developments

The past two decades have seen the important development known as Precision Agriculture. In the CAB database one can find 2786 documents which contain the word "precision AND agriculture" from 1972 until now. The term "Precision Livestock Farming" itself was coined later, but its concepts were also an issue in the past. Norbert Wiener predicted half a century ago, that robots will conquer our jobs. His predictions came true in the past and the robots will influence life on farms further more in future. This development won't stop in front of our barns. At the end of the 20th century there were interesting developments of robots used in livestock systems in different countries. The main focus was and still is on milking robots. Thum discussed the prospects and possibilities of automating the milking process as early as 1977 and 1979. Ordolff published papers about a system for automatic teat-cup attachment in 1983 and 1984. Rossing asked the question "Can a robot be used for milking in a concentrate feeding box?" in 1985. In the patent literature there are several early attempts to automate the milking process like Jakobson and Rabold (1985), Van der Lely and Bom (1986), Bartmann, *et al*. (1988) and Habelt (1988) to name just a few. These patents and papers indicate the beginning to the revolution.

A search of CAB Abstracts finds about 700 records about robotics (robot*) for the years 1996 to the first half of 2004 but only four percent of them address mobile robotics. Although there are a rapidly increasing number of papers about Automatic Milking Systems (AMS), the use of mobile robots in livestock farming systems is still not discussed much. There are however some patent approaches in this area. In patent literature from 1995 one can find an invention by Van der Lely for a milking robot that can move "to an animal to be milked and performs the milking on the spot". In recent years there has been more activity inventing devices and developing methods for mobile robots used for livestock. Ally *et al*. patented in 2003 new ideas developed from Van der Lely's. The inventors show a shed in which cows can move freely and can be retained at a feeding station. Fransen *et al*. (2002) developed a new idea of mobile robots, where a milk collecting unit may serve as a master station for mobile milking units. The mobile milking units have their own propulsion, resulting in a multifunctional construction. Their use is not restricted to barns.

It is apparent that there are three main developmental trends:

a. Growing use of expert systems, and thus decision support systems
b. Smarter learning machines
c. More mobile robots with tracking systems

a. Growing use of expert systems, and decision support systems

Both expert systems (ES) and decision support systems (DSS) contain knowledge bases. The difference is that the expert system provides an inference machine whereas a helpful DSS requires the farm manager to draw conclusions him/herself, leaving responsibility with the farm manager. ES can therefore only be used where technology is sufficiently reliable. For the animals this is not just an economic issue, but also an ethical problem. We can raise reliability by increased data acquisition and sophisticated analysis. With increasing freedom for animals in husbandry systems we have the potential to gain more information on animal behaviour. It is essential that we obtain reliable information about behaviour in order to provide a constant production level, assure animal welfare, and maximise animal health. The farmer therefore has to observe the animals more closely, which is time consuming, especially in systems that provide extensive freedom for the animals. Thus, observation must be automated by monitoring to keep costs low. The data on each animal should be stored in a knowledge base, so that an expert system can analyse all data with its inference machine. The data to be recorded could comprise characteristics of the animal's behaviour collected by tracking systems, or attributes of the health condition measured by special sensors, as well as performance features. Important information could be selected allowing the robot to respond to the particular needs of an animal. The analysis of data with respect to individuals is a major issue for improving animal welfare in larger herds. However, merely monitoring the animal's condition is not sufficient. The inspection of the technology itself is just as important. The early detection of problems in combine harvesters is already a subject of scientific research. In animal husbandry such an early detection is even more important for ethical reasons and as machines handle more and more animals.

b. Smarter learning machines

The more freedom allowed for animals in husbandry systems, the more the systems have to learn how to react and to behave. The increased freedom in our farms is correlated with increased intelligent technology. The animals need to know how to deal with such technology. But the development of the AMS has shown that cows do not know how to maximise their milk yield. Consequently, animals need to be trained. Since a farmer does not have enough time to teach all his cows to visit a milking box at the appropriate time, learning machines and learning programs are a suitable way to improve the performance of the cows. Control over optimal milking time is not the only conceivable activity. Some cows have to learn how to use a cubicle for ruminating and resting, or how the procedure of hoof trimming can be practised more comfortably. This should result in reduced stress. These training exercises are known from experiences with horses or zoo animals, e.g. visits of a veterinarian.
Conceivably, learning machines could be shared between farms. Another interesting aspect would be to enrich the environment for animals, an important issue in pig farming. With learning machines pigs or other animals can be kept sufficient busy. For instance, Manteuffel *et al*. (2005) developed a technique for active feed acquisition by pigs. Anomalies in behaviour could be reduced and health problems might be identified over time, as ill animals may show less interest in learning. In addition, animals have to be treated individually because of their different learning abilities, motivation and status in the herd hierarchy. Figure 1 displays a machine that can be used for two different occasions. The animal can either choose different switches and is able to express its demand or there is a 4 or 6 field monitor that acts as a learning machine. Each switch is connected with one symbol and the animal has to choose the right symbol to get for example food or water. Some work has been done regarding goats and field monitors (e.g. Franz, 2001; Franz and Reichart, 1999, Franz and Roitberg, 2001).
Another aspect is the ability for a machine to learn by itself. A lot of research has been carried out on machines which can learn via observation (e.g. Dillmann, 2004; Bentivegna *et al*., 2004). The farm manager could easily teach the robot by demonstrating the task. The robots then "increase their performance through practice" (Bentivegna *et al*., 2004). In this case, the technology is more flexible for the farmer, because the re-programming is much easier. A third aspect is the ability of the robot to learn from the animal. The technology needs to observe the reactions of the animal (emotional etc.) in order to improve handling. Dominguez-Lopez *et al*. (2004) studied adaptive neurofuzzy control of a robotic gripper with on-line machine learning. The authors wrote that "pre-programming complex robotic systems to operate in unstructured environments is extremely

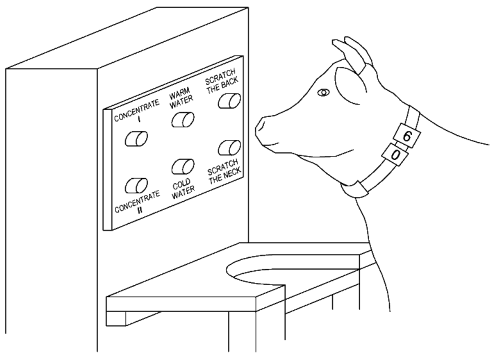

Figure 1. It is possible to use special tools as learning machines where animals can show their preferences.

difficult because of the programmer's inability to predict future operating conditions in the face of unforeseen environmental conditions. The solution to this problem is for the robot controller to learn on-line about its own capabilities and limitations when interacting with its environment." This is an interesting approach for robotics dealing with animals because the animal's behaviour is very often unpredictable.

In order for the machines to learn on-line animal handling they either have to be equipped with adequate sensors that measure the behaviour itself or they have to be provided with data from a knowledge base. Technology that reacts to human behaviour and feelings is called "affective computing". "Affective Computing is computing that relates to, arises from, or deliberately influences emotions" (M.I.T. Media Lab). The question "could a wearable computer be designed to recognize a person's emotion over an extended period of time?" was investigated by Picard (2003). Four skin-surface sensors (electromyogram, skin conductance, blood volume pulse, and respiration) for long term monitoring were used. Such parameters could also be used for animal assessment. If the emotional state of an animal is known it can be controlled and trained more efficiently and technology can change its handling due to the new information. If we want to avoid attaching too many sensors to the individual animals we could mount sensors onto the machines. The advantage would be the use of a single sensor for the entire group or herd. To reduce irritation to the animals visual sensors are a good choice. Wilhelm *et al*. (2004) described a multi-modal system for tracking and analysing faces on a mobile robot. Such a system could be combined with a Facial Action Coding System. Bartlett *et al*. (1999) measured facial expressions by computer image analysis. The authors used the Facial Action Coding System (Ekman and Friesen, 1978). This is an objective method for quantifying facial movement in terms of component actions. The question arises whether such an idea could work for animals.

In addition to monitoring individuals, we should strive to acquire information about the entire herd or flock in order to make statements about infectious diseases, or other factors affecting the herd. This information can complete the view.

c. More mobile robots with tracking systems

Currently robots are mainly used in industry, although there is a growing number of robots deployed in domestic parts of our lives, like medicine, and of course agriculture. The AMS is the best known example of a robot used in agriculture. Besides milking robots there are other interesting approaches like sheep shearing robots (Trevelyan, 1982) or the invention of Van den Berg (2002). In the patent specification an unmanned vehicle "provided with detection components for determining the health and behaviour of the animals in the stable or meadow" is described. Already fully developed and available on the market are manure removing robots, developed especially for agricultural use. Robots to remove manure are mobile (e.g. Joztech, JOZ) and they have learned to use special routes through the barn. Other interesting ideas can be found in areas of industry or homes. Lawn mowing robots (e.g. Automower, Electrolux) could be used to keep the grass short underneath electric fences.

To improve the efficiency and flexibility of mobile robots it would be helpful to couple them with animal tracking systems. Due to improved wireless technology there are already systems available which have accuracy of at least 20 cm in all three dimensions. Information about the position of individual animals can be very useful in aiding the task of a mobile robot. The required accuracy depends on the environment and the size of the animal.

Good ideas already exist for using robots in husbandry. Yet the only system that has been accepted so far is the milking robot. AMS have proved to be very suitable on farms in spite of some problems that remain unsolved and which have been criticised in recent years. The aim of constant milking intervals can not be assured. The cows are supposed to be milked at constant intervals but it cannot be expected that they visit the milking robot at constant intervals in order to maximise their milk yield. This view would be anthropomorphic. Moreover, the best time to be milked is not necessarily the same from either a biological or an economic point of view. There is no evolutionary sense to this, especially if there is no calf.

Three different solutions are possible if we want to maintain the freedom for cows. First of all the robot could be partially mobile. Although, much research has been done over the past two decades on AMS, the most recent conference with the topic "Automatic milking, a better understanding" was held in Lelystad, NL (eds. Meijering *et al*., 2004), where only a few advances on mobile robots were proposed. One was in Japan, although the robots are intended to be used in byres (Hachiya *et al*., 2001; Ishii, 1998). But adaptation of such a system to loose housing is conceivable if the cows are retained at feed barriers (Figure 2). A mobile robot could drive along the barriers and milk the retained cows. Stalls could be used to improve the separation between feeding places. In combination with pasture a mobile robot has advantages. The fixing of the cows could be done at the water trough or a mobile feeding stance (e.g. trailer) (Umstätter and Kaufmann, 2003). Ally *et al*. (2003) have already patented a similar idea.

The second possibility is a completely mobile robot which drives through the alleyways and milks the cows e.g. in the cubicles where they can be fixed for that short period of time required. After milking process the robot would release the cow and drive to the milk tank for cooling. Such a robot needs access to data from animal tracking systems that provide it with the position and action of an animal. If the animal is resting the robot can decide to wait and milk another cow instead.

The third possibility can be divided into two options:

- The robot finds the cows and motivates them to follow, requiring data on the animals' positions. The best motivation to follow is to feed a concentrate on the way to the milking box.
- The robot leads the animals to the milking box. Vaughan, *et al*. (2000) have developed a mobile robot in the "robot sheepdog project" "that gathers a flock of ducks and manoeuvres them safely to a specified goal position." The authors state that "this is the first example of a robot system that exploits and controls an animal's behaviour to achieve a useful task." Such a system could guide cows to the milking box at a specified time.

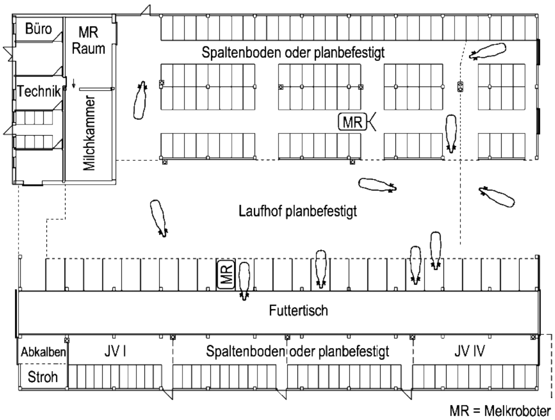

Figure 2. Mobile Milking Robots.

Advantages and disadvantages

The three main trends have to be combined for useful SLF. Our modern large herd sizes can only maintain high welfare standards if smart technology is used. Because of high labour costs one employee has to deal with an increasingly large number of animals. To react to individuals we need data collected by sensors and stored in knowledge bases. Information has to be filtered with expert or decision support systems. Learning machines that teach animals and/or which learn themselves present many opportunities. To control the production process learning machines and robots are useful devices that help to reduce labour costs. The three dimensional movements of each individual animal can be recorded with a suitable tracking system. Afterwards the data can be processed and saved in a knowledge base. The behaviour can be analysed under different aspects like oestrus, the period near birth, diseases and hierarchy in the herd.

In a good husbandry system it is necessary to perform an optimised balance between the reliability of the environment for all animals on one hand and enough stimuli on the other. The reliability of robots is often better than that of humans, because machines are not bad tempered, oblivious, ill etc. An interesting stimulus can be provided by robots if they have learned enough about the special behaviour from the individuals. E.g. housing systems for pigs often show a great lack of stimuli. Robots can help to keep pigs busy, distracting them from their companions when necessary. They can guide cows to find a "traditional" fixed milking robot at the right time, adapt them to cubicles, improve the handling for veterinarians, and facilitate hoof trimming.

The three options to optimise milking intervals for cows by using a milking robot show that there are versatile ways to solve the problems. At the moment milking robots look more like milking parlours without a milker. The new generation of milking robots can be totally different, and there are many ways to reach the goal. The systems are not fully developed but there is a great potential. The adoption of improved, smart systems depends on the advantages and costs of the systems.

To reduce the costs of robots it would be useful to design a basic robot with accessory equipment. Then it is possible to sell higher numbers of robots. Moreover the capacity of such a robot can be fully used even with a smaller number of animals in one production unit. The robot could for example both feed and milk the cows. To satisfy the aim of flexibility the robot needs a compact format and has to work as autonomously as possible. Both qualities are requirements for a competitive product. With increasingly flexible applications and the reduction of the problem that not all cows visit the AMS voluntarily, sales could be increased. Economic advantages arise with compact size.

