Data acquisition in Precision Livestock Farming for improved calf rearing

Viktoria Spreng*, Markus Ehrl, Martin Bachmaier and Hermann Auernhammer
Technical University Munich, Agricultural Systems Engineering, Am Staudengarten 2, 85354 Freising-Weihenstephan, Germany

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Abstract - Kurzfassung

The networking of electronic process control systems offers new possibilities for individual calf management. The different systems are implemented as automatic systems or robots in order to reduce labor. Within this paper, the experimental setup of the underlying investigation and first results with a statistical evaluation of feeding data are presented. Intake amounts of water and dry matter as a function of age are shown. The results require an individual adaptation of the milk-drinking programme. All known authors either refer separately to drinking water, feed concentrate, forage intake or body weight but so far there has been no evaluation of combining these data. Use of computer-controlled interlinked feeding systems allows economic advantages in many respects and provides a comprehensive decision-support system for the management.

Keywords: Calf rearing, calf husbandry, system networking, water intake, feed intake, labor requirements

Datenerfassung im Precision Livestock Farming für eine verbesserte Kälberaufzucht

Durch die Vernetzung elektronischer Steuerungssysteme werden neue Möglichkeiten für das tierindividuelle Kälbermanagement eröffnet. Die verschiedenen Systeme werden dabei als automatisierte Systeme oder als Vollautomaten aufgebaut, um den Arbeitsaufwand zu reduzieren. In dieser Veröffentlichung wird der Aufbau des zu Grunde liegenden Versuchs beschrieben und erste Ergebnisse in Verbindung mit einer statistischen Auswertung der Fütterungsdaten dargestellt. Dabei werden Aufnahmemengen von Wasser und Trockensubstanz der Kälber in Abhängigkeit des Alters aufgezeigt. Die Ergebnisse bestätigen die Notwendigkeit einer tierindividuellen Anpassung des Tränkregimes. Alle bekannten Autoren beziehen sich diesbezüglich entweder auf die Trinkwasser-, Kraftfutter-, Grundfutteraufnahme oder das Tiergewicht, aber nicht auf eine Kombination dieser Daten. Der Einsatz einer automatischen, vernetzten Fütterungstechnik hat in vielerlei Hinsicht ökonomische Vorteile und bietet eine umfassende Entscheidungshilfe für das Management.

Schlüsselwörter: Kälberaufzucht, Kälberhaltung, Systemvernetzung, Wasseraufnahme, Futteraufnahme, Arbeitszeitbedarf

1 Introduction

In animal husbandry, electronics ought to assist the farm manager by gathering data on feed intake, animal behaviour and animal health and helps to identify unusual or critical situations as soon as possible. The use of sensor technology, robotics and information technology aims to improve animal husbandry. In the field of dairy cattle husbandry, technical development focuses on the mechanization and automation of milking and feeding, which count for approximately 70 % of the entire work, as well as improvement of animal monitoring (Auernhammer et al. 1983). A further reduction of work time required for feeding can only be achieved through automation. The main goal is further development of the existing computer-based techniques in animal husbandry, such as electronic animal identification and automatic milking, with the aid of modern micro-electronics and information technology and their integration into a comprehensive system (Bywater 1981, Devir et al. 1993, Wendl & Schön 2002). The identification associated with concentrate feeding robots for cows or milk feeding robots for calves ranked first. Because of the design of the body weighing systems and the promising possibilities for automatic health control, Auernhammer (1983) designed different concepts for process control in livestock husbandry. A high degree of automation of operative processes should lead to improved work quality and optimize the production process as regards economics and ecology (Pirkelmann & Wendling 1985). In this sector, many proprietary isolated applications for monitoring and control are available commercially, whereas the interconnection of the systems is very difficult because of unpublished or even lacking standards (Ratschow & Artmann 2003). These systems often provide large amounts of data, but the inherent information is frequently not used for man-

* Corresponding author. Tel: ++49 (0) 8161 713884; Fax: ++49 (0) 8161 713895; E-mail: viktoria.spreng@wzw.tum.de

agement. Undoubtedly there is important information within these data concerning animal behaviour and health status. From this, decision-making rules can be generated to assist management. It is necessary to determine how far valuable management information can be obtained by intelligent interconnection of different sub-systems. Furthermore, it must be clarified to what extent this information can be used to improve the output and the potential of further automation in order to reduce labor. The technical practicability of complex interconnection of all available systems in calf rearing was proved in a full-featured calf barn.

2 Materials and methods

For calf rearing, a set of electronically controlled technologies is already available (Käck 2004), which simultaneously allow recording of important process parameters (Büscher & Käck 1995). To obtain a full set of all relevant process parameters, a measurement system for drinking water intake and a weighing system for ingested roughage were added in the current investigation. This ensures consistent documentation of all processes (Spreng et al. 2006a).

