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Knowledge-Based Information Systems for Dairy Herd Management

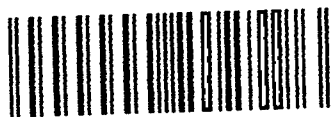
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I. ABSTRACT

Algorithms were developed, advanced personal computer techniques were investigated, and hardware subsystems were tested toward a goal of a knowledge-based dairy herd management system consisting of automated acquisition of individual-animal production data on a personal computer (PC) followed by analysis of the data for improved herd management by embedding knowledge in the algorithms used to produce reports. Specific algorithms were developed for predicting intake of feed in individual animals, predicting body weight changes at various stages of lactation, and for ranking cows for nutritional adjustments based on expected partitioning of nutrients into either body weight gain or milk. Parameters identified as being important for including in the prediction of a "lactation potential" based on early lactation performance included parity number, expressing performance as a % of body weight, body weight change after calving and body condition scores. Natural language interface via a PC version of LISP and the application of a PC version of a machine learning program to produce expert system rules were tested as advanced PC record analysis techniques. Hardware subsystem components evaluated or developed included a technique for achieving a range of interrogation of up to 1.3 m for electronic identification of animals, automated electronic capture of every-milking milk weights and body weights of individual animals, programmable processors for feed dispensed to groups via total mixed rations and computer-controlled concentrate dispensers.

II. OBJECTIVES

1. To develop knowledge-based and data-based dairy herd management subsystems for improved production management and inventory of the dairy herd based on electronic data acquisition followed by automatic analysis.
2. To integrate the subsystems into a comprehensive management program suitable for on-farm implementation with PCs.

III. THE REPORT

A. Introduction

Milk production remains a labor intensive enterprise in spite of many recent advances in technology. Personal computers (PC) have special application on dairy farms for database management, automatic monitoring or measurement of events, control of equipment and analysis of data. Automation has the potential result in economic efficiencies through reduced labor, more consistent treatment of animals, reduced drudgery, more convenience, greater production per cow, and as a decision support tool.

This project extends the research in a previous BARD project (US-439-82, Automation and Electronics for Dairy Herd Management) with an emphasis toward embedding management knowledge in an on-farm electronic data acquisition and control system for dairy cattle. The retirement of H. B. Puckett (USDA, Illinois) and the death of R. Sagi (The Technion and Volcani Center, Israel), the main engineers on the previous project, dictated that the research in the current project take a different direction. Therefore, we sought to expand the knowledge engineering part of a PC-based herd management system in the present project.

B. Research Plan

The research plan was for the investigators in each country to conduct specific trials designed to fill voids in knowledge-based dairy herd management models, develop and test specific knowledge-based subsystems, and to combine their results toward the development of a hardware and software-based system for improved

dairy herd management that would be applicable to both Illinois and Israel. The work was divided into the following areas:

1. Development and concurrent testing of algorithms necessary for operation of the system. The algorithms were to be suitable to serve as decision aids for implementation in an individual animal inventory database maintained on-farm with a PC. Algorithms were developed and tested both at Urbana and at the Volcani Center.
2. Testing of advanced PC-based techniques, particularly promising artificial intelligence approaches, for use in a knowledge-based dairy herd management program. Database management occurred at both locations; investigation of the artificial intelligence approaches of natural language interface and machine learning occurred at Urbana.
3. Development and testing under on-farm conditions of hardware subsystems for automated data acquisition of animal performance. Testing of new hardware subsystems occurred at both locations.
4. Comparative evaluation of differences between U.S. and Israeli animals and conditions for possible modifications of herd management recommendations. Data from both locations were utilized for the comparative evaluation.

B.1 Development and testing of algorithms.

- a. Intake. Predictions of individual animal intake of dry matter were developed at both institutions. The predictions depend on the body weight of the cow, daily yield of milk

Technical requirements for the daily assessment of individual cows' dry matter intake in the dairy herd

O. Kroll¹, E. Maltz², S. Denvir², S. L. Spahr³ and U. M. Peiper²

The dry matter intake (DMI) of individual dairy cows in a herd is a parameter that cannot be routinely measured at present. Substantial research has been carried out to provide formulae for its estimation according to a cow's performance. As long as cows are fed as a group by complete diet, DMI is considered as a mean value for the average cow in the herd. The herdsman controls the diet composition and allows the cow to consume it *ad libitum*. In this case the mean values of production, weight, DMI etc. are considered sufficient for nutritional and economic decisions.