Modern technology used in SLF is a great opportunity for the improvement of animal welfare standards whilst sustaining economic production, but this development has to be observed critically. Implementing robots in housing systems without sufficient knowledge about animal behaviour could have harmful effects on animals, such as distress and injuries, and it could also increase labour.

A major disadvantage is the cost of such a system. The implementation of cybernetic husbandry systems appears very expensive, but we should remember that we are already implementing AMS. Possibilities of cost reductions in such systems are a major task for scientists.

A critical comparison of robotic systems is important. Many currently do not perform adequately. They have to become more flexible, more intelligent, more reliable and cheaper.

Outlook

The quality of relationship between animals and corresponding technology has already changed in recent years and future changes will go further. Animals and their supporting technology will have a new form of partnership. Technology like robotics and sensors can react to the animals' demands allowing individuals to act and decide.

The idea of improved animal welfare by SLF is based on the concept of bringing the animal and smart technology together in a new relationship. The advantages of smart machines are that they are less emotional and therefore more reliable than human beings. Additionally, the duration of their memory is not limited. Robots can function as fair and reliable trainers that can focus on the individual's character with different learning strategies.

With such a system an environment can be created which satisfies the need for enrichment. Stress can be reduced by a reliable environment, and by special training and exercises for stressful situations like visits of veterinarians and hoof trimmers. We can deal then with the animals as individuals and thus optimise performance.

Certainly, such systems are far from completion and will not be ready for use in the near future. But we have to be conscious that computers and a growing number of different sensors are already part of our life. Weiser and Brown (1996) stated that "it is easy to find 40 microprocessors in a middle class home in the U.S.A. today". The authors forecast a new era called "ubiquitous computing" (UC), which means "lots of computers sharing each of us. Some of these computers will be the hundreds we may access in the course of a few minutes of Internet browsing. Others will be imbedded in walls, chairs, clothing, light switches, cars - in everything. UC is fundamentally characterized by the connection of things in the world with computation...When our world is filled with interconnected, imbedded computers, calm technology will play a central role in a more humanly empowered twenty-first century." When such scenarios come true, the technology will not stop at the barn door.

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Lying behaviour of dairy cows under different housing systems and physiological conditions

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Abstract

Rest and activity are fundamental and complementary indices of animal behavior. Monitoring lying behaviour (LB) for individual dairy cows can advance precision dairy farming by indicating animal comfort in different housing conditions and physiological status.
The objectives were: 1) to study diurnal lying behaviour (LB) of dairy cows under normal commercial management routine; 2) to compare the effects on LB of different housing systems; 3) to study LB in relation to activity, normally and during oestrus.
A leg-mounted sensor to monitor and register lying times was developed, tested, and found reliable. Data were downloaded during milking times.
In a first trial 12 multiparous cows in a roofed no-stalls barn, under comfortable thermal conditions. lay for 8.8 ± 1.6 h per day. Lying periods ranged from 3.7 ± 1.3 h, between 20:00 and 05:00, and 2.3 ± 0.8 h, between 13:00 and 20:00.
In a second trial, 8 first-calving cows were housed in each of two adjacent completely roofed barns: one no-stall and the other free-stall; the third trial repeated the second trial, with 4 cows from each group interchanged. In both trials, cows of both groups demonstrated diurnal lying patterns similar to that of trial 1, except that those in the no-stall barn lay for 2 h more then those in the free-stall barn.
The free-stall cows were more active; there was a significant negative correlation between activity and lying time in the free-stall barn, and no correlation in the no-stall barn. Lying time was significantly shorter in cows that were in oestrus, in accordance with the increase in activity.
The lying sensor can indicate the suitability of housing conditions for animal comfort, can improve oestrus detection, and probably can provide early indication of health problems.

Keywords: Lying behaviour, dairy cows, comfort, welfare

Introduction

Rest and activity are fundamental and complementary components of animal behaviour. In ruminants in general, and dairy cows in particular, lying behaviour (LB) reflects the rumination activity as well as resting patterns. The LB may be affected by the daily routine activities such as feeding and milking, and by individual temperaments; it is often considered as an indicator of cow comfort in comparisons between different housing environments (Metz 1985, Singh *et al*., 1993; Ketelaar de Lauwere *et al*., 1999; Sonck *et al*., 1999; Fregonesi and Leaver, 2002; Haley *et al*. 2001; Horning *et al*., 2001). LB measurements may be used to reveal physiological changes in dairy cows, such as onset of oestrus (Phillips and Schofield, 1990; Brehme *et al*., 2004) or health problems (Galindo and Broom, 2002). In the cited studies the LB data were obtained through visual observations whereas in the present study a leg-mounted sensor was developed and was used to monitor, record and transmit lying times.

The objectives of the present study were: 1) to study diurnal LB under normal commercial management; 2) to compare the effects of two different housing systems on LB; and 3) to relate LB to activity in regular and in oestrous cows.

Materials and methods

A leg-mounted sensor to monitor and record lying times and periods was developed in the Institute of Agricultural Engineering, The Volcani Center. The sensor is based on ability to measure the angle of the leg in relation to the ground as the horizontal axes, and can store and transmit data. The sensor starts recording 60 sec after change of position. Ongoing patenting prevents the disclosure of technical details of the sensors at present. The sensor was tested by comparison with parallel visual observations (example in Table 1) and by comparing data obtained by two sensors fitted to the same cow (Figure 1). The power source (commercial batteries) was sufficient to run the sensor for at least one month. Collected data were downloaded during milking.
Trial 1: The sensor was used to monitor and analyze the LB of 12 Israeli Holstein multiparous cows for 3 weeks. The cows, which produced an average of about 35 kg milk/d, were housed in a completely roofed, no-stall barn in the research dairy of the Volcani Center. The weather conditions were comfortable. Feeding (total mixed ration - TMR) and feed recovery (i. e. moving

Table 1. Visually and sensor measured lying time of one cow between 10:00 and 16:00h.

Lying time hh:mm:ss			% difference
Visually observed	Sensor measured	Difference	
00:42:53	00:43:57	+ 00:01:04	2.3
00:41:20	00:41:33	+ 00:0013	0.5
01:02:00	00:59:18	- 00:02:42	4.8

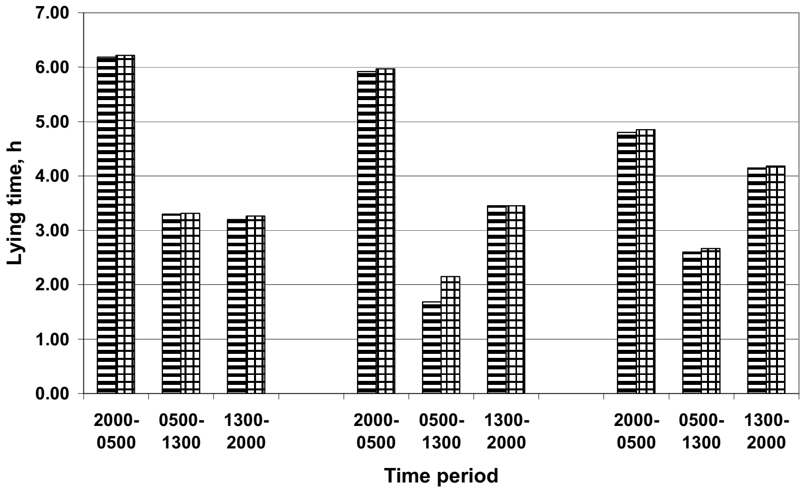

Figure 1. Diurnal lying times during between-milking intervals of one cow measured by two different sensors (different bar shadings) each fitted to a hind leg.

mechanically scattered food to within reach of the cows) were performed once daily (09:00-10:00, and 16:30 respectively), and milking thrice daily (05:30, 13:30, 20:30).
Trial 2: In a commercial dairy farm in which 550-600 cows were milked thrice daily (04:00, 12:00, 20:00), two adjacent barns at equal walking distances from the milking parlor were used for this trial. Both were completely roofed; one was a no-stall barn, the other free-stall. Each barn housed about 100 cows. Sixteen first-calvers were selected (eight in each barn) and each was paired with a counterpart in the other barn, with similar time after calving, milk yield (MY) and body weight (BW) (Table 2). LB, activity, and performance were monitored for 10 days, starting on the 5th day carrying the sensors. The cows were fed four times daily (04:00, 07:00, 11:00 and 18:00) with a TMR, and feed recovery five times daily (03:00, 08:00, 12:00, 17:00 and 01:00). Activity and performance were monitored with an Afifarm Management System (S.A.E. Afikim, Israel). Significance of differences was evaluated with Student's t-tests: unpaired, between groups; and paired, between periods and between treatments in the same cows.
Trial 3: Eight cows that participated in Trial 2 - four cows from each of the two barns were switched over to the other barn. After the transferred cows had been allowed one week to adaptat to the new conditions, performance activity and LB were monitored for 11 successive days and analyzed.

Table 2. Average details of 16 1st-calving cows tested in a completely roofed, no-stall barn or free-stall barn (8 cows in each barn) (mean ± SD, and range).

Pen type	Days in milk	Body weight, kg	Milk yield, kg/d
No-stall barn	141 ± 40 (74 - 186)	480 ± 41 (434 - 552)	35.5 ± 4.3 (26.0 - 39.5)
Free-stall barn	139 ± 42 (71 - 182)	482 ± 17 (461 - 510)	35.7 ± 3.1 (31.8 - 42.0)

Results

In the first trial, the cows spent 8.8 ± 1.6 h per day lying; the longest lying time (3.7 ± 1.3 h) was recorded between 20:00 and 05:00; the shortest (2.3 ± 0.8 h) between 13:00 and 20:00.
In the second trial, cows of both groups demonstrated qualitatively similar diurnal lying patterns to that observed in trial 1, but quantitatively there was a significant difference between the two groups (Table 3). On average the cows in the free-stall barn lay for approximately 2 h (20%) per day less than those in the no-stall barn. The greatest difference (1.5 h) was recorded between 13:00 and 20:00, and the smallest (0.5 h) during the morning.

Table 3. Lying times (means ± SD) during daily between-milking intervals of eight cows in a no-stall barn and eight in free-stall one

Time interval	Lying time (min)		Free-stall lying time, as % of no-stall lying time	Significance (P<)
	No-stall	Free-stall		
04:30 - 12:30	157 ± 42	120 ± 43	76.4	0.01
12:30 - 20:30	118 ± 50	108 ± 49	91.5	ns
20:30 - 04:30	258 ± 51	199 ± 50	77.1	0.001
24h total	533 ± 87	427 ± 90	80.1	0.001

This pattern was fully confirmed by the switch-over results obtained in Trial 3 (Table 4). The cows that were transferred from one barn to the other adopted the lying behaviour characteristic of the cows that had always inhabited their destination barn (Table 3). Cows that had spent about 10 h lying in the no-stall barn spent lying 3 h less lying diurnally after their transfer to the free-stall barn (Table 4), but maintained the same proportions of lying time between milkings (Table 5).
The activities of the cows that were transferred between the two barns were compared (Trial 3). The data in Table 3 are presented for individual cows in order to highlight the differences between individual cows as well as the diurnal uniformity of each cow's activity (Table 6). Whether cows were transferred from no-stall to free-stall conditions or vice versa made no difference: In each case the activity level was higher and lying time lower in the free-stall barn (except for one cow, #6734, that did not change her lying time). The individual differences in lying times were much smaller than those in activity levels. There was a significant negative correlation between cows' activity levels and lying times in the free-stall barn (R^2 = 0.6663), and no correlation between these two variables in the no-stall barn. No significant changes in milk yield and body weight were recorded as a result of the transfer from one type of barn to the other.
There were only three cases of oestrus that could be monitored in relation to LB and activity level. In all of them the lying time dropped significantly during the day of detection of oestrus, similarly to the increase in activity in timing and magnitude (Figure 2).

Table 4. Lying times (means ± SD) during daily between-milkings intervals of two groups of four cows that were transferred from one type of barn (period 1) to the other type (period 2).

Time interval	Period 1 (min)		Period 2 (min)	
	No-stall	Free-stalls	No-stall	Free-stalls
04:30 - 12:30	153 ± 41[*a]	120 ± 39[*]	178 ± 55[a]	126 ± 55
12:30 - 20:30	110 ± 45[*]	113 ± 48[*]	148 ± 46[a]	78 ± 43
20:30 - 04:30	254 ± 51[* a]	180 ± 56[*]	259 ± 58[a]	200 ± 75
24h total	517 ± 73[* a]	414 ± 77[*]	585 ± 75[a]	404 ± 69

*Significant difference (P < 0.01, paired t-test) in lying behaviour of the same cows when transferred from one barn to the other in different periods.
[a]Significant difference (P < 0.01, unpaired t-test) in lying behaviour between groups (4 cows) inhabiting different barns within period.

Table 5. Cows lying time distribution (percentage of 24-h total) in between-milkings diurnal intervals of two groups of four cows that were transferred from one type of barn (period 1) to the other type (period 2)

Time of day	Period 1		Period 2	
	No-stall	Free-stalls	No-stall	Free-stalls
04:30 - 12:30	29.5	29.0	30.5	31.2
12:30 - 20:30	21.3	27.4	25.2	19.3
20:30 - 04:30	49.2	43.6	44.3	49.4
24-h total	100.0	100.0	100.0	100.0

Table 6. Maximal diurnal activity level (steps/h, average ± SD, and range of 11 successive days) of two groups of 4 cows transferred from one type of barn to the other. The first group of 4 cows were moved from a no-stall barn to an adjacent free-stall one, and vice-versa for the second group.