The data were collected from March to November 2006 during a comprehensive 33-week trial at the experimental station Hirschau of the Technical University Munich with 33 female and 33 male calves.

2.1 System setup

The barn interior is composed of two mirrored sections. Each section is equipped with a milk feeding robot, an automatic tongue temperature measurement system inside the sucker, an electronic animal forefoot-weighing machine, a movable seesaw, a concentrate feeding robot, a drinking water robot and 12 electronic roughage weighing troughs to acquire all relevant parameters (Fig. 1 and Fig. 2). The identification of all calves with RFID transponders allows individual attribution of the retrieved amounts of feed as well as a documentation of all other relevant process parameters. The available amount of pelletized concentrate at the feeding robot is adapted to the rationed amount of milk and the age of the animal. An important part of the investigation marks the individual acquisition of the drinking water intake. Therefore, one drinking water robot of the company Förster-Technik GmbH (Engen, Germany) was mounted at the feeding area of each section. In addition, at each side of the animal area one logger for measuring climate parameters was installed in order to take these influences into account when analyzing the data. To quantify the individual amount of hay, weighing troughs used for fattening bulls (Fröhlich et al. 2005) were equipped with more sensitive load cells and adapted to the animal size in collaboration with the Bavarian State Research Centre for Agriculture (LfL, Freising-Weihenstephan, Germany). 12 of these weighing troughs have been installed in the calf barn. All systems are networked with a personal computer via different communication lines (Fig. 3). As the experimental station is 12 km outside Freising, a remote control software (pcAnywhere, Symantec) was installed for controlling and monitoring the overall system via Internet (Spreng et al. 2006b).

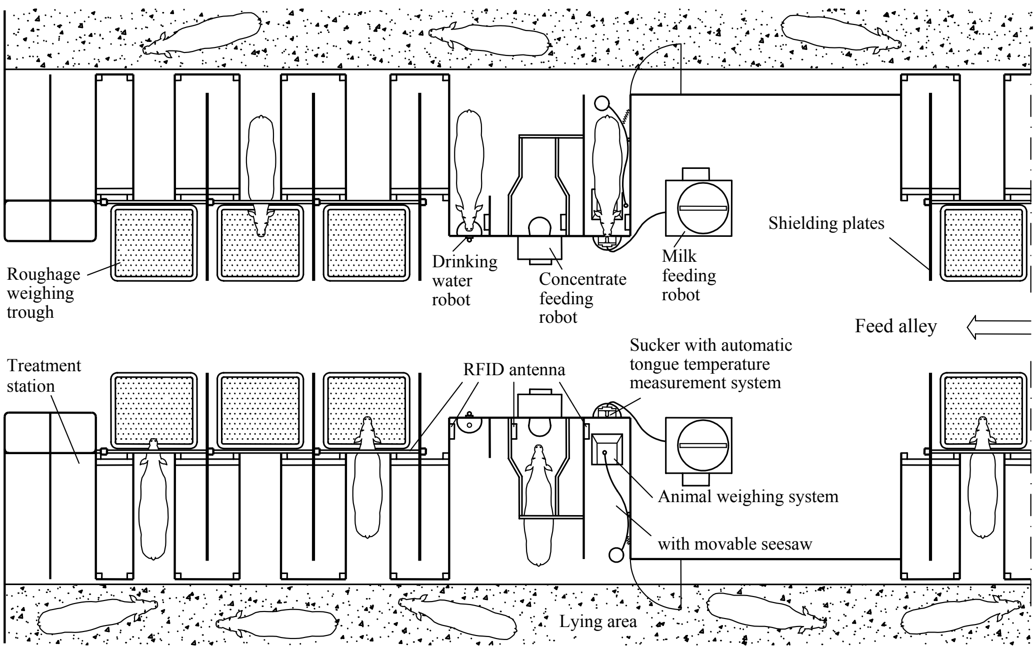

Fig. 1: System setup inside the calf barn of the experimental station Hirschau, Freising, Germany

Fig. 2: System set-up (from left to right): milk feeding robot, feeding station with temperature measuring system and animal weighing system, concentrate feeding robot, drinking water robot and separated roughage weighing troughs

For each action at a certain station, the available information such as the retrieved amount of milk, concentrate, water and hay, number of visits to the station, number of break-offs during milk drinking, sucking speed, tongue temperature or body weight as well as the beginning and ending of the visit together with the transponder number is recorded as a dataset in the database.

A preliminary eight-week trial period with 12 calves was carried out to prove the correct functionality and operational reliability of the technology.