Recently, technological development and the use of controllers and computers in the industry, have permitted continuous performance data collection and automatic supplementation of the cow with concentrates accordingly. However, compound is only one fraction of the diet. Its consumption strongly affects the intake of the other fractions that must still be given to the group as a whole. The difficulty is that accurate rationing of concentrates in the individual concentrate supplementation system (ICS), without a good estimate for the DMI of other available feeds, limits our ability to exploit efficiently the available technologies. Estimating the intake of the other available feeds becomes even more complicated when there is a large variety of agricultural wastes and recycled feedstuffs.

Method

In order to provide a working tool for an accurate ICS feeding system, the necessary data were applied to calculate the DMI of the individual cows by using the available formulae to estimate the DMI of the whole group. To examine this system, the calculated values were compared to measured ones in three experimental groups (about 60 cows in each group). Two groups were given complete diets of 50:50 and 27:73 forage:concentrates ratios *ad libitum*. The third group (ICS) was given a 50:50 diet supplemented individually with concentrates through automatic self feeders for cows producing more than 30 kg milk daily (Maltz, Kroll and Spahr, 1987).

Daily milk yield was recorded from individual identification (ID) and electronic milk meters, daily bodyweight from electronic walk-through scales (located on the route out of the milking parlour) and a gate ID system, both connected to a computer, and time post-partum from the herd management program.

The complete diets were fed to the three treatment groups using a weighing mixer wagon with a controller for accurate recording of feedstuff weights.

The measurement periods were for 6 weeks in the ICS and 27:73 forage:concentrate ratio groups, and 5 weeks in the 50:50 groups. Two formulae

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Source: New Techniques in Cattle Production 1989.
C.J.C. Phillips, ed. Butterworth and Co., London.

Results and discussion

The two formulae used correlated differently with the actual DMI measured in both groups fed complete diets. There is an indication that formula 1 (Mertence, 1985) correlated better with the 50% forage diet group, and formula 2 (Vadiveloo and Holmes, 1979) with the 27% forage diet group (Table 1). In the ICS group the two formulae demonstrated a similar correlation with the measured DMI (Table 1).

Table 1 Actual mean daily DMI and calculated mean DMI according to performance in cows given different diets

Week	n	Actual DMI (kg/cow per day)	Calculated DMI formula 1 (kg/cow per day)	Calculated DMI formula 2 (kg/cow per day)
27:73 forage:concentrates ratio				
1	60	21.97 ± 1.67	20.74 ± 3.98	18.24 ± 2.88
2	64	19.51 ± 1.69	19.33 ± 3.53	20.18 ± 2.69
3	65	22.79 ± 1.31	19.41 ± 3.01	21.80 ± 2.91
4	68	21.92 ± 1.31	19.76 ± 3.00	21.78 ± 2.80
5	66	22.87 ± 1.56	19.80 ± 3.14	17.83 ± 2.47
6	69	22.68 ± 1.15	20.76 ± 3.57	21.53 ± 3.02
50:50 forage:concentrates ratio				
1	55	20.94 ± 2.03	20.77 ± 3.82	17.72 ± 2.46
2	58	18.90 ± 2.01	19.87 ± 3.01	17.12 ± 2.14
3	58	19.55 ± 0.87	19.06 ± 3.65	17.81 ± 2.12
4	61	20.57 ± 1.79	18.75 ± 3.64	17.81 ± 2.14
5	65	20.97 ± 1.05	20.25 ± 5.10	17.83 ± 1.93
ICS				
1	53	21.31 ± 1.89	21.66 ± 4.04	18.48 ± 3.54
2	58	19.66 ± 1.90	20.16 ± 3.54	18.31 ± 3.83
3	56	21.91 ± 1.02	19.18 ± 3.54	19.87 ± 4.14
4	61	21.39 ± 0.21	19.48 ± 3.68	19.74 ± 4.04
5	61	22.39 ± 1.93	19.33 ± 3.46	19.74 ± 3.93
6	60	23.04 ± 1.18	19.97 ± 5.53	19.86 ± 4.03

Formula 1 - Mertence, 1985.

Formula 2 - Vadiveloo and Holmes, 1979.

DMI - dry matter intake.