Cow	Activity* (steps/h)		Lying time* (min)	
	No-stall	Free-stall	No-stall	Free-stall
6634	179 ± 26	237 ± 33	601 ± 50	446 ± 96
	151 - 237	190 - 307	542 - 669	251 - 531
6734	237 ± 21	346 ± 34	417 ± 77	449 ± 63
	201 - 284	285 - 402	305 - 547	354 - 517
6736	137 ± 17	165 ± 19	492 ± 87	341 ± 74
	126 - 184	153 - 216	356 - 595	263 - 458
6738	75 ± 10	142 ± 13	576 ± 38	383 ± 42
	59 - 88	113 - 155	528 - 648	318 - 446
6655	147 ± 15	169 ± 11	647 ± 62	365 ± 55
	128 - 180	153 - 194	523 - 720	301 - 448
6677	124 ± 24	187 ± 25	511 ± 51	400 ± 70
	94 - 159	151 - 234	460 - 600	268 - 508
6684	151 ± 23	180 ± 31	624 ± 95	461 ± 95
	115 - 185	114 - 229	481 - 718	303 - 633
6811	142 ± 13	156 ± 17	579 ± 58	444 ± 82
	122 - 164	134 - 196	479 - 650	344 - 536
Average	149 ± 46	201 ± 65	556 ± 77	411 ± 45

* Significant difference in activity and lying time between treatments ($P < 0.005$, paired t-test)

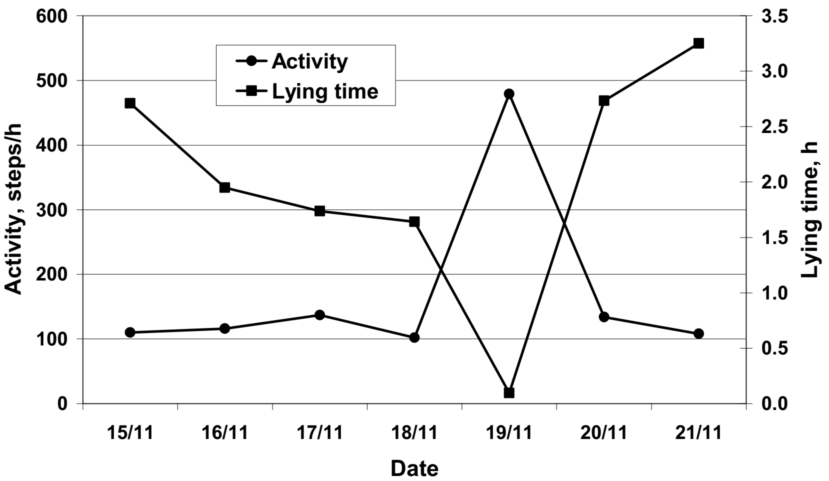

Figure 2. Lying time and activity of a cow in oestrus.

Discussion

The range of diurnal lying times recorded in the present study was similar to those recorded in other studies of dairy cows (Singh *et al*. 1993). Although the longest lying periods occurred during the night, a substantial part of the cows' daily lying time occurred during daytime. There was a range of differences of only 20%, approximately, between individuals in their daily lying times, whereas the difference in activity levels could exceed 100%. The lying behaviour can, therefore, be considered as a relatively stable parameter, similar to feeding (Halachmi *et al*., 2004), indicating its significance in the natural diurnal behaviour pattern of the dairy cow.

First-lactation cows were selected to evaluate the effectiveness of the sensor as a device for measuring lying times in two different housing systems, in order to eliminate the possible effects of size, hoof problems and acquired lying behaviour habits, especially in the free-stall system. The cows were selected to be in a lactation stage in which they were well adapted to the daily routines, and the variations in milk production over the measuring period were very moderate (Maltz *et al*. 1991). The lying behaviour as measured diurnally is likely to indicate differences in the cows' comfort in two different housing systems. One of the definitions of animal comfort is the freedom to persist in its natural behaviour, therefore, the fact that a cow spent about 8-10 h diurnally lying in a no-stall barn and 20% less in the other housing system may indicate that something is wrong with the latter system. It is impossible to claim at this stage that the no-stall barn is a superior housing system to the free-stall, even though shorter lying times have been recorded in the latter systems (Singh *et al*. 1993, Fregonesi and Leaver, 2002). Such a conclusion would require more measurements under similar controlled conditions in more dairies, with different stalls and bedding, especially since contrary evidence has been reported as well (Horning *et al*. 2001). However, in the case of the particular two systems in the present study, it seems that the no-stall system provides more comfortable conditions for dairy cows than the free-stall one. The fact that the milk production and body weight were not affected by the housing conditions does not necessarily lead to a contrary conclusion. Indeed, MY in Jersey cows was not affected by restriction of lying-time (Verkerk *et al*. 1999). However, it can be suggested that the driving force for milk production is strong enough to maintain performance despite less comfortable conditions. Rumination also takes place while cows stand. It is possible that the "payment" for overcoming this discomfort is, in the long run, reduced resistance to the extreme physiological demands of lactation, which leads to a higher replacement rate. The cows in the free-stall barn were significantly more active than those in the no-stall barn, perhaps because they were more restless. This is confirmed by the negative correlation between lying time and activity level that was observed in the free-stall barn but not in the no-stall one. This may indicate that in the no-stall barn cows may just stand if they prefer this activity, while in the free-stall environment this alternative (standing) seems less evident.

The effect of housing conditions on LB indicates that LB monitoring could be used for evaluating and improving animal welfare. For this purpose it might be sufficient to monitor the LB of a few cows in order to evaluate the suitability of facilities or management routines. Monitoring the LB of cows transferred from one facility to another, or monitoring the changes in LB that follow a change in a routine could be a useful tool in the adoption of animal-friendly routines and facilities. In addition, this sensor could contribute to more efficient oestrus detection, in parallel to other existing methods. In tied stalls, this is likely to be the most efficient single sensor for detecting standing heat. The stability of LB, on the one hand, and its sensitivity to physiological changes, on the other hand, suggest that this sensor could also indicate deterioration in animal health.

Conclusions

The lying sensor which was developed for research purposes was found to be useful for reliably and continuously monitoring the lying behaviour of dairy cows in different housing environments, as well as their physiological conditions. In this particular case it seems that the no-stall environment was superior to the free-stall.
It was concluded that an LB sensor could serve as an indicator of the cow's welfare and for use in comparing different housing conditions. The sensor has the potential to improve oestrus detection, and it is likely that it can indicate health problems, and this is an objective of our future work.

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Information management within Australian precision dairy systems

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Abstract

Precision farming research has primarily focussed on the development of technology while the social component, that of the farmers who are responsible for realising the potential of the new system, is often overlooked. As precision farming becomes more prevalent in the Australian dairy industry farmers will face the challenge of management within information intensive systems. Preliminary research into farm management on farms using individual cow management shows that use of information for decision making, the role of employees, and training and learning processes for users are primary issues requiring attention.

Keywords: dairy, electronic identification, information management

Introduction

Precision farming is a strongly techno-centric concept and could be accused of representing technology-push from scientists and manufacturers. Yet when the systems are installed on farms it is the farmer who has the primary role of achieving a benefit from their investment. The post-adoption utilisation and performance of precision farming has sometimes lagged behind the expectations of those viewing from the outside, such as scientists. In most cases this is not due to problems with the hard technology itself, rather with uncertainty over what the technology can do and interpretation of the information being collected. Little research has been focussed on how the precision concept works in terms of a whole farm system, from the perspective of the end user, the farmer. This paper reviews the need for research on how precision dairying technologies fit into Australian dairy systems, with particular emphasis on information management. Preliminary results of a study into information management in individual cow management systems are presented.

Precision dairying in Australia

Precision dairying as a concept is largely unheralded in Australia, where dairy farming systems are predominantly pasture-based and traditionally productivity is measured in terms of per hectare rather than per cow production (Shephard, 2004). While the importance of pasture as the feed base is still paramount, there is a move toward greater use of supplementary feeds to maximise cow production and fill feed gaps. This mix of pasture and supplementary feeding opens the door for precision farming systems in order to maximise utilisation of expensive purchased feeds. In such a system precision dairy farming will encompass both site-specific and animal-specific components. Currently in Australia the more obvious benefits of the latter has led to use of individual cow management in some herds. There is little evidence of significant use of technology for site-specific dairy pasture management, although research is being conducted on satellite and ground-based sward measurement, and on targeted fertiliser application.
The ownership structure of Australian dairy farms is primarily owner-operator, with approximately 15 percent having a share farming structure (Dairy Australia, 2004). Similar to dairy industries

around the world the total number of Australian dairy farms has been decreasing (20,000 in 1980 to under 10,000 in 2004) and average herd size is increasing (85 cows/farm in 1980 to 210 cows/farm in 2004), the number of very large herds (1000+ cows) is also on the rise. In recent years the Australian dairy industry has been faced with significant pressures from severe drought and domestic milk market deregulation leading to many farmers exiting the industry. Consider also consistently declining terms of trade and it is not surprising that ABARE (2002) suggests that those farmers left in the industry will remain viable by increasing herd size, farm size, and through adopting more intensive production practices.

Increasing herd size has been associated with specific challenges for farm management, such as a diminished ability for farmers to remember pertinent information about particular cows (Rossing, 1999). Electronic identification (EID) systems have provided a technological approach to the previously intuitive process of individual cow management (Reid, 2003). EID facilitates use of associated cow monitoring and management technologies such as milk metering, individual feeding, automated drafting, heat detection, and cow health and milk quality monitoring.

Dairy farming has been constantly associated with design and uptake of technology designed as farm management aids, for example the original pulsating milking machine and electric fencing. Information technology (IT) promises to have a large impact on dairying internationally and Australia is no exception. Little published information exists on the level of IT use in Australian dairy systems but approximately half use personal computers (Rodriguez, 2003), up from 38 percent in 1998 (ABARE, 2002). Anecdotal evidence suggests that EID-based systems are primarily installed at the same time as major upgrades to the milking shed and during the 1990s many farmers upgraded or replaced their dairy shed although there is no specific information on installation of EID systems during this period (ABARE, 2002).

A major increase in the uptake of individual monitoring may result as a consequence of the National Livestock Identification Scheme (NLIS) that has, in some states such as the dairy farming stronghold of Victoria, made RFID tags compulsory in all cattle. With the enabling technology already present in their herd, farmers may look at using other associated individual management technology.

These drivers of increasing herd size, increased used of supplements, uptake of on-farm IT, and the NLIS scheme, combined with the never-ending search for efficiency gains, will mean significant management at the individual animal level throughout the Australian dairy industry in the near future. For farmers, moving from a semi-intuitive management system to one based on significant amounts of regular information on each animal in the herd brings new challenges about which little is currently known.

The need for information management research

Cox (2003) outlined the two ways IT-derived data can be used, either to monitor and control machines and equipment, or to provide inputs for management decision making. The latter identifies a key foundation requiring further study, that although IT may help gather the information farmers need the key step still surrounds how the farmer uses the information in their decision making. In fact, investing in the technology is the comparatively easy step, the true test begins when learning to interpret and use the information, a challenge noted by several authors on precision agriculture. Spahr and Maltz (1997) identified the interpretation of sensor data and determining appropriate responses to individual cow information as a major challenge for managers of robotic milking systems and this applies to all users of individual dairy cow monitoring. Fountas *et al*. (2003) stated that ‘conversion of the gathered data into useful and valuable information for decision making and the interpretation of results still remain a challenge’. According to Robert and Iremonger (2003) many of the PA farmers they studied were not properly

using the data they had gathered and that one of the primary areas PA users require help is to 'process, manage, and use efficiently all the data collected'.
Research has been conducted into the use of IT and management information systems (MIS) to address dairy information needs (Van Asseldonk *et al*., 1999b) and potential farm impacts of MIS adoption (Tomaszewski *et al*., 2000a,b). Verstegen and Huirne (2001) conducted research into the relationship between farm management and value derived from MIS use in Dutch pig farming systems. However, there is a dearth of research specifically assessing the process farmers employ to use an individual cow management system and the information that flows from it.
Farmers often need to make decisions based on incomplete data and under significant uncertainty (Thysen, 2000). A goal of EID systems is improved control (Jongebreur, 2000) and provision of more decision making certainty in herd management. It is an inherently information rich approach to management and this can present specific challenges to farmers used to operating instinctively and from experience.
The use of IT in agriculture is also designed to streamline the decision-making process and simplify management. Yet the installation of new technology and the intensive acquisition of data can be intimidating or confusing for farmers and therefore the whole system is perceived to be more complex than the previous system. According to Batz *et al*. (2003) this concept of relative complexity impacts on adoption and implementation of new systems and therefore could be a significant issue in EID and individual cow monitoring.

Materials and methods

Semi-structured interviews were used to uncover issues surrounding management of information intensive dairy farms. Potential participants were selected based on the following criteria. Participants will:
- Dairy farm in Victoria, of any size or structure;
- Utilise, or intend to utilise, information in the form of electronic data/numbers regarding system variability at an individual animal scale;
- Use the information gained to guide farm management policy at an animal specific scale;
- Be the primary people using the collected data to make management decisions.

Farmers were identified through industry contacts and where possible a range of farming types were sought (large/small, family/corporate). Snowball surveying, where participants were asked if they knew of anyone else using individual cow management systems, was also utilised. A sample size of 20 was targeted, contingent on the coverage of issues.
The study was designed with an inductive perspective and aimed to uncover issues and provide a base for more focussed investigation on the topic. The method therefore is not expected to present views that could be seen as applicable to the entire Australian dairy industry.
Interviews of approximately 1.5 hours length were conducted on the participant's property. Each interview was audio taped and participant's comments were also noted on paper. Participants were asked to share their views and experiences in the use of animal-specific information around the topics of reasons for uptake, role in decision making, skill and learning required, and problems experienced with the system.
Data from the interviews were analysed using NVivo software with main themes from each interview noted from a revision of both interviewer notes and revision of digital recordings.

Results and discussion

At the time of submission half of the 20 interviews had been conducted and the primary issues uncovered to date provide a guide to potential areas for further investigation and analysis. The main areas of interest included reason for uptake, system composition, labour issues, decision making, and training. Farmers interviewed operated systems ranging from 240 cows to 1000. Farm ownership structures included family, partnership, and corporate.

Reasons for uptake

The drivers for adoption of EID-based systems for the farmers interviewed varied and predominantly reflect specific farm characteristics and goals. One major reason stated was a desire for more information on the herd and linked to this was the need for more timely information on which to base supplementary feeding decisions. The goal of having less stress during milking was often mentioned, with alarms and voice alerts for issues such as mastitis and heat detection meaning that operators had more confidence that important cows would not be missed. It also provided the owner or manager the option of spending less time in the shed at milking while having confidence that the workers would pick up these cows. Less contact time with the cows was offset by increased monitoring of production data after milking via the computer software.