2.2 *Experimental setup*

The crossbreed calves (German Holstein Frisian x German Red Holstein Frisian) were inserted in deep litter loose housing after a period with colostrum feeding and habituation to milk replacer. The housing age varied from 7 to 17 days of life (8.1 ± 1.3 d). Both partitions were consecutively filled with up to 20 animals, irrespective of their sex. Consequently, it was not possible to apply the all-in/all-out system. The temporally distributed birth rate resulted in a long investigation period of 33 weeks and a varying number of animals in the groups. Furthermore, in the course of the trial, 6 female and 33 male animals were slaughtered at ages from 44 to 105 days for anatomical analyses (Lesmeister et al. 2004).

A total of 66 animals were fed with milk replacer (MR), pelletized concentrate (PC), hay and water. The amounts of MR-drinking (MRD) and concentrate were offered according to a milk and concentrate-feeding programme. Water and hay were offered *ad libitum*. After housing, up to 14 days of life (DoL) each calf received up to 6 l MR-drinking per day; up to 21 DoL, the daily available amount increased continuously to 8 liter. A three-week period with 8 l d^{-1} followed. From 42 DoL milk was reduced, phased until 56 DoL to 6 l d^{-1}, and finally until 70 DoL to a maximum of 2.5 l d^{-1}. As defined in the milk-feeding programme, after 70 DoL, the calves were weaned. The MRD concentration increased continuously from 85 g dry matter (DM) per liter at the beginning to 113 g l^{-1} until 18 DoL, and was then maintained until 70 DoL. Up to 14 DoL, the feeding programme allotted an available amount of PC up to 0.176 kg DM per day, then increased it up to 1.76 kg d^{-1} until 49 DoL, maintaining this until 91 DoL. To provide the growing animals with sufficient energy, the PC amount was continuously increased up to 2.2 kg DM per day until 98 DoL and maintained at this level. The age of leaving varied

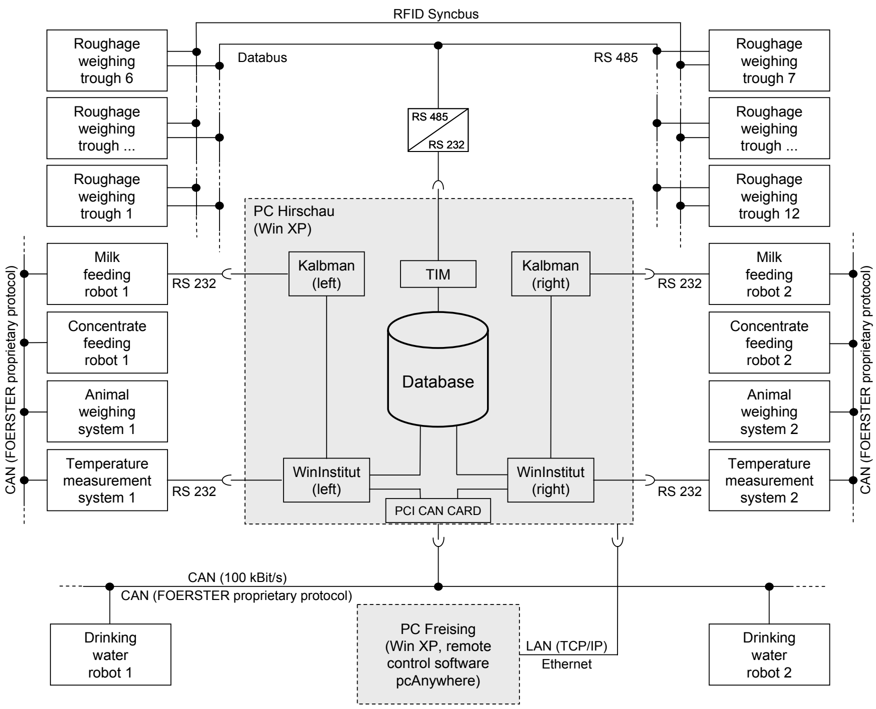

Fig. 3: Scheme for data networking in calf rearing

from 44 to 105 DoL due to slaughtering or reaching the age limit.

In addition to the automatic calibrations, the feeding systems were calibrated manually. To control the forefoot weighing technology, all calves were regularly weighed with a mobile weighing system. A video system documented the behaviour of the animals to allow interpretation of any unusual data and to trace their development.

3 Results

During the preliminary trial period, some malfunctions of the single systems and accordingly data acquisition were eliminated, so that the hardware and software used operated reliably and almost failure-free during the 234 days of trial. Apart from a few system interferences, high quality data were acquired. If the system had malfunctions or if the animals' water or feed intake was limited unintentionally (power outage, failure of drinking water robot, faeces in the water bowl), the data of these days were not used for analysis. The housing day and the last day in trial of each animal were excluded from the analysis. To simplify terminology, the abbreviations listed in the glossary at the end are used in the following. The DM portions of MR, PC and hay intakes are summed up to the TDM intake. The retrieved amounts of MRD and DW are aggregated together with the water contents of MR powder, PC and hay to TW intake.