Analysing the two formulae on individual cow's data (Table 2) suggests that the higher the supplementation level the greater the diversion between the two formulae. The individual estimates according to the two formulae may differ largely (Table 2), but it is not reflected in the mean values (Table 1). Each formula may be applicable in a different complete diet system, but the temptation to apply either of them to individual cows in an ICS system should be avoided. It is necessary to examine each formula according to the herd feeding regimen. In our

Table 2 A sample of individual bank DMI of cows in the ICS group given 50:50 forage:concentrate ratio, and the parameter used to calculate it. Individual supplementation for cows producing over 30 kg milk per day

Cow no.	Week post-partum	Mean weekly bodyweight (kg)	Mean bodyweight change during the week (kg/day)	Milk yield (kg/day)	Butter fat (%)	Concentrates supplementation DM (kg/day)	Calculated DMI	
							Formula 1	Formula 2
54	21	556	1.60	28.3	3.1	-	21.59	17.11
57	27	570	-0.24	26.0	3.8	-	16.32	16.61
105	14	557	0.24	30.9	4.1	2.7	17.04	16.54
642	22	534	0.96	32.0	3.8	2.7	18.96	16.43
401	19	659	0.88	37.8	3.1	5.4	17.05	19.17
119	16	509	-0.96	37.2	3.9	6.3	11.06	15.72
1119	13	730	0.20	46.0	3.3	8.1	15.97	21.36
1898	7	661	-0.92	44.1	2.9	8.1	10.25	18.88
634	7	647	0.16	48.9	3.1	9.0	14.69	19.48

DMI - dry matter intake.

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case, it seems that formula 1 is applicable to the ICS group with a correction of +10-15% to the highest supplemented cows and a gradual reduction in the correction factor to zero when no supplementation is given.

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RATION REPORT

COW NUMBER	DHIA	BODY WT.	L A C T	DIM	C O N D	MILK LB	FAT%	ADF%	NDF%	DMI LB	E X D M	F O R %	NDF FOR. (LB)	GRAIN (LB)	SUPP (LB)	L O U I P
4706	4427	1659	6	79	3	92	3.30	23.0	37.2	52.6		60	15.9	19.1	4.4	
4797	4465	1509	6	42	3	99	3.30	18.4	31.0	53.9		41	11.1	28.7	6.7	
5008	4704	1324	4	64	2	104	3.30	19.9	33.0	55.2		45	12.7	26.3	7.2	
5014	4599	1527	3	173	2	68	3.30	24.1	38.7	43.9		66	14.6	14.5	2.2	
5078	4665	1540	4	98	2	83	3.30	22.7	36.8	49.6		59	14.7	18.8	3.9	
5098	4643	1580	4	93	2	75	3.30	23.4	37.7	47.6		63	15.1	17.0	2.7	
5125	4674	1470	4	70	2	91	3.30	21.6	35.3	51.8		54	14.0	21.5	5.1	
5135	3771	1285	4	59	2	88	3.30	20.4	33.6	50.5		48	12.3	23.2	5.9	
5222	3775	1478	3	65	3	75	3.60	23.3	37.6	45.8		61	14.1	16.3	3.5	
5331	4849	1606	2	108	3	68	3.30	24.5	39.2	44.4		69	15.4	14.3	1.3	
5340	4834	1602	3	95	4	63	3.30	25.8	40.9	40.4		75	15.3	11.2	0.0 *	
5343	4836	1483	2	67	3	100	3.30	20.7	34.1	55.6		51	14.2	25.0	5.6	
5354	4840	1382	3	81	2	92	3.30	21.0	34.5	51.3		51	13.2	22.4	5.5	
5355	4856	1360	2	151	2	87	3.30	20.5	33.9	50.8		51	13.0	23.4	4.5	
5356	3955	1179	2	68	2	76	3.30	20.5	33.8	44.3		50	11.3	20.4	4.0	
5394	4871	1219	2	63	3	99	3.30	19.5	32.5	51.8		45	11.7	25.4	6.5	
5465	4908	1395	2	91	3	81	3.30	21.7	35.4	47.7		55	13.3	19.9	3.8	
5468	4910	1311	2	90	3	78	3.30	21.6	35.3	45.0		55	12.5	18.8	3.6	
5474	4931	1505	2	98	3	56	3.30	25.4	40.4	38.9		73	14.4	11.3	0.3 *	
5505	4936	1302	2	45	2	70	3.30	21.5	35.3	44.7		55	12.5	19.0	3.3	
*** Total ***													317.6	492.3	98.0	