System composition

All but one farmer installed their system during a major shed upgrade or replacement. The one farmer who did retrofit equipment was only utilising EID as an operational tool during milking and did not carry out milk metering or individual feeding.
As with the goals for the system, the level of investment also varied, from solely EID to full EID-based milk metering, individual feeding and automatic drafting system. Approximately two thirds used collar EID while the remainder used NLIS tags. Two farmers were using pedometers.

Labour

The relationship between the farm labour force and the EID system was one of the most important issues to arise from the interviews to date. The availability of dairy farming labour is an issue of concern throughout the Australian dairy industry currently. As discussed previously the use of individual monitoring allows the primary decision makers to free themselves from the routine of milking and focus more on management. In most cases this required confidence in the staff to reliably carry out daily herd management tasks. Some farmers said that EID gave them this confidence while others were not so sure. When questioned on whether EID allowed them to employ less skilled labour there were also varied responses with some saying yes while others commented that they only employed skilled and adaptable labour. Respondents were divided over whether having new technology in the dairy shed made it easier to attract workers with a concern voiced that computers actually intimidated some potential employees.
There tended to be one person responsible for data analysis. In several cases the farmer interviewed commented that staff only used the computer system for the most basic data entry, such entering alarms for cows with health problems or noting joining dates.
From the preliminary investigation completed it appears research is required regarding the roles and responsibilities of dairy farm staff in systems utilising EID.

Decision making

The use of information for decision making among participants can be grouped into the three areas of feeding, operational decisions, and tactical decisions. Where farmers were using individual feeding the presence of milk meters is proving invaluable. Previously decisions were made based on 1 monthly herd testing alone, and production variation between herd tests would not be picked up. This is reinforced by Spahr and Maltz (1993) who state that the measurement of milk production is important for fine-tuning management of high-producing herds. Herd testing is still important in these systems to provide information on milk quality and somatic cell counts.

EID-based systems are extremely important for decision making at an operational level. Cows with problems can be easily identified and drafted out automatically and all farmers interviewed highly appreciated the aid of the computer system in picking out these cows. A pertinent issue here for information management is the setting of parameters for computer alerts. Farmers appeared to use a trial and error system of setting this targets/limits and further research into guidelines for parameter setting would prove useful to the industry.

Currently most use of the systems appears to be at the operational level rather than tactical or strategic. Milk flows are used to aid decisions on drying off dates and cow culling but little structured data analysis is undertaken, which is surprising given the wealth of information being collected.

Training/learning

Most of the participants received some training at the time of installation, ranging from two hours to one day. However it is uncertain how useful these sessions are. The consultant will explain the potential uses of the system and the computer procedures required, but at this stage the farmer has difficulty contextualising what the system is capable of, and is sometimes overwhelmed by the computer commands required. Learning the system requires time and skills will improve over several years after adoption (Van Asseldonk *et al*., 1999a). It appears that it is not until after several months of using the system that farmers begin to understand what they what to achieve with it. It is at this stage that additional training is most required.

Another major issue is the timing of system implementation. Due to the EID-based technology being installed along with a shed upgrade a farmer's first experience with use may be at the start of a new season. Stress levels are high with farmers and employees disinclined to spend time exploring the potential of the new system or fix glitches. In the words of one respondent 'we just tried to survive the first months with the new system'.

Conclusions

Precision dairy farming is set to become recognised as a system applicable in the Australian context. Information management will be one of the major obstacles to farmers realising the full potential of their precision technology investment.

The topic of management within precision dairy farming systems has received very little research attention yet it is an area where significant work is required to ensure farmers are equipped to reap the rewards of their technology investments.

Preliminary results from this research indicate that the areas of labour, decision making and training/learning are where problems can arise. It is in these areas of management that researchers can aid farmers, by highlighting potential pitfalls and suggesting practices to avoid them.

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Control charts applied to individual sow farm analysis

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Abstract

The aim of the study was to quickly detect weak elements in pig production using statistical control charts. Two charts were used to detect small deviations: the cumulative sum (CUSUM) control chart and the exponentially weighted moving average (EWMA) control chart. For an optimal design of the EWMA- and the CUSUM-charts a Monte-Carlo-Simulation was performed. The trait considered was piglets born in total. Specific small shifts were implemented to test the performance of the charts. The average time to signal (ATS) and false positive rate (FPR) were taken as classification parameters to evaluate the performance of the charts. All shifts were detected with CUSUM and EWMA control charts. CUSUM showed ATS ranging from 1.3 (FPR= 33.5%) to 8.9 weeks (FPR= 0.2%). In EWMA charts the ATS ranged between 2.0 (FPR= 14.8%) and 7.3 weeks. Both charts are useful tools to trace weak elements in commercial swine farming EWMA is easier to set up and to optimise in online controlling, it enables a clear graphical presentation.

Keywords: EWMA, CUSUM, control chart, farm analysis, weak-point-detection

Introduction

Growing sow herd sizes and narrowed margins are main characteristics of modern pig production. Therefore the need for effective management information systems becomes more important with the increasing demand on the management skills of the farmer. Information technology enables the farmer to record and analyse farm data. But effective tools for tracing deviations are missing. The aim of the present study was to quickly detect weak elements in pig production for improving the production process. This paper presents an approach for computer based farm analysis, to support the decision making of the farmer.

Materials and methods

Statistical process control charts are control methods that are widely used to monitor the consistency of production processes (Montgomery, 1997). A control chart consists of a centre line (target specification) and a lower and upper control limit (Figure1). These control limits are chosen so that if the process is under control, nearly all observations range within these limits. A shift of the production process outside of the control limits indicates that the process is out-of-control and a signal occurs. Corrective action is required to find and eliminate the assignable cause.
Various types of statistical control charts have been developed and are widely used in industrial quality control. The Shewhart chart is the oldest control chart. The Shewhart control chart uses the information of the last plotted observation, ignoring any information given by the entire sequence of the foregoing observations. Therefore this control chart is very insensitive to small shifts (Montgomery, 1997).
There are two effective charts that may be used when small deviations are of interest: the cumulative sum (CUSUM) control chart and the exponentially weighted moving average (EWMA) control chart.

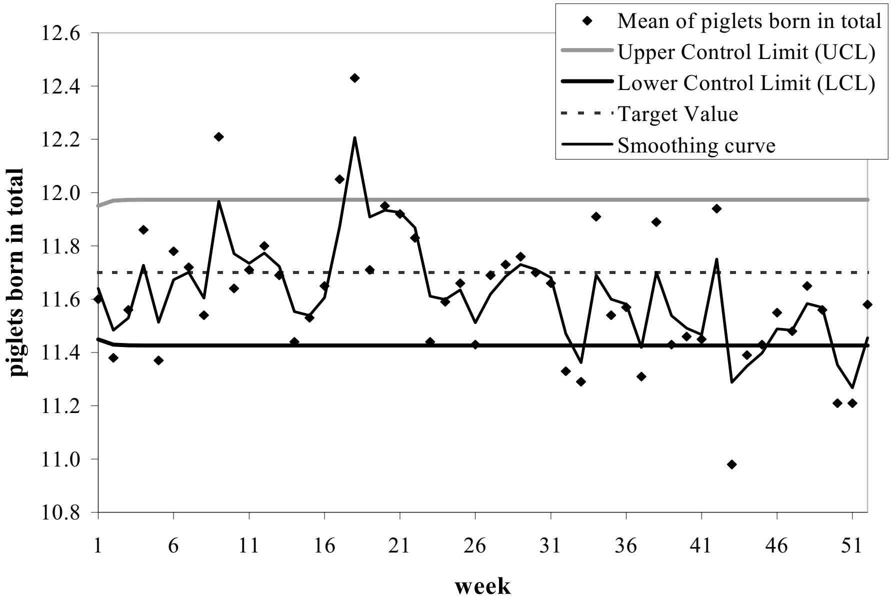

Figure 1. Illustration of a control chart.

CUSUM-Charts

The CUSUM chart, originally developed by Page (1954), plots the cumulative sums of the deviations from a target value using samples from all prior weeks. This method differentiates between upward and downward drifts, therefore the calculation of the upward and downward cumulative sum of the observations is performed.

The variable x_i (mean value per week for piglets born in total per litter), independently distributed as $x_i \sim N(\mu_0,\sigma^2)$, is standardised before adapting the CUSUM with the overall mean (μ) and standard deviation (σ):

$$y_i = \frac{x_i - \mu}{\sigma} \tag{1}$$

Through standardising the target value (μ_0) becomes 0 with $\sigma_0 = 1$.

The standardised two-sided CUSUM accumulates deviations above μ_0 to the upper CUSUM (C_i^+) and below μ_0 to the lower CUSUM (C_i^-). Starting values for upper and lower CUSUM are 0. In the chart the CUSUM (C_i^+ or C_i^-) with the higher value is plotted. For clear presentation the C_i^- are graphically shown as negative values (multiplied with -1).

$$C_i^+ = \max[0, y_i - k + C_{i-1}^+] \tag{2a}$$

$$C_i^- = \max[0, -k - y_i + C_{i-1}^-] \tag{2b}$$

With the reference value k the CUSUM-chart can be adjusted. Low k-values effect a high sensitivity, higher values result in lower reaction of the chart.

The upper (UCL) and lower control limit (LCL) were determined by the h-value. This value expresses the factor of σ_0 defining the distance between μ_0 and the limits UCL and LCL, respectively.

$$UCL = h * \sigma_0 \tag{3a}$$

$$LCL = h * \sigma_0 \tag{3b}$$

EWMA-Charts

Since EWMA was first introduced by Roberts (1959), a variety of methods have been developed to detect shifts in the process mean. In EWMA control charts the process is monitored using a weighted moving average of the foregoing observations. The weights decline exponentially depending on the smoothing parameter λ with increasing time distance between historical and actual value.
The EWMA (z_i) is defined as:

$$z_i = \lambda x_i + (1-\lambda) z_{i-1} \tag{4}$$

If the observations x_i are independent random variables with variance σ^2, the variance of z is:

$$\sigma_z^2 = \sigma^2 \left[\frac{\lambda}{2-\lambda}\right]\left[1-(1-\lambda)^{2i}\right] \tag{5}$$

UCL and LCL were derived from (5).

$$LCL = \mu_0 \text{ - L}\sigma_z \sqrt{\left(\frac{\lambda}{2-\lambda}\right)\left[1-(1-\lambda)^{2i}\right]} \tag{6a}$$

$$UCL = \mu_0 + \text{L}\sigma_z \sqrt{\left(\frac{\lambda}{2-\lambda}\right)\left[1-(1-\lambda)^{2i}\right]} \tag{6b}$$

The upper (UCL) and lower control limit (LCL) are determined by λ, overall mean (μ_0) and standard deviation (σ).The L-value has the greatest impact on distance between μ and the limits.

Classification parameters

There are two different types of errors that can be made by an statistical control chart. First, the type I error (false positive), if the chart gives a signal, but the process is in control. Second the type II error (false negative), that is the risk of an observation falling within the control limits when the process is really out of control.
Crowder (1987) and Lucas and Saccuci (1990) evaluated the average run length (ARL) as a performance criterion of EWMA charts. The ARL is the number of points that must be plotted before a point indicates an out of control condition. In this study the parameter *in control average time to signal* (ATS_0) is used, analogous to the average run length (ARL_0), due to time based data. ATS_0 should be high to minimise the type I errors. This type of error is also classified by the *false positive rate* (FPR), that is the percentage of false positive alerts in relation to all in control values. The third parameter used in this study is the *average time to signal* (ATS), which characterises the mean time to detect a shift in process.

Monte Carlo simulation

Biological data differs compared to industrial process data. To get the optimal design for the EWMA- and the CUSUM-charts in pig production a Monte Carlo simulation was performed using statistical software SAS (SAS, 2004). The trait considered was piglets born in total per litter with μ_0=11.7 and σ = 2.5 following the investigation of Kirchner *et al.* (2004). Simulation was performed in two steps. First 100,000 data points (analogous to weeks in the real pig production process) were generated with 100 litters per week. No shifts were implemented. On the basis of the simulated 100 values per week [$x_i \sim N(\mu_0,\sigma^2)$], means were calculated. For evaluation ATS_0, the number of weeks (100,000 in this simulation) was divided by the number of false positive alerts. With the ATS_0, the value of the two parameters h and k of the CUSUM control chart as well as L and λ of the EWMA control chart can be roughly designed (Figure 2).
As shown in Figure 2, the ATS_0 level increases with rising L-Values, e.g. a L-= 2 results in ATS_0 from 163 to 45 weeks. Choosing a smaller L-value (L= 1), ATS_0 from 31 to 7 weeks occur. Low λ-values result in exponentially higher ATS_0.
Comparable calculations of ATS_0 were accomplished for the CUSUM chart.
The adjustment parameters of the charts were chosen, based on the results of the first part of the simulation.
In the second part of the simulation, 100 litters per week were generated. In this simulation the time period was 52 weeks. A negative shift of 0.1 σ and 0.2 σ, respectively was implemented from week 33 till week 52. This simulation was replicated 100 times.

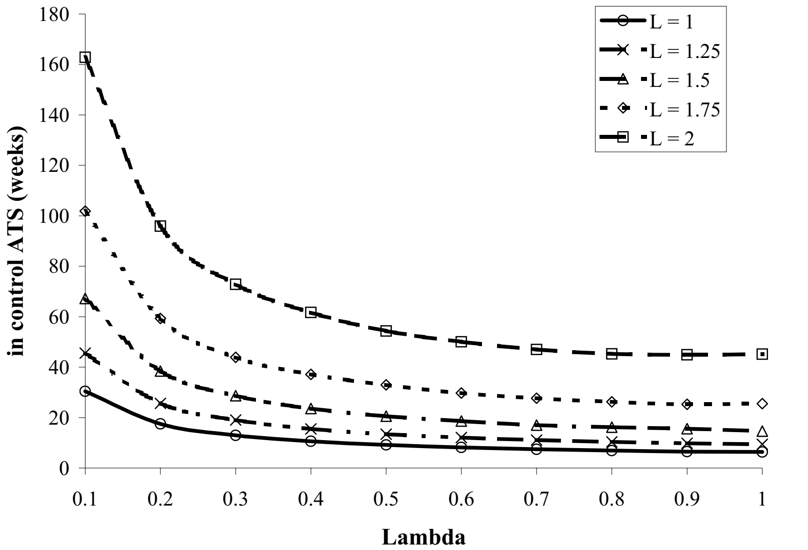

Figure 2. ATS_0 depending on the smoothing parameter λ and varying L values.