3.1 Measurement accuracy

For this specific analysis, 96.5 % of the 2210 daily TDM intake data and 95.9 % of the daily TW intake data of the male animals were used. For the female stock tested, the ratio of analyzable data was 95.7 % of the TDM intake data and 95.5 % of the TW intake data. Data of TDM intake, which distinguishably topped the reality in terms of nutritional physiology, were classified as outlier (1.8 % of the males' daily TDM intake data and 1.4 % of the females') and not analyzed. During the trial, the measuring accuracy of the technical equipment (Table 1) was continuously validated. For example, to ensure a correct mixing ratio of the MRD, the dosed milk powder and the dispensed water were measured for control. From a total of 51 and 105 measurements respectively taken during the trial, the mean deviation from the reference value (0.1 kg milk powder and 0.5 l water respectively) was quantified. The mean deviation value and its standard deviation was 0.004 ± 0.017 kg for the milk powder (minimum of -0.044 kg, maximum of 0.084 kg) and -0.001 ± 0.007 l for the water (minimum difference of -0.017 l, maximum of 0.035 l). Expressed in percent, this means deviations of 0.35 ± 17.47 % and of -0.25 ± 1.36 % respectively. The mean deviation of the measured weight value from the reference of the six used weighing troughs was tested in the weight field from sensible 0.020 to 0.900 kg. The results show a total mean deviation of 2.28 ± 10.26 %. The result of body weighing illustrate that the animal weights measured by the forefoot-weighing system were on average 0.769 ± 2.468 kg and 0.94 ± 3.79 % respectively lower than the control value.

3.2 Data analysis

As mentioned, the stocking rate and the number of female and male calves in the groups varied. Therefore, the number of samples varied from 3 to 33 of the males and from 9 to 33 of the females. DM contents of 94 % for MR, 88 % for PC and 86 % for hay were assumed. Fig. 4 and Table 2 characterize the development of the daily mean values of fluid and dry matter intake amounts relative to age. As predefined, from 71 DoL the calves did not receive MRD anymore, except for small amounts of robbery. This explains the abrupt rise of DW from 6.6 ± 2.9 to 8.8 ± 3.0 l d^{-1}. Expectedly, the TW intake rose, but with a decrease from 49 DoL to 63 DoL, where it starts to rise again (TW intake of 7.6 ± 1.5 l at 49 DoL, 6.9 ± 1.6 l at 59 DoL, 7.9 ± 2.1 l at 66 DoL). While reducing MRD, the calves started eating HDM and reached the intake of more than 0.1 kg d^{-1} at 47 DoL (from 0 to 0.6 kg d^{-1}). So the TDM intake rose continuously, above 1 kg d^{-1} from 36 DoL (from 0.6 to 1.8 kg d^{-1}) and above 2 kg d^{-1} from 62 DoL (from 0.7 to 2.9 kg d^{-1}). When the amount of DW decreased because of reducing MRD, the calves reacted with a small increase with an in-

Table 1: Mean deviation from the reference and standard deviation (D ± s) with minimal and maximal deviation value of the different feed components and body weight (n = number of measurements)

Measurement	MR powder [kg]	MR water [l]	PC [kg]	Hay [kg]	DW [l]	Body weight [kg]
n	51	105	36	90	76	659
D ± s	0.004 ± 0.017	-0.001 ± 0.007	0.001 ± 0.009	0.001 ± 0.005	0.000 ± 0.012	-0.769 ± 2.468
Min.	-0.044	-0.017	-0.018	-0.010	-0.060	-10.4
Max.	0.084	0.035	0.021	0.015	0.020	11.4
D ± s [%]	0.35 ± 17.47	-0.25 ± 1.36	0.42 ± 5.07	2.28 ± 10.26	-0.07 ± 11.97	-0.94 ± 3.79