Example Ration report for individual animal recommendations for grain (or concentrate mixture) and protein supplement from ration balancer developed at Illinois. Dry matter intake of each cow is estimated based on body weight, daily yield of 3.5% fat corrected milk, and stage of lactation. Grain and protein supp recommendations are specifically designed for a dual-feed computer feeder system or for individual feeding of a concentrate mixture topdressed with protein.

corrected for energy to 3.5% fat content, stage of lactation and fiber content of the feed as main factors. Our first attempt in this area (Kroll, et al., 1989, attached) suggested that the large amount of feed byproducts and agricultural waste that is utilized as cattle feed in Israel would significantly reduce the accuracy of prediction of individual feed intakes in lactating cows. Thus our attempts were redirected to predict milk yield and body weight change by early lactation response rather than by animal-by-animal predictions of intake and nutrient balance.

Later in the project, substantial success was achieved under Illinois conditions when "traditional" feedstuffs (alfalfa haylage, corn silage, ground corn, soybean meal, and small quantities of meat and bone meal, corn gluten meal and soy hulls) were fed with consideration given to expected appetite depression during the first 50 days of lactation, and to body condition scores (see attached example of the use of predicted dry matter intake, predicted forage intake, body condition scores, and estimated nutrient requirements to recommend concentrate and protein supplement for individual cows). This type of knowledge-based ration balancing is essential to the full utilization of computer feeders since the key to maximizing their utilization is individualization of the concentrate dispensing.

b. Lactation potential. A primary decision in the feeding strategy for dairy cows is to decide when and how to change the nutrient density for an individual cow as she proceeds

through lactation. Traditionally, "rules of thumb" mainly relating concentrates to current daily milk served as decision guides during most of lactation in situations where individual-animal feed allocation was possible. The current widespread use of group housing and total mixed rations depends more on multiple rations, each with a standard nutrient density designed to support a particular daily yield of milk. The decision then becomes one of deciding which cows should be matched with a particular ration. Practical limitations usually include facility limitations in the number of rations possible (often only one or two) and the number of animals that can be fed and housed in the area served by a particular ration.

A main part of the current project has been the testing of a concept that an individual cow's performance in mid-to-late lactation could be predicted early in lactation (starting by the 2nd week for very high or very low producers, and for almost all cows by 6-to-7 weeks into lactation), and that the decision of when to move a cow from one total-mixed-ration to another should include an estimate of her expected performance, that is, her expected partitioning of nutrients into either milk or body weight gain, considering stage of lactation and parity number. This concept also is applicable to computer feeders and is particularly important in Israel where the use of a high proportion of food by-products in dairy rations has caused some difficulty in the acceptance of computer feeders and individual-animal feeding programs.

The concepts of a "lactation potential" were presented by Kroll, et al., 1987 from our previous BARD research. In these publications we reviewed the basis for a lactation potential, and summarized the literature indicating that cows of different milk yield potentials respond differently to similar feeding systems and diet compositions. In a second publication on this topic (Maltz et al., 1991a), we concluded that: 1) maximum utilization of individual supplementation of concentrates (as with a computer feeder) requires a constant inflow of individual animal performance data that include daily milk yields, frequent milk composition, frequent body weights and individual-animal estimates of dry matter intake; and 2) a well-defined individual-animal strategy for supplementation of concentrates should consider the animal's production potential in order to exploit her full physiological potential within the constraints of minimizing feed cost and controlling excessive body weight gain. This publication showed clearly that both parity number and milk yield potential within parity were important factors to consider in concentrate allocation decisions.

Two trials, one at Kibbutz Alumim in the northwest Negev in Israel and one at the University of Illinois at Urbana, were conducted as part of the current project. In Trial I (Maltz, et al., 1991b) we tested the use of milk yield potential based on early lactation performance, body weight and body weight changes to provide estimated individual-animal

dry matter intakes and estimated performance toward a goal of economizing the intake of grain concentrates via individual animal supplementation of concentrates with a computer feeder. A second goal was to improve the grouping procedures commonly used in Israel for feeding via a total mixed ration (TMR).

Trial I also utilized neutral detergent fiber (NDF) as an estimate of feed intake, modifying the values of Mertens (1985) to conform to the high feed byproducts utilized in Israel as part of the bunk mix. The formula developed for Israel was:

$$\text{NDF Intake} = 1.3\% \text{ of body weight.}$$

Other significant features of Trial I were the implementation of automatic recording of body weights of cows at every milking (see section B.3.b, Electronic scale subsystem) and daily linear ration preparation orders to the weighing mixer wagon and monitoring of actual preparation and distribution of the bunk mixture (see section B.3.f, Mixing wagon electronics).