Results

With CUSUM- and EWMA-charts small shifts in pig production process are to be found. In the present study all simulated shifts (0.1 and 0.2 σ, respectively) are detected, but ATS and FPR differ strongly, depending on the parameter settings.

Using CUSUM-charts, an increasing h-value (from 1 to 2, k=0.5, shift=0.1 σ) leads to decreasing FPR from 18.7% to 6.1% but simultaneously ATS increased from 2.5 to 4.2 weeks (Table 1). The FPR is independent of the implemented shift due to the fact, that the calculation is performed on the basis of the time period where no shifts are implemented (week 1 to week 32). FPR vary analogue to the ATS_0, which are calculated on the basis of the first simulation. The ATS_0 show the mean interval between the false alerts if no shift exist and therefore indirectly the probability of false alerts. A smaller k-value makes the CUSUM-chart more sensitive, showing short ATS and high FPR.

Higher shifts in the mean lead to better classification. The mean time until detection of the shifts is reduced and the relative number of false positive alerts are constant.

Using EWMA (λ=0.2), FPR decreases from 6.8% to 1.0%, if L increases from 1 to 2, LCL is moved away from the target value. ATS ranges from 3.5 (L=1) to 5.8 (L=2) weeks due to the fact that the probability of an observation falling beyond the control limits is reduced with higher L-values.

By the choice of weighting factor λ, the EWMA chart can be made sensitive to a small or gradual drift in the process. If $\lambda \rightarrow 1$ EWMA puts all the weight on the most recent observation, a small value of λ gives more weight to older data. A higher λ leads to lower ATS but the number of false positive alerts increases significant. With a shift in the mean of 0.1 σ the ATS are determined between 2.0 and 7.3 weeks. If the shift in the mean rises up to 0.2 σ, ATS declines (1.2 to 3.3 weeks).

Table 1. Classification parameter average time to signal (ATS) and false positive rate (FPR) for different settings (h- and k-value) and different shifts using CUSUM.

h	k	ATS_0 (weeks)	FPR (%)	ATS (weeks) shift = 0.1σ	ATS (weeks) shift = 0.2σ
1.0	0.25	2.7	33.5	2.1	1.3
1.0	0.50	5.3	18.7	2.5	1.3
1.0	0.75	11.7	8.4	3.8	1.6
1.5	0.25	3.5	24.8	2.7	1.4
1.5	0.50	8.7	10.6	3.4	1.6
1.5	0.75	25.8	3.2	5.4	2.0
1.5	1.00	56.3	1.0	7.3	2.6
2.0	0.25	4.5	17.8	3.2	1.5
2.0	0.50	14.4	6.1	4.2	1.9
2.0	0.75	56.4	1.2	6.8	2.4
2.0	1.00	244.5	0.2	8.9	3.2

Discussion

The application of statistical control charts in agriculture is not very common. De Vries and Conlin (2000) applied CUSUM control charts to oestrus detection in dairy cows. The authors mentioned, that changes were detected soon enough to be potentially useful in dairy management. Pleasants *et al*. (1998) applied CUSUM for monitoring effects on ultimate muscle pH in Angus and Hereford steers.

Table 2. Classification parameter average time to signal (ATS) and false positive rate (FPR) for different settings (L- and k-value) and different shifts using EWMA.

L	λ	ATS_0 (weeks) shift = 0	FPR (%)	ATS (weeks) shift = 0.1 σ	ATS (weeks) shift = 0.2 σ
1.0	0.1	31.3	4.8	4.3	2.4
1.0	0.2	17.8	6.8	3.5	1.8
1.0	0.4	10.7	10.1	2.6	1.4
1.0	0.6	8.2	12.7	2.3	1.5
1.0	0.8	7.0	14.9	2.0	1.2
1.5	0.1	67.2	1.7	5.4	2.7
1.5	0.2	38.5	2.9	4.3	2.2
1.5	0.4	23.6	4.3	3.8	1.7
1.5	0.6	18.6	5.4	3.5	1.5
1.5	0.8	16.2	6.3	3.3	1.4
2.0	0.1	162.9	0.8	7.3	3.3
2.0	0.2	95.9	1.0	5.8	2.6
2.0	0.4	61.7	1.7	5.4	2.2
2.0	0.6	50.1	1.9	5.6	2.0
2.0	0.8	45.3	2.0	6.3	1.9

Decisive for the performance of both CUSUM and EWMA charts are the parameter settings. The design parameter L and λ of the EWMA Chart and h and k of the CUSUM chart are not easy to choose. Therefore a simulation study is useful, to find the best parameter settings for, in this case, sow production data, with the aid of classification parameters ATS_0, ATS and FPR. The different shifts that were implemented resulted in different ATS, but the FPR were not affected. There have been many analytical studies of the average run length performance of the CUSUM, e.g. Montgomery (1997) recommended h=4 or h=5 and with k=0.5 that leads to in control ARL_0,=168 or ARL_0=465. On the one hand such high ARL_0 would perform very low FPR and on the other hand too long time intervals until shifts result in alerts. The data were based on weekly sub-groups, resulting in 52 means per year. If an ATS_0= 370 following Montgomery (1997) would be used, a false positive alert would theoretically occur every 7 years. On the other hand the chance of finding shifts in the process would be very low.

In some investigations the Markov Chain approach (Lucas and Saccucci, 1990) or the Fredholm Integral of the second kind (Wieringa, 1999) were used to find the in control average run length. The authors applied parameters adjusted to industrial processes with high L-values > 2 and consequently high ARL_0. Although the high values are not suggestive for the biological data in this study, calculation of ATS_0 (analogous to ARL_0) with the same parameters show similar results.

The adjustment of λ, influences the detection of shifts. With lower λ ($0.05 \leq 0.25$) smaller shifts can be detected (Montgomery, 1997). A high λ will detect larger shifts faster, if $\lambda = 1$, the EWMA chart behaves like the Shewhart chart. These statements can be confirmed in the present study. The choice of λ is more important if small shifts should be found. Differences between ATS for different λ get smaller with higher shifts. For sow farm analysis small shifts, that can not be detected without detailed analysis implemented in management information systems, are of interest. After an alert occurs, troubleshooting should be started, to eliminate the problem.

The setting of the classification parameters also depends on the willingness of the farmer, to accept false alarms. If ATS is low, more false positive alerts will occur, but the chance to detect real shifts earlier, increases. The classification parameters L (EWMA) and h (CUSUM) behave in a similar way: a high value results in broader control limits, which cause longer ATS and smaller FPR. Parameters λ (EWMA) and k (CUSUM) are not comparable.

Conclusions

With the optimal design, both charts were well qualified to detect small shifts in the pig production process. EWMA provides lower FPR with the same level of ATS. EWMA is advantageous, due to the fact that the chart is easier to set up and to optimise in online controlling of a process.
Both EWMA and CUSUM charts enable a clear graphical presentation of the results. The presentation of the EWMA chart is easier to understand, because real values are assigned in contrast to CUSUM, that works with deviations. Modern computer technology enable the implementation of control charts in online production monitoring. Further analysis of the relevant (out-of-control) deviations should examine the underlying causes to improve the farm performance. Control charts are useful tools to trace shifts and deviations in commercial swine farming. The next step in optimising the EWMA chart is to assemble the different parameters in sow farm performance to design a combined evaluation system for detection of weak points.

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Precision livestock farming in developing countries: creating order where uncertainty prevails

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Abstract

In resource poor systems, knowledge on the animals, processes and the environment forms the basis for the daily decision making of the livestock keepers. However, their ways to control the production process has so far been largely ignored in production system research. The aim of the present paper is to devise a systematic approach to describe and analyse the management of livestock keepers in resource poor systems. The control loop is used to analyse the information flow in the production system.
The analysis reveals the distinctions made by livestock keepers, what they consider as information in their production process and upon which rules they base their actions. It shows how far the livestock keepers in resource poor systems are able to control the production, i.e. create order and reduce uncertainty, and which aspects remain uncontrollable to them. Following the precision livestock farming approach the results form the basis for the identification of relevant traits for assessment by researchers e.g. in the form of recording systems in order to provide feedback to the livestock keepers on their success or to develop methods to improve the monitoring capabilities of the livestock keepers themselves in order to increase their possibilities to control production.

Keywords: resource poor systems, management, control loop, information flow

Introduction

Precision livestock farming deals with the exact and detailed assessment of animal-, process- and environment-related data with the aim to better control a production process. Livestock keepers in resource poor systems cope with high spatio-temporal heterogeneity and production risk and usually manage highly diverse systems (Udo and Cornelissen, 2002). They possess detailed knowledge on the animals, processes and the environment and their decisions and actions, i.e. their management plays a major role in creating and maintaining order in the systems. Their knowledge and ways to control the production process has so far been largely ignored in production system research (Chambers and Ghildyal, 1985). To show the importance of the management in the production system, Sørensen and Kristensen (1992) depicted a farming system in the form of a control loop, in which the production system (bio-technical system) is connected to the management system (social system) via communication and control. However, as Noe and Alrøe (2003) note, the management itself still remains a black box.
The aim of this paper is to devise a systematic approach to describe and analyse the management of livestock keepers in resource poor systems, through the example of camel keepers controlling reproduction of their camels. The control loop is used as an analytical tool. Management is described in form of “Aim-Observation-Action-loops”, which are sustained through a flow of information. An observation is defined as “indication by means of distinction” following Spencer Brown’s differential theory (Spencer Brown, 1979) and information is defined as “the differences that make a difference” following Gregory Bateson (Luhmann, 2004). This means that a distinction made while observing may lead to an action (resulting in change/difference in the

production system) and/or learning (resulting in change/difference in the mind of the livestock keeper) (Flechtner, 1966). The guiding questions are:

- Which distinctions do livestock keepers make when observing?
- What do livestock keepers consider as information in their production process?
- Which rules do livestock keepers base their actions upon?

Materials and methods

Production system under study

This study forms part of a long-term study (1994 - present) of the Rendille camel dominated pastoral livestock husbandry system in the drylands of Northern Kenya. Livestock husbandry is the only means of livelihood. All products for subsistence and income generation, as well as a number of security and socio-cultural functions, are provided by livestock. The Rendille keep sheep and goats as small stock and predominantly camels, but also a few cattle as large stock. The camel is the backbone species of the system, ensuring survival in the harsh area.

Median annual rainfall for the years 1980 - 1994 across the 10 range units of Marsabit District varied from 200 mm to 380 mm, whereby two thirds fell during the long rains (March to May) and one third during the short rains (October to November). Droughts of 12-20 months occur once every 5 years (Schwartz *et al*., 1991). Rainfall varies greatly both temporally and spatially, whence a large spatial and temporal heterogeneity in vegetation from natural pasture results. Across the 10 range units, herb layer forage biomass production ranges from 608 to 1332 kg/ha and 293 to 702 kg/ha following the long and the short rains respectively. Shrub layer forage biomass production ranges from 242 to 668 kg/ha and 57 to 298 kg/ha after long and short rains respectively (Schwartz *et al*., 1991). Livestock mobility is essential, as none of the range units alone can provide year round forage to any of the livestock species kept.

Households are largely sedentary and pasture areas around settlements are deteriorated. Livestock species are herded separately. The camel herd is further split into one smaller home based herd, which contains just a few milk camels to cover the household's needs, and one larger satellite herd, which contains the remaining camels. Rendille camels are a comparatively small and hardy breed (Hülsebusch and Kaufmann, 2002). The reproduction is seasonal in both male and female camels, with males being sexually active (rutting) during the rainy season and females having an induced ovulation.

Data collection and analysis

The present study is based on information gathered together with Rendille pastoralists in their endeavour to compile a standard text book on camel management practices to be used in school education for their children. The information and data was collected in a series of open interviews with key informants, i.e. camel herd owners known to be knowledgeable in livestock management and outspoken. The information provided was structured by the informant. Mostly 2-3 key informants were present, whereby one was the lead interviewee and the others added information and commented affirmatively or challenged. The information was verified, clarified and complemented twice in consecutive interviews with other key informants from different locations and clans, in order to avoid biases. Informants assume responsibility for the information provided through authorship for the respective sections in the textbook.

For the present attempt to establish "Aim-Observation-Action-Loops" following the rationale of the control loop, a subset of information on management of female camels was used. As in the present approach, the control loop is employed as tool to systematically describe and analyse

management, the terminology of a conventional control loop used in control engineering is maintained and the equivalent elements in the livestock production system are identified.
The analysis is directed towards: a) identification of traits, which livestock keepers consider for their management, b) determination of the trait expressions that are differentiated and lead to an action, and c) identifying the rules behind the actions.

Results

Livestock keepers attempt to control conception in primi- and multiparous females. This control not only influences the number of offspring but also milk offtake from the herd since milk and offspring production are interlinked in a cow-calf system, which is intensively used for milk production. The parameters of the control loop for conception in heifers and multiparous females in Tables 1 and 2.
The *Controller* is the livestock keeper and the *Controlled Process* is the female camel. When reading the information given for the control loop in the Tables, it must be kept in mind that the livestock keeper has a certain idea about the *Target value* (which might depend on his wealth status), and that the deviation of the *Actual value* from the *Target value* is due to the *Disturbance variables* given. After observing such a deviation from the *Target value*, the livestock keeper thinks about what to do to reduce the difference, i.e. he sets a *Command signal* and decides in which management area (*Actuating element*) he can achieve it and what he has to do specifically (*Manipulated variable*).