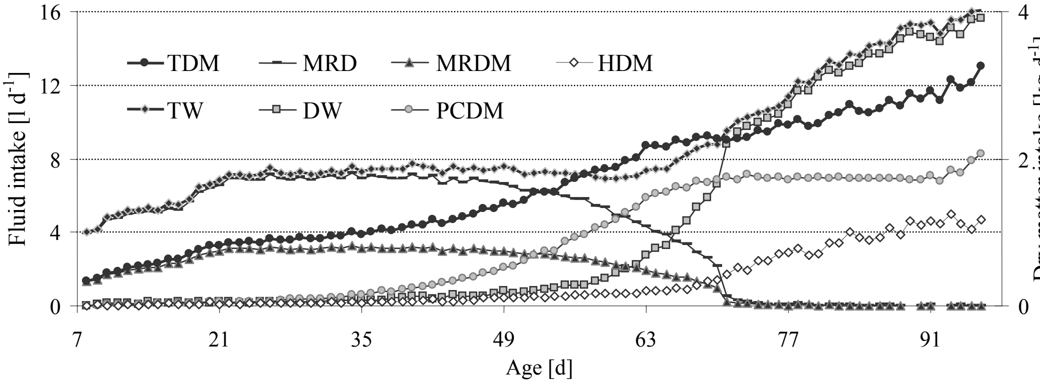

Fig. 4: Daily mean values of fluid and dry matter intake relative to age

terim cessation of TDM intake. A second cessation was from 63 to 74 DoL when the available amount of PC was reduced. Considering both sexes separately, on the average males drank 5.2 % (0.24 l d^{-1}) more water, consumed 5.9 % (0.02 kg d^{-1}) more HDM and 6.7 % (0.06 kg d^{-1}) more PCDM than females. Generally, the graphs of female and male intakes show similar characteristics, but in particular there are evident differences (Spreng et al. 2007). The data indicate a high bandwidth of fluid and dry matter intake of same-aged calves. Table 3 shows a two-way ANOVA with the factors age and sex for all seven variables. There were 88 nominator degrees of freedom for the factor age and one for the factor sex. The number of degrees of freedom in the denominator was about 5,000 in each variable. The high influence of age on all seven variables proved evident ($P < 0.0001$). The influence of sex can clearly be statistically proved ($P < 0.0001$) for all variables except for HDM ($P = 0.4084$) and DW ($P = 0.0212$). The influence of sex on DW is statistically proved under the usual significance level of $\alpha = 5$ % ($P = 0.020$). To show the influence of sex on the seven response variables more detailed, age-adjusted confidence intervals (CI) for the mean difference of these variables between male and female calves were additionally computed in Table 3. For example, the CI [0.045, 0.086] for TDM denotes that with a confidence level of 95 %, the mean TDM consumed by male calves is at minimum 0.045 and at maximum 0.086 kg d^{-1} higher than the TDM intake of the female calves. Except for HDM, such differences apply by analogy to all other variables. The age-adjusted averages of male calves have always proved greater than those of female calves, except for HDM where a difference could not be proved.

During the 63-day milk drinking period at the robot, each calf was offered a total of 414.6 l MRD and 48.8 kg MR powder, but the mean intake was 367.6 l and 43.4 kg respectively, which approximates to 88.7 %. The calves had an estimated daily metabolizable energy (ME) intake from the whole ration of 15.6 MJ ME at 36 DoL, 26.4 MJ ME at 62 DoL and 34.2 MJ ME at 93 DoL. The averaged body weight gathered automatically rose from 47.9 ± 3.2 kg at 9 DoL to 81.2 ± 8.3 kg at 70 DoL. At 96 DoL, the averaged body weight of a calf was 107.2 ± 10.4 kg. All through the test period, males were heavier than females, but as of 92 DoL females had a higher weight. During the milk drinking period (from 9 to 70 DoL), calves had an average daily gain (ADG) of 0.548 kg. During the whole trial period, the ADG was 0.682 kg.

4 Discussion

4.1 Technical equipment

The results of the measurements for control shown in Table 1 affirm a high measurement accuracy (better

Table 2: Selected daily mean values and standard deviation ($\bar{x}$ ± s) of fluid and dry matter intake relative to age

Age [DoL]	TW [l d^{-1}]	DW [l d^{-1}]	MRD [l d^{-1}]	TDM [kg d^{-1}]	MRDM [kg d^{-1}]	PCDM [kg d^{-1}]	HDM [kg d^{-1}]
10	4.87 ± 1.38	0.12 ± 0.30	4.71 ± 1.27	0.45 ± 0.13	0.42 ± 0.11	0.02 ± 0.04	0.01 ± 0.02
21	6.83 ± 1.54	0.21 ± 0.42	6.54 ± 1.39	0.81 ± 0.21	0.74 ± 0.16	0.05 ± 0.08	0.03 ± 0.06
36	7.46 ± 1.35	0.33 ± 0.43	7.08 ± 1.21	1.01 ± 0.23	0.80 ± 0.14	0.16 ± 0.16	0.05 ± 0.05
49	7.61 ± 1.50	0.79 ± 1.01	6.64 ± 0.85	1.39 ± 0.47	0.75 ± 0.10	0.53 ± 0.41	0.12 ± 0.11
62	7.04 ± 1.67	2.25 ± 1.55	4.55 ± 0.41	2.01 ± 0.48	0.51 ± 0.05	1.34 ± 0.45	0.17 ± 0.13
74	10.46 ± 3.01	9.97 ± 2.95	0.14 ± 0.33	2.39 ± 0.38	0.01 ± 0.04	1.74 ± 0.10	0.62 ± 0.36
93	15.56 ± 3.90	15.07 ± 3.87	0.03 ± 0.12	3.07 ± 0.53	0.00 ± 0.01	1.74 ± 0.10	1.24 ± 0.54