The results of Trial I indicated that milk yield potential was closely related to body weight changes after peak lactation milk yield and minimum body weight; cows with a low rating for milk yield potential gained more weight than cows with medium or high ratings. The results from Trial I also suggested that additional improvement in rating the milk yield potential of individual cows could have been achieved by expressing milk yield potential as a % of body weight. This approach considers that small cows producing at the same daily

RUNNING HEAD: INDIVIDUAL CONCENTRATES SUPPLEMENTATION

Key words: concentrates supplementation, parity, potential, body weight

COMPARATIVE RESPONSES OF LACTATING COWS TO A TOTAL MIXED RATION OR TO COMPUTERIZED INDIVIDUAL SUPPLEMENTATION OF CONCENTRATES

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ABSTRACT

A trial was conducted in a commercial Kibbutz dairy herd in which the grain concentrates part of the ration was fed individually to a group of cows through computerized self feeders. The performance results were compared to those of a group fed total mixed ration of 65-67% concentrates. Rationing of individual concentrates was according to lactation number, milk yield potential, milk yield, body weight changes and bunk feedstuffs. Mean intake of grain concentrates per cow was about 1 kg/d lower in the individually supplemented cows. This was partly compensated by a higher intake of bunk feedstuffs. Overall daily milk production per cow was similar to the cows receiving a total mixed ration in first parity cows, but higher in second parity cows and lower in third and greater parity cows. The higher performance of the second parity cows was achieved in all milk yield potential classes while the lower production in the third onwards lactation cows was due to lower performance in low and high potential classes. The individually supplemented cows gained less weight than those in the total mixed ration group. Milk production per unit body weight as a potential variable rather than milk yield was indicated as an improved method to refine the individual animal supplementation strategy for allocation of concentrates. The results also suggest that the same criteria as are used for supplementation of concentrates can be beneficial to cows' assignments and movements among different feeding total mixed ration groups. Computerized dispensing of concentrates, when applied properly, can economize on consumption of concentrates in cases where grouping and feeding different total mixed rations is impossible.

INTRODUCTION

The economic potential, feasibility and suggestions to implement individual supplementation of concentrates (ISC) by computerized self feeders were described by Maltz et al. 1990 (7). It can be summarized in two points: a) ISC requires a constant inflow of individual performance data that include: daily milk yields (MY), frequent milk composition, frequent body weights (BW) and dry matter intake (DMI); b) ISC strategy should be applied considering the cow's production potential in order to feed the dairy cow economically on the one hand and exploit her full physiological potential under given conditions on the other hand. Since that work was performed, frequent BW measurement (10) and individual DMI estimates (5, 13) became commercially available. Cows in different parities (PAR) and of different production levels responded differently to rations of different nutrient density (7), it was therefore assumed that ISC strategy will benefit when PAR and milk yield potential (MYP) will be factors in concentrates allocation decisions. MYP is defined as the potential to produce a certain amount of milk in the current lactation as reflected by peak production. The possibility to predict MYP as early as wk 2-4 of lactation (4, 6) with automatic data acquisition equipment can provide this estimate accurately and early enough to plan the ISC strategy for an individual cow. For ISC strategy to be successful, it should also take into consideration the BW changes within lactation in relation to the lactation curve. This strategy will allow the manager to reduce ISC to cows that increase in BW early in lactation while watching the effect on milk

production, and increase ISC when it's most likely to be partitioned into milk production rather than BW (7). Since byproducts as bunk feeds are widely used in Israel, the composition of bunk feed stuffs should be taken into consideration when applying ISC. Estimates of DMI for each cow (a variable of great importance for ISC) are greatly improved by BW data being available routinely throughout lactation and bunk feed stuffs preparation and distribution being monitored daily by a controller on the weighing mixer wagon (See material and methods). An accurate and frequent group bunk feed stuff intake, enables calculation of daily bunk feed stuffs quality in terms of "fill" factors like NDF (8) after being incorporated into proper formulas (7, 13).