Traits considered by the livestock keeper and differentiations made

When controlling the conception in females, livestock keepers observe the following traits: age of the female, period since last parturition, sexual behaviour, occurrence of mating and conception, pregnancy behaviour, health status, body condition, conception problems, infertility and fate of the calf.
Observation of environmental disturbance factors is also mostly done using those traits of the animals that are affected. For instance, poor pasture condition is observed through trait expressions such as “animal is not satisfied when feeding” and “poor body condition”.
The trait expressions differentiated by the livestock keeper are given in Table 3.
For each of the different trait expressions observed there are rules on how the livestock keeper reacts to the disturbance. The rules are *if-then*-statements such as
“*If* the female does not conceive but the bull is rutting and the season is normal *then* treat it with specific herbs”. “*If* the female does still not conceive in the next season *then* ask a specialist to look for intra-vaginal warts”. “*If* there are warts, *then* remove them and have the female mated immediately”.

Discussion

Analysis of “How” instead of “What” is produced: second order cybernetics

The main characteristic of the present analysis is that the researcher does not collect data on elements of the production system (like reproduction data, amount and quality of feed supplied) and analyses them to create order for scientific or extension purposes (e.g. determining reproduction parameters, energy supply to the animals) and to come up with hypotheses (i.e. rules), but rather assesses how the livestock keepers create order for their managerial purposes, i.e. what they observe, differentiate and which actions they take depending on their observations (i.e. their rules). This approach follows the theory of the observer (Winter, 1999) which is a systems theory

Table 1. Control over conception in heifers.

Target value	For normal camel owners: heifers conceive at the age of 4 yrs. For wealthy owners: at the age of 5-6 yrs. For poor owners: heifers in good condition conceive at 2.5-3 yrs.					
Sensor	Herd owners count the age of their females. They notice whether and when a female has been mated and whether it shows pregnancy behaviour.					
Actual values, in yrs	Conceiving at 2.5 -3	..at 4	..at 5-6	..at 5-6	..at 7	at > 7 not yet conceived
Observations on disturbance variables	Not mature: no signs of sexual behaviour. Bull is not interested	Quasi mature: signs of heat, but not ready to accept the bull; Only a bull which is used to heifers is interested	n/a. (fully mature)	Possible conception problem: if mated before and still not conceived	Confirmed conception problems	Infertile (=does not conceive in at least 4 normal seasons)
Command signals	Forcing (if poor owner)	Assisting	No action	Treating	Treating	Using alternatively
Actuating elements	Selection of a heifer in very good condition	Choice of bull; Assisting during mating by skilled person	Mating is responsibility of the bull	Decision about the treatment	Decision about the treatment	Decision about alternative use
Manipulated variables	Tie the heifer in the morning in the pen and get it mated by a bull that likes heifers	Prevent female from running away when mated; Avail a bull used to heifers or a bull that mates the first season	Rutting bull is present	Treat with traditional remedies	Check for intra-vaginal warts and remove by specialist	Sell, slaughter, train as pack camel if your own camel

Table 2. Control over conception in multiparous females.

Target value	Female camel conceives 8-12 months after the previous parturition (PP) so that it calves down every two years						
Sensor	Counting months elapsed since previous parturition; recording of the mating event; observing occurrence of pregnancy behaviour						
Actual value, in months	conceiving at 0-3 mo after PP	..4-7	..4-7	..8-12	..13-18	..19-30	at >31 mo not yet conceived
Observations on Disturbance variables	Not ready to be mated (risk to get infertile)	Not ready to be mated (pregnancy would affect body condition and milk yield)	If calf died, and/or if too few camels to be mated in the herd	n/a (ready to be mated)	Possibly poor condition because of lack of pasture or disease	Conception problems (2-3 normal seasons not conceived)	Infertile (4 normal seasons not conceived)
Command signals	Preventing from being mated	Preventing from being mated	Allowing to be mated	No action	Improving feeding or treating	Treating	Using alterna-tively
Actuating elements	Careful supervision near the homestead; Avoiding loitering bulls	Decision about herd to be kept and about area; Avoiding loitering bulls	Decision about herd to be kept	Mating is response-bility of bull	Decision about pasture area or treatment	Decision about treatment	Decision about alternative use
Manipulated variables	Protect from own and foreign bull; tie bulls securely at home, herd the new-lactating camels	Put in herd without bull, do not go to grazing area with other camel herd with a bull	Put in the herd with rutting bull	Rutting bull is present	Go to good pasture in the dry season or treat against recognised disease	Treat with traditional remedies	Sell or slaughter if your own camel

Table 3. Traits observed when controlling the conception of females.

Trait	Differentiation level
Sexual behaviour	Is or is not interested in the bull (grazing in the vicinity, running after when bull is mating another camel), does or does not sit down for being mated, does or does not search actively for a bull (e.g. jumps over the fence).
Mating	Has or has not been mated.
Conception	Does or does not show pregnancy behaviour one week after been mated.
Pregnancy behaviour	Does or does not stand in an alert position raising the tail high up and urinating (called Gogisa), which is only shown by pregnant camels when approached by a bull or human beings.
Age	Half years, depending on season born they belong to a certain "generation".
Period since last parturition	Months and later also half years, they belong to a certain "generation" depending on which season they have calved down last.
Health status	Does or does not exhibit usual activities (e.g. walking at the usual speed, ruminating, being alert) and characteristics (shining eyes, shining fur). Does or does not show specific disease symptoms e.g. for Trypanosomiasis, Pneumonia, Malah, Khanid (the last two are diseases with unknown etiology).
Body condition	Poor (small hump, ribs can be seen etc.) because of disease, unknown reason or double stress of early lactation and pregnancy; good; very good in young heifers (precocious).
Conception problems	Does not conceive for 2-3 normal seasons due to poor body condition, warts in the vagina, no obvious reason or because of been mated soon after calving down.
Infertility	Does not conceive for 4 normal seasons although all treatment possibilities have been tried.
Fate of the calf	Alive, dead.

developed by Heinz von Foerster and used e.g. in sociology, business process management (Winter, 1999) and knowledge management (Willke, 2001). The scope of this theory for system analysis in agricultural sciences is explored in Alrøe (2000). The analysis does not focus on the elements of the production system in the first place but on the relations between the elements. It directs the attention from "What" is produced to the producers themselves and on "How" they produce (Pask (1969) in Foerster 1997:239).

How order is created

Efforts of the livestock keepers to create order have the following general features:

- keeping a certain species and breed with a constitution that fits the production conditions well, hence with specific production and adaptation traits, that can be exploited by the livestock keeper through his management;

- making use of traits with long lasting expressions, e.g. long life expectancy, since they reduce uncertainty;
- grouping the animals in specific classes, age and sex classes, but also according to their reproductive status (e.g. generation ready to be mated), their performance potential, the age of their calves, so that the whole group can be treated similarly, hence little information is necessary and management can be efficient;
- knowing possible disturbance variables and their effects and applying certain rules in case of their occurrence on herd, group or individual animal level;
- discussing their experiences and problems regularly with other livestock keepers to learn about the rules they employ and how effective they are.

Livestock keepers are able to create order when there are rules, predictability and necessity. But where the livestock keepers see disturbance, unpredictability and chance, there they are not able to create order and have no control. Especially in the latter case, demand for import of new knowledge (control possibilities) is high.

Limitations to creating order by livestock keepers in resource poor systems

Livestock keepers make quantitative observation in the case of counting (e.g. number of animals, length of periods), or observing the occurrence of events (e.g. mating has happened or not) or specific signs (animal is coughing). Mostly the observations are multidimensional, e.g. mating has happened at a certain point in time or space, or under certain conditions. The observations are mostly qualitative in nature when trait expressions are assessed, as for instance body condition or growth. It is an examination with the eye, whereby the animal's actual state is compared with its former state or compared with that of other animals within their reach.

The fact that the livestock keepers purely rely on their own senses as "sensors" and that they therefore lack quantification possibilities leads to coarse differentiations. It further leads to the impossibility to compare individuals over greater distances, or with a higher number of other individuals. This hampers more detailed observations, which could lead to more differentiated actions, and it also hampers the assessment of effects of certain actions on the trait expression in question.

Furthermore the degree of order of data obtained through the observations is low because livestock keepers hardly use any calculations to determine parameters, hence miss the order creating potential of computations. A Rendille camel keeper knows for each female camel in his herd how many calves it had, but he does not know the reproductive performance of his herd and cannot compare it with others. This was the same with livestock keepers in Europe about 60 years ago (Meyer, 1946) and was the reason for the establishment of performance recording systems. However, there are not many examples of well-organised field performance recording schemes in developing countries, and if at all, they cater for the needs of intensive production systems (Trivendi, 2002). From the above analysis it can be seen that the traits usually recorded in recording systems might not be of prior interest to the livestock keeper in resource poor systems. It is therefore suggested that prior to the introduction of any kind of performance recording system an analysis of the information flow in the production system should be conducted. Researcher and extension officers will thereby be in a position to agree with livestock farmers on traits useful to be assessed at population level. Such mutual understanding is seen as a prerequisite for the implementation of decision support tools in agricultural R&D (McCown, 2002).

Conclusions

Analysis using the control loop shows how far the livestock keepers in resource poor systems are able to control the production, i.e. create order and reduce uncertainty. It reveals that more factors influence reproductive performance than is the case in intensive production systems. When attempting to improve such complex production systems, researchers have the shortcoming that they do not know "which differences make a difference" for the livestock keeper and the livestock keepers have the shortcoming that their means to monitor and evaluate are very limited. The analysis of the information flow makes use of synergetic capabilities of both parties. The result should be used to identify relevant traits for assessment by researchers or extension staff (e.g. in form of recording systems) in order to be able to give feedback to the livestock keeper on their success or to develop methods to improve the monitoring capabilities of the livestock keepers themselves in order to increase their possibilities to control production.

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Identification of animals

Electronic identification (RFID technology) for improvement of traceability of pigs and meat

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Abstract

The steadily growing demands for documentation in integrated animal production systems and the need to optimize technical processes requires individual identification and a secure traceability of livestock animals. Within the framework of the EU Project "EID + DNA Tracing", investigations were carried out to improve the traceability of pigs using a combination of electronic identification (Low Frequency (LF, 134.2 kHz) and High Frequency (HF, 13.56 MHz) transponders) and DNA profiles to overcome the gaps between primary production, trade and consumer. In a preliminary research phase three different injection spots were examined concerning age of application, transponder size, losses and the recovery in the slaughterhouse. The intraperitoneal injection achieved the best results as far as readability, losses and recovery are concerned. In the implementation phase of the project, involving about 2,000 animals, only this injection spot was used. A total of 0.2 % of the animals died due to complications during injection and 1.5 % of the transponders were lost during lifetime. The recovery rate of the transponders in the slaughterhouse was higher than 98 %. A carcass identification system was also examined in the slaughterhouse with the aim of transferring the ID code from the LF transponder to a HF transponder which could in future accompany each single piece of meat to the sales counter. The carcasses could be labelled successfully, but in the event of non-readability of transponders or transponder losses further steps are necessary to ensure traceability.

Keywords: electronic identification, RFID, transponder, injectable transponder, traceability

Introduction

More and more consumers are requiring safety of foodstuffs after a lot of scandals in the food chain. Complete traceability makes it possible to remove dangerous or contaminated products from the food chain and to make food production safer. Therefore each animal has to be tagged individually, in order to remove single animals from the food chain in the event of diseases like BSE or Foot and Mouth. In Germany the identification of pigs with visual ear tags is compulsory. Unfortunately these tags do not offer any possibility for automation; therefore one of the main tasks in the EU Project "EID + DNA Tracing" was to examine electronic identification as an identification technique for pigs. In a research phase investigations were carried out to define an injection spot which enables an easy injection, low rejection, minimised loss rate and easy handling of a secure recovery of the transponder in the slaughter line (Klindtworth *et al*., 2004; Spiessl *et al*., 2004). Three different injection spots (outer ear, ear base and abdominal cavity) were tested, regarding three sizes of transponders and two different ages of application. The injection in the abdominal cavity was judged as the best method. The aim of the implementation phase was to apply the knowledge gained in the research phase to a higher number of animals under practical conditions, to take DNA samples for increasing secure animal identification and to transfer the ID code of the LF transponder to HF labels during slaughtering for carcass identification. By that it should be tested if barcode labels currently used in slaughterhouses could be replaced by HF labels.

Materials und methods

Figure 1 gives an overview of the traceability chain, as it was implemented in the project. Every piglet was electronically tagged and DNA sampled on the farm where it was born. The animals were regularly controlled every time they moved farm and were registered in a database. In the slaughterhouse the LF transponder was removed and the transponder code was transferred to a HF label, which identifies the carcass and in future also the meat package for sale in shops.
The project was carried out in collaboration with experimental stations and practical farms. Approximately 1,000 animals were born and fattened in two experimental stations of the Bavarian State Research Centre for Agriculture (LfL) (Karolinenfeld, Baumannshof) and were slaughtered in the experimental slaughterhouse of LfL (Grub). Nearly 500 animals were born and fattened in the experimental station of the Federal Research Station for Agricultural Economics and Engineering (FAT, Switzerland) and were slaughtered in a commercial slaughterhouse of the Micarna Group. In order to gain further experience under practical farm conditions, one breeding farm and one fattening farm in Bavaria were included in the implementation phase. These animals were slaughtered in a commercial slaughterhouse of the Südfleisch group.
A 32 x 3.85 mm transponder (HDX, Allflex, sterile packed in one way needles) was injected in the intraperitoneal region of 2,049 piglets, using the Hüther application tool. All animal products were in compliance with the ISO Standards 11784 and 11785. The tagging of the piglets was accomplished in groups of 100 to 200 animals from August 03 up to May 04. The animals were tagged in the 3rd or 4th week of life when about 3 to 5 kg live weight. The tagging process required two persons, one for the injection and a second one for restraining the animal.
For the intraperitoneal injection the piglet was either put in a hanging position, head down (82 % of the animals), or in a lying position (18 % of the animals) according to Caja (Caja, 2002). The