Table 3: F- and P-value of a two-way ANOVA of different feed intakes in dependence on age and sex and confidence intervals (CI) for their mean difference between male and female animals

Component		TDM [kg d^{-1}]	TW [l d^{-1}]	MRD [l d^{-1}]	DW [l d^{-1}]	MRDM [kg d^{-1}]	PCDM [kg d^{-1}]	HDM [kg d^{-1}]
Age	F	227	72	464	311	553	436	110
	P	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Sex	F	39	21	25	5.3	19	64	0.7
	P	< 0.0001	< 0.0001	< 0.0001	0.0212	< 0.0001	< 0.0001	0.4084
CI	lower limit	0.045	0.171	0.077	0.020	0,007	0.044	-0.018
	upper limit	0.086	0.430	0.176	0.248	0.017	0.072	0.007

than 1 %) for the technical equipment, except for the weighing troughs (mean deviation of 2.28 ± 10.26 %). However, it must be considered that the accuracy of the weighing troughs was tested in the weight range from sensible 0.020 kg up to 0.900 kg.

The individual intake amount of MRD after drinking was acquired by the use of a mixer balance, which is integrated in the milk-feeding robot. Just after drinking, the sucker was covered so that the calves could not suck air. The eating of straw, especially just after littering, which was detected by analyzing the video recording, could not be quantified. To prevent PC robbery, the allotted amounts were adapted to the age and to the daily available amount respectively. Because the systematic deviation of the dose accuracy is higher for lower target quantities, gravimetric concentrate dosing and a reduction of the maximal allotted amount from 50 down to 20 % of the daily demand are necessary to reach high dose accuracy. According to the manufacturer, the data of the weighing troughs have an output resolution of 0.010 kg and a measuring precision of 0.033 kg. Using this system runs the risk of incorrect data because of the low hay intake of young calves and hay losses during eating. Büscher & Hütter (2001) developed an automatic roughage dispenser to examine roughage intake as a control parameter for early weaning.

The investigation provided a required feeding place-animal ratio of 1:10 that, like concentrate intake and roughage consumption, exhibits great individual differences. This can be confirmed within the present investigation, although the feeding place-animal ratio was at maximum 1:7. Perhaps the construction of the hay stations caused the hesitant visits, but Ipema & Rossing (1987) showed that animals fed in automatic feeding stations had the same intake amounts as others with permanent access to forage at the feeding trough. Because of the regular calibrations of the drinking water robot and age-adapted amounts, accuracy was ensured during the trial, but the remaining quantity in the bowl, robbery or water losses caused by splashing during drinking were not recorded. The measuring accuracy of the forefoot-weighing system is dependent on the temporal spread of the intraday visits, the number of visits, the duration of stay and the behaviour during weighing (Engelhardt 1990). The older the animal, the larger the measurement error because of increasing muscle building at the rear sector of part weighing (Pirkelmann & Freiberger 2001). Ipema & Pluijgers (1987) reported that the information about weight gains or losses can be used for feed adaptation, but that for reliable information about body weight changes from day to day, body weights over longer periods should be averaged and compared.

4.2 Intake data

The results show that there is a fluctuation range between the animals for each parameter. This demands involvement of individual parameters in process control so that expedient strategies can be mapped out for the extent or feature characteristic.

During the first weeks, the analyses show that the calves satisfy their energy and fluid needs almost exclusively by MRD intake (Fig. 4 and Table 2). But it is remarkable that they drank only 88.7 % of the allowed amount. Morel & Schick (2002) noticed similar intakes. Therefore, Bogner et al. (1985) deduced that the reason that 5 to 10 % of calves are not appropriate for milk drinking robots. Dirksen (1990) notated that animal welfare can be indicated by drinking behaviour because healthy calves should drink their offered amount uninterruptedly and completely. During the period where MRD was restricted to a maximum of 8 liters per day, TDM intake rose constantly because of higher energy needs caused by body growth. According to Pirkelmann & Freiberger (2001), the intake of concentrate as control parameter for weaning leads to a delayed begin of DM intake because delayed motivation for PC intake obviously arises due to the close interaction between MRD and PCDM intake. Williams & Frost (1992) and Büscher & Käck (1995) also assessed that all known investigations agree that there is a high bandwidth of feed concentrate and roughage intake of same-aged calves. Because of the reduced number of samplings at the end of the data survey, the intake graphs in Fig. 4 rise non-uniformly. Weaning enforced the intake rise, whereas despite the reduced MRD the water needs were only hesitantly substituted by DW. This marks the light decrease of TW intake. It is important to record the DW intake, because it can be used not only for health monitoring, but also as a control variable for milk dispensing (Käck 2004). Kertz et al. (1984) reported that there is a strong relationship between DW intake, concentrate intake and body weight gain, whereas Gottardo et al. (2002) affirm that DW does not affect calf growth performance. The provision of water reduces milk refusals and, in calves fed straw, it positively affects the development of rumen mucosa. Quigley (2001) wrote that water refusal has an effect of slowing dry feed intake, delaying rumen development, increasing stress, and possibly increasing the risk of disease. A study carried out by Ruis-Heutinck & van Reenen (2000) showed that when water is available, the intake by veal calves can be very high, suggesting that the MR alone could not be sufficient to cover the need for water. As is shown in Table 3, DM intake and thereby particularly PCDM intake is dependent on sex. No literature was found concerning the different feed intakes of female and male calves sex-related feeding proposals are first given above a body weight of 150 kg (differentiation between heifer rearing and cattle fattening). The plateau of TDM from 63 DoL resulted from the limited available amount of PC. During this period the intake of HDM rose. According to Pirkelmann & Schlichting (1992), modified hay and concentrate intake behaviour reveals a change in health status more strongly than the preferred milk intake.