For herds that group and move cows between different TMR groups, incorporation of automatically acquired data of the above mentioned variables can provide individual animal response to improve decisions concerning cows' assignments and movements between different TMR groups. Appropriate coefficients for models to include varying levels of production are lacking. The advanced technology in the dairy industry is available to collect and use data and improve both ISC and TMR feeding strategies.

An experiment that estimates the feasibility of a feeding strategy for possible adaptation as a management routine in the future needs to be performed under commercial dairy farm conditions in which economical considerations are dominant. The TMR feeding strategy in Israel is based on the availability of byproduct concentrates (C_{bp}), like cotton byproducts and citrus pulp, throughout the year. As a result, the ratio of grain and C_{bp} in the TMR varies according to availability, cost and nutritional requirements. Therefore, this experiment was conducted allowing the normal fluctuations in the ratio of grain: C_{bp} concentrates, dictated by market forces and nutritional requirements restricting only the overall concentrates forage ratio of the ration.

The objectives of this trial were: a) To economize intake of grain concentrates by applying a flexible ISC strategy according to MYP, estimated DMI and actual performance parameters (MY, BW, and BW changes) and provide guidelines for management application of such a strategy; b) To evaluate the possibilities for using the above mentioned variables to improve the grouping procedures commonly used in Israel for TMR feeding.

MATERIALS AND METHODS

General

The experiment was conducted in a commercial kibbutz dairy herd located in the northwest Negev in Israel, an area of 300 to 400 mm winter rainfall. The herd included about 350 cows, with 250-280 milking at any time. Previous to the trial the milking cows were divided into four corral groups (65 cows capacity of each group) and fed a single TMR of 65-70% concentrates. Milking occurred thrice daily at 8-hour intervals (4:00, 12:00 and 20:00). The ratio of grain: C_{w_0} varied according to economical (availability and cost) and nutritional (Table 1) considerations. The prospects at the beginning of the experiment were that the C_{w_0} in the bunk mixture of the ISC group would be between 20 and 45% of DM as it was during the year prior to the experimental period and rations (TMR and ISC) were designed accordingly. After freshening, the cows were assigned alternately by freshening date within parity (1st, 2nd, 3rd or >3rd) to one of two groups in two adjacent lots out of the four available.

Equipment and facilities

Four computer-controlled self-feeders (Alfa-Laval, Tumba, Sweden) were installed in the shady area of the corral used by one group. The self-feeders were placed 5m from

one another and 20m from a drinking trough. Each self-feeder dispensing rate was checked every week according to the built-in calibration technique supplied by the manufacturer and readjusted if necessary to dispense 150-200 g/min of a pelleted concentrate mixture. The mixture was fed to the self-feeders from a 6 ton container, which was filled periodically with weighed amounts of concentrates of a similar composition to that fed to the TMR group as crushed grain concentrates. The concentrates were pelleted because of unacceptable day-to-day inconsistency of the dispensing rate found when crushed grain was dispensed through the self-feeders (6). The accumulated filling amounts were compared to the self-feeders' records monthly to confirm the calibration technique.

The cows were equipped with two neck transponders, Alfa-Laval neck transponders for automatic recording of milk yield via meters in the milking parlor and for identifying the cows at the self-feeder stalls, and BouMatic (Dairy Equipment Company, Madison, WI USA) neck transponders to identify cows in the exit lane as they walked across an automatic recording scale system. The scale system (10) was built especially for this experiment (Carcon Ltd., Kfar Saba, Israel), to weigh the cows automatically at each milking. The scales were checked routinely by comparing weights with those obtained by mechanical scales and by recording the same cows walking on them several times. Bunk feeding regime was twice daily by a mixer wagon equipped with an electronic scale.

Bunk mixtures were prepared and distributed twice daily (after morning and noon milking) by a weighing mixer wagon. Preparation and distribution of rations were monitored daily by a special purpose portable controller (Anat, Bror Hail, Israel) which received ration preparation "orders" from a personal computer equipped with a linear ration preparation program (Anat, Bror Hail, Israel). The controller was transported to the

weighing mixer wagon and connected to the wagon's electronic scale daily, thus becoming an integral component of the control system to communicate ration instructions to the operator and monitor the actual preparation and distribution of the mixture to the cow groups. The controller was then reconnected to the computer at the end of the day to feed back the actual preparation and distribution data (12).