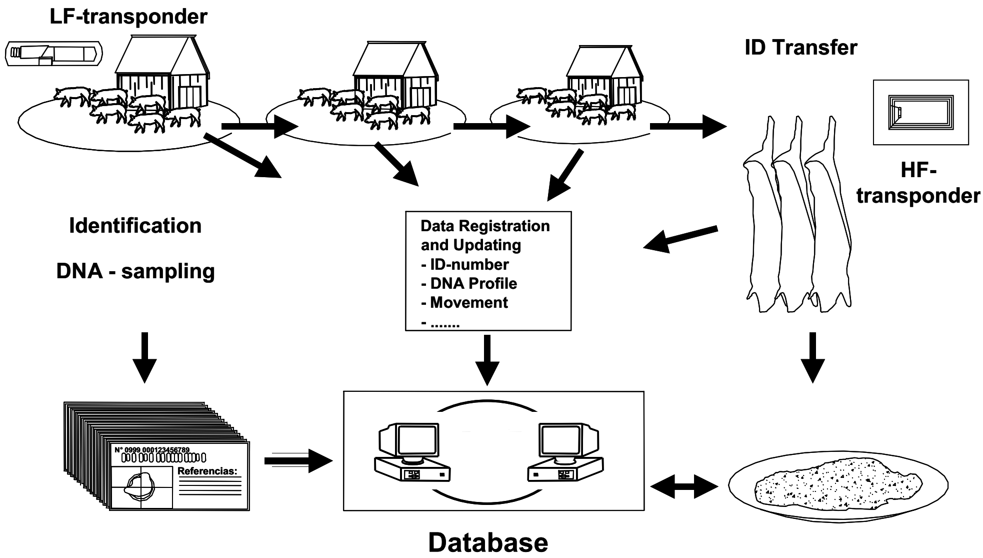

Figure 1. Scheme of traceability.

transponder was placed between median and teat line caudally to the navel at the level of the fourth and fifth pair of teats.
With 200 animals the injection spot was coloured with tattoo ink in order to control the occurrence of hernia close to or at the injection spot. Animals which died soon after the application of the transponder, or animals where potential problems were evident, were sent to an independent laboratory for a pathological examination.
The control readings were performed at tagging, one day after tagging and after every movement or change of sty (25-30 kg). On-farm controls were performed with handheld readers (ISOMAX III from Datamars SA and Gesreader 2S ISO from Gesimpex) as well as stationary readers (DSE 500V2 from Agrident), which were combined with electronic weighing scales. The reading controls at the entrance of the experimental slaughterhouse were carried out with a stationary reader (ASR 454 from Agrident).
All animals were slaughtered at a live weight of about 100 kg and at an age of 5 to 6 months. At slaughtering the animals were read and registered at different stations: At stunning, scalding, evisceration and before the carcasses were transported into the cooling chamber. The transponder was separated from the carcass at the station where the carcass was divided and the organs and intestines were removed. The required time for recovery of the transponder was measured with a stop watch from opening of the carcass up to the recovery of the transponder.
In the last part of the project a carcass identification system was tested on 219 animals. For this purpose a synchronised long range-reader (ASR454 with 50x60 cm antenna from Agrident) was used, which was combined with a controller (from Rumitag) and a device for programming HF labels. This system was integrated in the slaughter line after flaming. After a successful reading of the LF transponder in the carcass two HF labels were programmed and fixed on both front legs of the carcass. At the station where the carcass was classified for quality purposes, a DNA sample was taken from the ear and was assigned to the corresponding animal. For the sampling procedure sampling pliers and sample kits from Biopsytec were used. A PDA (Fujitsu Siemens 610 Loox) was chosen as the read and write unit for the HF labels, connected with a RFID reader equipped with a compact flash interface (ACG).

Results and discussion

A total of 2,049 animals were tagged on different farms, of which 9.3 % left the group due to alternative commercialisation or due to animal losses. The number of lost animals on the farms varied between 6 and 7 %, which is higher than comparable figures (4 %) (VIT, 2005). From all animal losses on the farms (128 pigs), 46.5 % (60 pigs) were pathologically examined in order to establish the cause of death. As displayed in Table 1, four animals died because the injection was probably done too deeply, which caused in one case a perforation of the intestines, in two cases a perforation of the aorta and in the last case the transponder was placed in the urinary bladder. Three cases led to death of the piglets due to high blood loss and a blockage of the urethra. The fourth animal was killed to avoid unnecessary suffering. Two animals died due to a bacterial infection shortly after injection. Three animals died from a peritonitis shortly after injection. Further nine animals were lost because of hernia. Two of this group were slaughtered ahead of schedule for that reason, the remaining seven died because of incarcerated hernia and were pathologically examined. Two animals were killed for pathological analysis. It should be mentioned that some of these hernias were observed close to the injection spot, which could be recognized through the coloured injection spot. It should be investigated in more detail whether there is a correlation between the injection and hernia.
Overall 30 transponders (1.5 %) were lost during life time (Table 2). Two animals lost the transponder twice, which is not included in this calculation. A total of 14 losses were observed immediately after injection at day one. In animal group D the numerous losses were conspicuous;

Table 1. Animal losses.

Animals			Incoherent with transponder			Correlation with transponder possible				Death caused by transponder
1	2	3	4	5	6	7	8	9	10	11
TG 7	289	19	-	16	2	-	-	-	-	1
TG 8	220	11	-	8	-	2	1	-	-	1
TG 9	290	20	1	13	-	-	1	3	1	1
TG 10	231	12	-	11	-	-	-	1	-	-
TG A	130	3	-	3	-	-	-	-	-	-
TG B	115	9	-	7	-	-	1	-	1	-
TG C	141	8	-	4	-	-	-	4	-	-
TG D	144	12	-	10	1	-	-	1	-	-
TG FAT	489	34	-	33	-	-	-	-	-	1
Sum	2049	128	1	105	3	2	3	9	2	4
Per cent	100%	6.2	0.0	5.1	0.1	0.1	0.1	0.4	0.1	0.2

1: Group of animals; 2: Amount of animals; 3: Animal losses on the farm; 4: Animal absent; 5: Death not in correlation with transponder application; 6: Animal died before slaughtering; 7: Death caused by a bacterial infection after infection; 8: Death caused by peritonitis; 9: Death caused by hernia; 10: Euthanasia after injection; 11: Death caused through transponder application.

Table 2. Transponder losses during lifetime.

Animal group	1		2	3	4	5	6
	Abs.	Rel.					
TG 7	3	0.1%	H	3	-	-	-
TG 8	4	0.2%	H	2	-	2	-
TG 9	4	0.2%	H	1	-	3	-
TG 10	1	0.0%	L	-	-	1	-
TG A	0	-	H	-	-	-	-
TG B	1	0.0%	H	-	-	1	-
TG C	0	-	H	-	-	-	-
TG D	8	0.4%	L	8	-	-	-
TG FAT	9	0.4%	H	-	2	7	-
Sum	30	1.5%	-	14	2	14	0

1: Transponder losses in the whole animal group; 2: Injection method L=lying position, H=hanging position; 3: Retagging 1 day after application; 4: Recognised transponder losses after first movement (5-6 kg); 5: Recognised transponder losses after second movement (25-30 kg); 6: Recognised transponder losses before slaughtering (1000-110 kg).

it was the first group tagged in a lying position. It has to be assumed that in some cases the injection was not deep enough and the transponder was pressed out from the injection spot. 2 losses were recognised at weaning at approx. 5 -6 kg and 14 losses were noticed between and after changing the sties at approx. 25 -30 kg. It has to be assumed that these transponders were injected in the urine bladder or urethra and left the body over the urethra during lifetime. This can be confirmed by the fact, that 0,6 % of all recovered transponders in the slaughterhouse were found in the urine bladder or urethra (Table 3).

The recovery of transponders in the slaughterhouse could be done by one person, even at a chain speed of 200 animals per hour. Altogether a recovery rate above 98.2 % was achieved in the slaughterhouse. As Table 3 displays, from a total number of 1,840 transponders, 78 % were found in the omentum majus, fixed in connective tissue. A further 13.6 % of the transponders fell out when the carcass was opened. These cases must be considered as critical, because all animal parts have to be scanned in order to guarantee a transponder-free carcass. In some cases the transponder was found in unusual places: 0.6 % were recovered from the urethra and urinary bladder, 0.1 % from the fat tissue of the longissimus dorsi and 0.3 % were found under the skin. A further 1.6 % of the transponders were lost in the slaughterhouse, but it could be excluded that the transponder remained on the carcass; only in 0.2 % of the cases the transponder could not be recovered from the carcass and the carcass left the slaughterhouse without control.

Figure 2 shows the time needed for the recovery of transponders in the experimental slaughterhouse. Time measurements where carried out for 534 animals. In 50 % of the cases the transponder could be recovered in a time period from 12 to 32 s; the calculated mean value was 30 s. Altogether 65 outliners occurred, which can be explained with the higher time needed to search for the transponders when they could not be found in the omentum majus.

Table 3. Location where the transponder was found in the slaughterhouse.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TG 7	258	151	23	5	4	72	-	-	-	-	1	-	1	-	1	-
TG 8	207	176	24	1	1	-	-	-	1	1	2	1	-	-	-	-
TG 9	256	221	18	5	2	-	-	1	-	5	3	-	-	-	-	1
TG 10	219	202	4	-	3	4	-	-	-	3	1	-	-	-	-	2
TG A	127	101	17	2	3	-	3	-	-	-	-	-	-	1	-	-
TG B	106	92	11	1	1	-	-	-	-	-	1	-	-	-	-	-
TG C	133	109	20	1	2	-	-	-	-	1	-	-	-	-	-	-
TG D	132	101	21	-	2	-	-	-	-	1	1	-	4	2	-	-
TG FAT	421	287	112	-	11	-	-	-	-	-	9	-	-	2	-	-
Animals with TP	1840	1440	250	15	29	76	3	-	1	11	-	1	5	5	1	3
Per cent	-	78.3	0.8	0.8	1.6	4.1	0.2	-	0.1	0.6	-	0.1	0.3	0.1	0.1	0.2

1: Group of animals; 2: Animals slaughtered; 3: Transponder found in the omentum majus; 4: Transponder fell out of carcass; 5: Transponder found in container of intestines; 6: Transponder lost in slaughterhouse, not on carcass; 7: Transponder recovered no note about whereabouts; 8: Transponder broken; 9: Animal absent; 10: Transponder found close to liver; 11: Transponder in urethra, urinary bladder; 12: Animal without transponder; 13: Transponder found in fatty tissue of longissimus dorsi; 14: Transponder in fatty tissue; 15: Transponder found under skin; 16: Transponder left slaughterhouse (stuck on spleen); 17: Not found, no control possible.

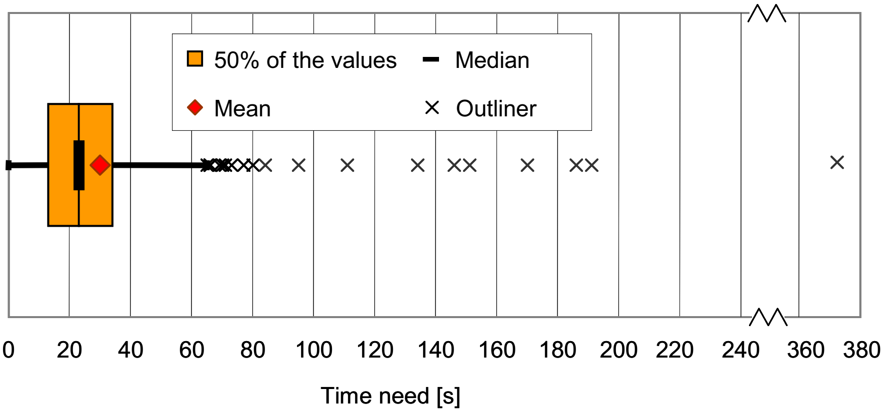

Figure 2. Time needed for transponder recovery.

After solving technical problems at the beginning the results of the carcass identification showed that 93.8 % of the carcasses could be successfully identified with two HF labels on both legs. Only in cases where the LF transponders could not be read by the stationary reader or was lost by the animal during fattening, a programming of the HF labels was not possible. One label was destroyed during slaughtering and could not be read anymore. Despite these exceptions all carcasses could be identified with HF labels.

Conclusions

The method of identifying pigs with transponders in the intraperitoneal region is feasible, however having an experienced person for the injection is compulsory and it is necessary to have a second person to restrain the animal, which makes the tagging time-consuming. Good reading results were obtained with the 32 mm transponder, which could be read at every stage of growth; especially for full-grown pigs a bigger reading distance is necessary, which can be fulfilled with this transponder. For widespread practical use more investigations are necessary to improve the method of injection. With an optimised injection method the observed losses can probably be decreased and the recovery in the slaughterhouse might be easier. To guarantee transponder-free carcasses and to exclude the danger of transponders getting in the food chain, additional measures are necessary for control purposes. The analysis of the DNA samples is not yet finished, but results will be available later.

The first tests with programmable HF labels showed that programming and reading of HF labels under slaughterhouse conditions is possible. This transponder technology opens the possibility to store more relevant animal data on tags and offers a further step to complete traceability of livestock and meat. However in practical use more possibilities to intervene and to control the process are necessary in cases when the transponder is lost or not readable. It is also fundamentally important to check the function of the labels before use and to have a suitable and quick method of attaching them. For a cost effective and widespread implementation the transponder recovery and the identification of carcasses needs to be automated otherwise more manpower will be necessary in slaughterhouses.

Acknowledgements

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Automatic identification and determination of the location of dairy cows

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Abstract

In loose housing of dairy cows there is a need of behaviour studies in respect of where and when individual cows are to scientifically evaluate barn planning and management practises and also to identify cows in need of special attention. The paper describes and evaluates a system for automatic identification and determination of the location of dairy cows. The system consists of video cameras, tags with light emitting diodes (LEDs) that flash in a specific order and a computer with software. The system was evaluated with two tests, an accuracy test and a location ability test. The location ability test involved dairy cows. The accuracy test shows that the average difference between real x-y positions and the x-y positions given by the system is 38.5 cm, with a standard deviation of 17.9 cm. This is a satisfactory accuracy level to determine whether a cow was in a cubicle, at the feeding gate, or in the walking area. The location ability tests with cows in a free stall barn shows that the captured locations ranged from 19% when using 4 cameras per compartment, to 29% when using 12 cameras per compartment. This very low location ability rate can probably be explained by the LEDs, carried by the cows on their collars, tended to slide to either side of the cow's neck instead of staying on top and also by fitting details breaking the optical sight between camera and the LED. To be useful in scientific behaviour studies in dairy barns the system must therefore be improved and further evaluated by having LEDs on both side of the collar and cameras located minimizing risk of blocking optical sight to the LEDs.