According to Kirchgeßner (1997), the calves were marginally oversupplied in terms of energy intake. On average, males always weighed more than females except at the end of the experiment. The latter is due to the different number of weighings (fewer males and furthermore fewer visits to the drinking station) and the imprecision of the measuring system with increasing age already mentioned. Kung et al. (1997) noticed similar weight developments during their investigations, but there were no effects of sex-related to the ADG. Considering that all known publications had different feeding regimes, the intake amounts of calves at the same age cannot be compared directly. However, it can be asserted that the data for the calves in this investigation are average. For example, with a total of 73 l more MR for each calf during the rearing period and maize silage offered *ad libitum*, Büscher & Hütter (2001) determined a 68 g lower daily TDM intake (221 vs. 289 g d^{-1}) with a 36 g higher ADG (482 vs. 446 g d^{-1}) during the first 56 DoL, but nearly 500 g more TDM intake (1,089 vs. 590 g d^{-1}) with a 15 g lower ADG (533 vs. 548 g d^{-1}) during the first 70 DoL. Similar intake amounts and ADG respectively are described by Richard et al. (1988), Veen et al. (1989), Kung et al. (1997) and Abe et al. (1999). The intake amounts during the first 8 weeks of life reported by Hepola et al. (2006) are like those in the present trial, but the growth efficiency (ADG/DM intake) is much higher (0.79 vs. 0.48), whereas from age 9 to 12 weeks this ratio changes to 0.46 vs. 0.42 because the calves increased concentrate and hay intake rapidly after weaning. The less milk is available, the earlier rumen development and feed intake start because of hunger and energy demand, and the larger the savings potential of MR (Büscher & Biesinger 1997). Discrepancy prevails regarding the function of feed concentrate and forage in rumen development and therefore concerning the best weaning management (Büscher & Hütter 2001, Deininger & Käck 1999). As a result, the authors point out the great importance of individual registration of concentrate and forage intake. It is assumed that calves are able to compensate small daily gains at a later date, known as compensatory growth, so that total gain is reached with lower costs per bull and shorter fattening periods (Daenicke 1987, Choi et al. 1997). Opportunities for boosting the daily gain are for example feeding of higher crude protein contents (Schwarz et al. 1997) and rumen-protected methionin (Ettle et al. 1999). According to Halachmi et al. (2005), applying precision management to the individual calf by feeding via computer-controlled feeders offers the potential for achieving higher daily weight gains and improving calf health. The earlier the veterinary treatment can commence, the better the prospects for complete recovery of the animal and the lower the negative effects on the weight gains.