Feeding and supplementation strategy for concentrates

Rations of the two treatments (TRT) are summarized in Table 1. Group 1 was fed a TMR. Group two (ISC) was fed in the bunk a mixture of similar compositions as that of Group 1 excluding most of the grain components that were fed through the self-feeders. The composition of TMR and ISC rations were planned according to expected feedstuffs availability and costs. Proportions of the concentrates components in the TMR were allowed to fluctuate according to availability and costs while forage, protein and energy densities remain constant (for forages 2% fluctuations were allowed). Some grain concentrates were fed in the bunk mixture of the ISC cows to provide some flexibility to maintain a fixed concentration of protein. A clean bunk in the morning was followed by increasing the daily amount; leftovers resulted in reducing it. ISC for the fresh cows during the first 4 weeks of lactation is described in Table 2. The supplementation strategy considered the following variables: Initial BW of cows, density of byproduct concentrates in the bunk, gradual increase in DMI and gradual adjustment to self-feeders use by the cows. ISC cows were closely watched for their use of self-feeders. Cows that did not use the self-feeders for up to 7 days were transferred from the ISC group. After 4 weeks postpartum the MYP of ISC cows was estimated (4, 6). Cows were classified for MYP as described in Table 2 and ISC was changed if necessary to produce concentrate density for the entire individual DMI as described in Table 2. Between weeks 4 and 10

postpartum the MYP of ISC cows was verified according to actual performance, and changes in ISC were carried out for those cows that performed differently than estimated. After week 10, BW changes became a factor in ISC decisions. Any increase in BW above the standard deviation of the weekly mean was followed by reducing ISC by 1 kg/d as fed. This procedure was followed to a minimum of 2 kg/d as fed. For cows that maintained constant BW and MY, ISC was increased by 1 kg/d as fed. Total concentrates density was not allowed to be higher than described in Table 2. Any time that byproduct concentrates were changed in the bunk feed, ISC was adjusted to maintain the total concentrates density of the individual DMI the same as before the change. Whenever conditions required ISC reduction of more than 1 kg/d, it was carried out gradually by reducing 1 kg/d and after 2 days another 1 kg/d. The amounts of ISC for each cow to establish a desired total concentrates density of individual dry matter intake (DMI) were calculated according to the following formulas:

$$1. \quad \text{NDFI} = 1.3\% \text{ of BW}$$

Where NDFI is total NDF intake by the cow. This estimate differed from the 1.1% value described by Mertens (8) and was calculated from preliminary experiments to estimate group DMI according to cow performance in the Israeli environment with a high percentage of byproducts in the feed mixture (5).

$$2. \quad \text{NDFI} = F(\text{FNDF}) + C_{\text{so}}(C_{\text{so}}\text{NDF}) + C_{\text{f}}(C_{\text{f}}\text{NDF})$$

Where F, C_{so} and C_{f} are the fractions of forage, byproducts and self-feeders fed concentrates, respectively and FNDF, C_{so} NDF and C_{f} NDF are the NDF fraction of the forage, C_{so} and self-feeders fed concentrates, respectively.

$$3. \quad C_s + C_{bo} = X(F + C_{so} + C_i)$$

Where X is the fraction of total concentrates desired for a cow.

$$4. \quad C_{bo} = Y(F + C_{so})$$

Where Y is the fraction of C_{so} in the bunk mixture consumed *ad libitum*.

The Y values were recorded by the controller on the weighing mixer wagon. The X values were determined for each cow from Table 2. For example: for a 500 kg low potential cow in 2nd lactation at week 4 to 10 postpartum, the ISC required to establish 60% (Table 2) total concentrates of DMI when C_{so} is 20% of the bunk mixture is calculated to be 5.85 kg DM/d when: $X = 0.6$; $Y = 0.2$; $NDFI = 6.5$ (1.3% of 500 kg); $FNDF = 0.65$; $C_{so}NDF = 0.30$; $C_iNDF = 0.12$, $C_{bo} = 1.97$ and $DMI = 19.70$ kg/d.

Statistical Analyses

Milk yield (MY), body weight (BW), body weight as percent of initial (BW_I) and milk yield as percent of body weight (MYBW) were averaged over 20 weeks for each cow.