Keywords: identifying, location, remote measuring, animal behaviour, dairy cows

Introduction

In loose housing of dairy cows there is a need for behaviour studies in respect of where and when individual cows are to scientifically evaluate barn planning, floors and management practises. The interactions between the individual and group of animals and e.g. feeding regimes, number of feeding places, location and number of cubicles, location and conditions for passing smart or one way gates need to be investigated and evaluated. In barns with automatic milking the cow traffic is very important to get high efficiency and even and proper milking intervals. In a longer perspective automatic tracking of individual cows might assist the manager to detect cows which needs special attention.
We wanted to test a system that automatically could determine the identity and location of all individual dairy cows in a herd during longer periods (at least several days) under loose housing conditions. The system tested was the Optical Real Time Location System (ORTLS). This paper describes its technical layout and the application of the system under field conditions and evaluation of the data collected.

At the Swiss Federal Research Station for Agricultural Economics and Engineering, Tänikon (FAT), Switzerland, a system has been developed that uses infrared light to identify and determine the location of animals (Bollhalder *et al*., 2002 and Kaufmann *et al*., 2003). The positioning system

is called **F**or **A**nimal **T**racing 2002® (FAT) and it is based on the use of cameras that are able to detect collars which emit infrared pulses. This system can, according to the authors, keep track of 100 animals with a scanning frequency of 1 min and with a spatial resolution of 10 cm.
Using a technique based on radio frequency, RF, for animal detection and localisation proved to be very difficult inside a building with a great deal of metal structures, such as water pipes, cubicle partitions and feeding fence (Michael Braiman, personal communication). The building used by Halachmi and Braiman (2000) was constructed of wood (personal communication with authors). Since the system described by Halachmi and Braiman (2000) did not work satisfactorily in buildings with metal structures, Braiman then developed a new system, the ORTLS, manufactured by the company Precision Systems[1], Israel.
Precision Systems and the Department of Agricultural Biosystems and Technology of the Swedish University of Agricultural Sciences agreed 2003 to test ORTLS according to certain requirements, and carry out field trials to evaluate it.
The objective of this study was to answer following questions regarding ORTLS:

1. Investigate the accuracy of the system in its present configuration.
2. Study how it works when used with dairy cows in a conventional cubicle housing system with an integrated milking parlour;

Material and methods

Description of the ORTLS

The ORTLS consist of the following parts (Figure 1):

1. Tag for optical individual identification of each cow.
2. Video Processing server (VPS) with Video Capturing Software (VCS).
3. Video cameras and video protection housing (video domes).
4. Radio Frequency Synchronising Unit (RFSU) and receiver (RFSRU).

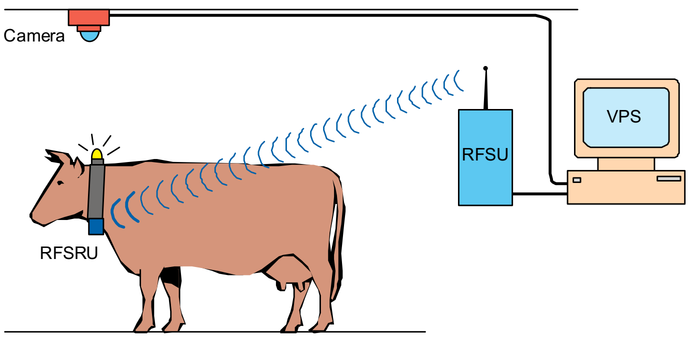

Figure 1. Design of ORTLS (Drawing: Kim Gutekunst).

[1] Mention of trade mark, proprietary product, or vendor is for information purposes only. No endorsement implied.

Tags

The tag consists of two essential parts: a light source (LED) and a Radio Frequency Synchronization Receiving Unit (RFSRU). Both parts are attached to a collar that is placed on the cow. The RFSRU is situated in a small plastic protective box, which also contains the power supply for the RFSRU. The light source consists of two red light emitting diodes (LEDs). The LEDs are inside a transparent flexible tube fitted on the top of the cow's neck. This tube not only protects the LEDs, but it also disperses the light so that a flash is visible from all directions. The LEDs in each tag flash once per minute, for a duration of 750 msec. Tag "1" flashes when the time is 1 second past the minute, tag "2" flashes when the time is 2 seconds past the minute, etc. In this way, 60 tags can be used simultaneously with this particular ORTLS version. Since a tag flashes once per minute, the ID and position of an animal can also be determined once every minute. On most farms, the cows already carry a collar. This collar can be furnished with a clearly visible ID number and also with one or more electronic ID-tags.
These electronic tags are relatively heavy, and maintain their position under the neck of the cow due to their weight. The tag can be stabilised by connecting it to the collar that the cows are already wearing.

Video processing server (VPS)

The VPS is a PC running under the Windows 2000 operating system. The PC controls the Radio Frequency Synchronisation Unit (RFSU) and captures the video signal from each camera that is installed. The video images are processed by an iLocate(r) software module into comma separated value files (csv files). These csv files contain the date and time stamp, tag ID, x and y position, identification of the camera that has been used for determining the x and y position, and codes that contain information about the data quality, i.e., if a data collision has occurred or not.

Video cameras and camera domes

The video cameras are of the type VC-7017HP (Appro Tech Inc.). Each video camera is installed within a special plastic cover, called a camera dome, which protects the camera from the environment.

Radio Frequency Synchronisation Unit (RFSU)

The RFSU is designed to be fully compliant with the ERC 70-03 (CE) and FCC part 15 (USA) requirements (requirements and recommendations for short range radio wave transmitting devices). The transmitted frequency wave is between 433.050 and 434.790 MHz, and the transmitted power is 10 mW (10dBm). The RFSU is installed in the middle of the covered space to provide the best RF coverage over the entire area. The unit requires a 12 V DC power supply. The "heart beat" is brought to the RFSU from the VPS using a dedicated unshielded twisted cable. If the RF coverage is poor, two or more RFSU's can be installed.

Evaluation tests

The ORTLS was evaluated using three separate tests; one accuracy test without cows, and two location ability tests with cows. The purpose of the accuracy test was to investigate how closely the x- and y-coordinates given by the system corresponded with the actual positions in the cowshed. The purpose of the location ability was to investigate how well the system located individual cows.

For the accuracy test, the ORTLS was installed in a dairy farm in South Sweden, in June 2003. The barn had four rows of cubicles and a feeding table along one side. The total area to be covered inside the barn was 40 x 17 metres (680 m^2). With 15 cameras, the ORTLS could cover the entire area, except for one small corner. Sixty-two test points were selected in the cowshed. These points were primarily chosen so that they could be easily located in an x and y coordinate system corresponding to the cowshed layout. Cows should not be able to move these test points, or in any other way disturb them. Therefore selected components of the fittings in cowshed were used. These components were the poles at the feeding fence, and the connections between the cubicle partitions and the neck rails. The positions of the test points were established using a measuring tape.
For the testing procedure, a special test tag was made. This tag flashed once per second completely autonomous of the RFSU. This tag was held at each test point for about 15 seconds. It was concealed from the cameras when moving from one test point to another. This was done because it would be easy to identify the separate test points in the data files. When it was covered, the system would not enter any data to the data file. No other tags were used during this test.
The location ability tests were carried out between May and June 2003 (2003 test) and between March and April 2004 (2004 test). Both tests were carried out at the Department's experimental farm, Alnarps Mellangård. The same compartments (A and B) were used for these tests. During the 2003 test, two groups of cows were used, group 1 and group 2. During the 2004 test two new groups, group 3 and group 4, were used.
Compartment A consisted of 23 cubicles, 22 feeding places and one automatic concentrate dispenser. Compartment B consisted of 21 cubicles, 20 feeding places and one automatic concentrate dispenser. Both compartments had slatted floors during the 2003 test. The surface of the floor in compartment B was cleaned by an automatic manure scraper, whereas no manure scraper had been installed in compartment A. For the 2004 test, the floor in compartment A had been changed to mastic asphalt and in compartment 2 to a rubber floor. Both compartment floors were cleaned with a manure scraper. The cows were milked and fed twice a day during all tests.
During the 2003 test, 4 cameras per compartment had been installed. The number of cameras per compartment was increased to 12 during the 2004 test. Group 3 was also video filmed for 4 consecutive days. From the videotapes, the number of cows in the eating area, in the walking area, and in the lying area was counted. This was done every 15 minutes.
During each test, all cows in a compartment carried a special collar fitted with a tag. These collars were attached to the ordinary collar with cable ties. The ordinary collar had been furnished with an id-tag used in the milking parlour and concentrate dispenser, and an activity tag used for oestrus detection. The tags on the ordinary collar served as a counter weight for the special collar. The tests lasted for 4 consecutive days in order to ensure that sufficient data sets would be collected. For the 2003 test, the cameras were attached to the existing roof frame structure. For the 2004 test, steel wires were used in order to facilitate additional attachment structures. Two steel wires per camera were used. Rigging screws were used to ensure that the wires would be under a high tension. In this way, a rigid structure was made for those cameras that could not be attached to any roof frame structure.

Accuracy test

For the accuracy test, the average distance between the x-y values obtained with the measuring tape (x_{mt} and y_{mt}) and the x-y values from the ORTLS (x_{ORTLS} and y_{ORTLS}) were calculated, thus 62 comparisons were carried out, one for each test point. A regression line comparing x_{mt} versus $x_{ORTLS,}$ and a regression line comparing y_{mt} versus y_{ORTLS} were then calculated.

Location ability tests 2003 and 2004

Each time a tag flashed, the ORTLS entered a line of data to the data file, but only when the line of sight between a camera and the flashing tag was not broken. From the data acquired a the location ability factor was calculated as the percentage of locations actually registered of possible ones.

Comparison test between video analysis and captured ORTLS data

The location ability factor did not, however, elucidate how well the ORTLS worked in different parts of cowshed. Therefore four days of data from the ORTLS was compared with the same four days analysis of video data for the cows in group 3. From the video analyses, the number of cows in the feeding area, in the walking area, and in the lying area was counted every 15 minutes. The data from the ORTLS was compared with the video analyses as follows: scan samples from the video analyses were multiplied by 15 to represent the number of cows in a specific area (eating, walking or lying area) over an entire 15-min period (each scan sample was the average of 4 days observations). Four consecutive 15-min periods were summed into one value, representing the number of cows that were in this particular area during this hour. This number was compared to the number of flashes that the ORTLS had registered in that specific area and during that time period (this was in fact a determination of the location ability factor for different areas).

Results

The average distance between the measured points (x_{mt} and y_{mt}) and the corresponding points from the ORTLS (x_{RTLS} and y_{RTLS}), was 38.5 cm, with a standard deviation of 17.9 cm.
The regression line between the comparison of the x-values pairs, x_{mt} with the corresponding x_{ORTLS}, had an R^2 of 0.99. The regression line between the y-comparison, y_{mt} and y_{ORTLS} had an R^2 of 0.99.

$$x_{mt} = 1.002 * x_{RTLS}$$

$$y_{mt} = 0.999 * y_{RTLS}$$

The system efficiency for the 2003 test turned out to be low, 18.8% (SD = 9.2) for group 1 and 13.1% (SD = 4.0) for group 2. For the second year (number of cameras per compartment increased from 4 to 12 cameras per compartment) the system efficiency factor was for group 3 27.3% (SD = 7.8) and 30.2% (SD = 12.7) for group 4.

Results from comparison test between video analysis and ORTLS data

The ORTLS did not perform equally well in the different areas of the compartments which can be seen in Table 1. The eating area proved to be the area where the ORTLS worked best, since more than 90 % of the flashes that was emitted from this area was captured by the system. For the other two areas the lying area and walking area, the percentage captured data was 10.6% and 40.2%, respectively.

Discussion

The ORTLS was a prototype, and this was the first time that it was tested under field conditions. This meant that many soft- and hardware problems and even many technical difficulties had to be overcome especially during the accuracy test.

Table 1. Actual number of flashes (based on video observation) emitted from the eating, lying and walking areas for a 24 hour period; captured number of flashes by ORTLS for a 24 hour period, and location ability factor for the three different compartment areas; lying, walking and eating, respectively.

	Eating area	Lying area	Walking area	Milking parlour
Actual number of flashes	4180	18460	3070	4530
Captured number of flashes	3815	1975	1235	Not captured
Location ability factor	91.3%	10.6%	40.2%	

A) The cameras could not be installed at the optimum height, since the water pipes and electricity cables would have blocked the line of sight (location ability test).
B) The RFSU antenna was, at the start, located in the same room as the VPS in order to keep the wiring to a minimum. However, the radio signal from the RFSU could not reach the tags. The antenna from the RFSU needed to be re-located inside the barn in order to good contact with the RFSRU on the cow´s tag and hence a good synchronization for individual flashing.
The main problem with the ORTLS turned out to be the very low location ability factor. In order to be able to make more useful and accurate observations it should not only be higher, but it must also be the same in the different areas. Bollhalder *et al*. (2002) and Kaufmann *et al*. (2003) reported that their infrared positioning system is designed on a basis of 98% location reliability. This considerably better performance might be explained by the fact that the LEDs in that system remained on top of the cows' neck, whereas the LEDs in the ORTLS tended to shift to either side of the animal. The PVC-tube that protected the LED's could not be balanced to stay on top of the neck. Extra counter weights were tried but did not help. For future experiments the tags should have LEDs on both sides of the cows' neck.
The large differences in location ability factor between areas might also be explained by the fact that the cameras that covered the eating area were directly above the feeding fence, whereas the cameras covering the lying area were not located directly above. The roof construction made this impossible. It could also not be ruled out that the cows themselves cut the lines of sight between the tag and camera more often when they were in the resting area than when they were in the feeding area. This meant that the location of the cameras was very important. Cameras should preferably be installed above the areas where the cows tended to bend their necks downward, i.e., the cameras should be installed directly above the feeding table and above the cubicles. If this was not done, the cows would then block the line of sight with their bodies when they bent their necks when eating, or when they stood in the cubicles with their heads lowered.
The level of positioning accuracy of the ORTLS proved to be satisfactory. With the obtained accuracy level, we could determine whether a cow was in a cubicle, at the feeding gate, or in the walking area.

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