4.3 *Labor time savings*

According to De Passillé et al. (2004), automatic calf feeders greatly reduce labor and reduce weaning age, because milk intake can be reduced with no extra labor, and starter intake can be monitored automatically so that milk feeding can be stopped as soon as the calf reaches a desired starter intake. Furthermore, De Passillé et al. (2004) established that raising heifers with a computerized calf feeder system required only one-third of the labor time (1.4 h/calf) needed for feeding the calves by bucket (4 h/calf). Schön & Wendl (1998) refer to labor time requirements diminishing to approximately 20 to 30 % of the time required for manual work. Although the calves of the present investigation were weaned age-dependently, such time savings in milk feeding compared with bucket feeding were confirmed by the herdsman too. Others also report important labor savings (De Ondarza 2003, KTBL 2002), which is a large economic advantage of using the computerized feeders. Labor time requirement per calf for work at the milk feeding robot is very high with small stock sizes because monitoring and servicing time at the robot are largely independent of the number of calves fed (Schick 1995). When feeding calves for a rearing period of 60 d with a milk feeding robot (6.0 l d^{-1}), and concentrate, hay and silage per hand, Haidn & Auernhammer (1992) ascertained labor requirements of 0.2–0.05 working hours (WH) per calf (depending on stock size) for milk feeding (when fed per bucket, labor requirements are about 2.7–1.3 WH per calf) and 2.6–0.3 WH per calf for forage feeding. It must be pointed out that no additional time is calculated for servicing and cleaning of the milk-feeding robot. Additionally, preparatory work and rework are not necessary and the time segment for mucking out decreases to only 3 % (0.07–0.02 WH per calf) compared with feeding milk per bucket. This cannot be calculated within the present investigation. Because the technical equipment was installed in an already existing shed, there was no area left to separate the calves. So more time was needed for mucking out compared with the bucket-fed situation, when each calf is closed in its drinking station. Summarizing the experience of the herdsman and the reports of the authors mentioned, it is obvious that computer-controlled feeding leads to labor time savings, improvement of workplace convenience, improved monitoring management, lower time constraint for the worker and huge flexibility of calf group combinations. Kung et al. (1997) calculated that at a farm with 200 dairy cows, a 35 % yearly cull rate and a mean calf mortality rate of 10 %, savings in labor would recover costs of initial investment for the computer feeder within 2 to 3 years. Perkiö-Mäkelä & Hentila (2005) reported automation in terms of feeding calves means lower physical workloads for farmers. If milk is fed with buckets, the mandatory contact with the calf at least twice a day facilitates the identification of health disorders and the initiation of adequate arrangements by the herdsman, according to Morel & Schick (2002). However, if using a milk-feeding robot the herdsman has so far had to use a printout, the computer screen or the display of the robot to detect health disorders, because mostly he does not see the calf drinking. Although the labor time was not recorded exactly during the present test period, it is assumed that the time savings were higher than those mentioned because of the interlinking of all the feeding and monitoring units. The compacted information on the automatically measured temperature, intake amounts, number of visits to the stations and daily body weight facilitates the control and monitoring substantially, because animals with a health risk can be detected more easily. In addition, the possibility of monitoring the overall system via Internet saved several WH per week.

5 Conclusions

The networking of electronic process control systems offers new possibilities for individual calf management. This paper explores the interconnection of a broad range of available calf rearing systems at the experimental station Hirschau of the Technical University Munich. The different systems are implemented as automatic systems or robots in order to reduce labor. On the basis of this technology, an 8- week pre-trial and a 33-week main trial were conducted. The pros and cons of the feeding and monitoring systems are discussed. All the hardware and software used functioned reliably with high measuring accuracy and allowed high data quality, so that individual feeding and monitoring data could be acquired. The relations between feed intake, age and sex were analyzed. The results presented required the use of individual intake recording and therefore individual or at least age and sex-related adaptation of the milk-drinking programme. In this regard, all known authors refer to either drinking water, feed concentrate, forage intake or body weight, but so far there has been no evaluation combining these data. Discrepancy prevails between the function of feed concentrate and forage concerning rumen development and hence the best weaning management. As is shown, the weaning period requires high attention because the voluntary increase in DW intake as a result of the early-reduced amount of MRD seems to be a problem for the animals. They react with an interim cessation of TDM intake. Compared with intake and weight data recorded by different authors, if procurable, the present intake amounts and weight gains of the 66 calves are average, especially regarding the possibility of compensatory growth. No literature was found concerning sex-related feed intakes. Using a complex computer-controlled feeding system means economic advantages in terms of reduced feed amounts and reduced length of rearing period, higher weight gains, labor and labor time savings, and lower veterinary costs. Moreover, it also means lower physical workloads and lower time constraints for the farmer, better animal welfare and improved monitoring management. The compacted information from all available feeding and monitoring systems facilitates management because health disorders can be detected. Activities and sub-processes need not be carried out in groups, but instead for the individual. As a result, preventive activities are displaced by demand-oriented individual treatments. Therefore, it is necessary to filter the information that is really relevant out of the large pool of collected data in order to provide a comprehensive decision-support system for management. This filtration can be done by using the correlations of feed intake, growth, age, rumen development and health status and automatically detecting behavioural changes so that the best rearing and weaning system can be realized.

Glossary

Component/Term	Abbreviation
Average daily gain	ADG
Confidence interval	CI
Day of life	DoL
Drinking water	DW
Dry matter	DM
Hay dry matter	HDM
Metabolizable energy	ME
Milk replacer	MR
Milk replacer drinking	MRD
Milk replacer dry matter	MRDM
Pelletized concentrate	PC
Pelletized concentrate dry matter	PCDM
Total dry matter	TDM
Total water	TW
Working hour	WH

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