These cow means were analyzed by a 3-factor factorial model including two-way and three-way interactions as illustrated in Model [1].

$$Y_{ijk} = TRT_i + PAR_j + MYP_k + (TRT * PAR)_{ij} + (TRT * MYP)_{ik} + (PAR * MYP)_{jk} + (TRT * PAR * MYP)_{ijk} + e_{ijk} \quad [1]$$

where Y_{ijk} represented performance variable (MY, BW, BW_I, or MYBW) on the i^{th} cow that was in the k^{th} milk yield potential (high, medium and low potential; HP, MP, LP, respectively), j^{th} parity (1, 2, >2) and i^{th} treatment (ISC or TMR);

TRT_i represented individual supplementation of concentrates (ISC) or

total mixed ration (TMR);

PAR_j represented first, second, or greater than second parities;

MYP represented one of three ranges of peak milk production in each PAR as described in Table 2;

$(TRT * PAR)_{ij}$, $(TRT * MYP)_{ik}$, $(PAR * MYP)_{jk}$ represent 2-way interactions between the main factors;

$(TRT * PAR * MYP)_{ijk}$ represents the 3-way interaction; and e_{ijk} represents random residual which was used to test all other terms in the model. Least squares means will be reported for TRT_i , $(TRT * PAR)_{ij}$, $(TRT * MYP)_{ik}$, and $(TRT * PAR * MYP)_{ijk}$.

Persistence of MY, BW, BW_I, and MYBW was estimated for each cow from the measurements taken on weeks 4 to 20 by linear regression. Persistence was the regression coefficient (slope) of performance variable on week of measurement. The persistence of each performance variable by cow were analyzed by Model [1]. Because analyzing performance variables according to cow potential (CP) was relevant only for cows that there was no attempt to affect their BW, only TMR treatment cows were used. Therefore, Model [2] was developed.

$$Y_{ik} = PAR_j + CP_i + (PAR * CP)_{ji} + e_{ik} \quad [2]$$

where Y_{ik} represents performance variables or persistence on the k^{th} cow that was in the i^{th} parity and j^{th} cow potential;

PAR_j represents first, second, or greater than second parity;

CP_i represents cow potential peak with yield as percent of body weight;

$(PAR * CP)_{ji}$ represents interaction between parity and cow potential;

and e_{it} represents random residual which was used to test all other terms in the model.

Analyses were performed by the statistical analysis system (11). To detect differences between TRTs of the performance variables in a particular wk postpartum student T test was applied.

RESULTS AND DISCUSSION

All cows

Performance results are summarized in Table 3. No differences in milk production between the two groups were detected but the ISC cows gained significantly ($P < 0.05$) less weight as percent of initial during the 20 wk trial period. This was primarily due to the effect of the treatment (TRT) on BW changes in LP and HP cows. Daily MY and MY as percent of BW correlated with MYP in both treatments. The LP cows in both treatments gained significantly ($P < 0.05$) more weight than MP and HP cows. MY of the TMR fed cows was significantly related to PAR while in the ISC cows there was no significant difference between PARs 2 and >2 . Mean BW in both treatments was significantly ($P < 0.05$) related to PAR. BW changes differed among potential groups only in the TMR fed cows where MP cows gained significantly ($P < 0.05$) more weight than LP and HP ones. MY as percent of BW correlated with MYP in both treatments ($P < 0.05$). However, in TMR fed cows 1st and 2nd lactation cows were similar while in ISC cows 1st and >2 nd lactation were similar.

Table 4 shows the persistency of performance variables from week 4 onwards (Table 4). No significant difference between treatments was detected when all cows were considered. A significant difference ($P < 0.05$) was detected for BW change as a percent of initial weight between LP cows of the two treatments and the difference in actual weight

changes was significant at the level of $P < 0.08$. ISC successfully balanced the strong inverse relation between MYP and BW changes (actual values as well as percent of initial) demonstrated in the TMR fed cows. The difference in slopes related to PAR were similar in both treatments except MY as percent of BW. In TMR fed cows daily milk yield declined significantly ($P < 0.05$) faster in 2nd and >2 nd parities than it did in 1st parity cows, while no such difference could be detected in ISC cows.

The mean daily intake of feedstuffs is summarized in Table 5. ISC cows consumed less grain concentrates than TMR fed ones and C_{50} consumption of ISC cows was higher. The ISC cows also consumed more forage (silage and hay) than TMR fed cows. This resulted in a ratio of 65:35% concentrates forage over the five months measured in the ISC group compared to 67:33% ratio in the TMR group. The overall DMI of ISC cows was higher than that of TMR fed ones.

The results regarding all cows indicated that the flexible changing ISC strategy applied in this work did economize on grain concentrate intake without damaging milk production by encouraging bunk feed stuffs intake (including non grain concentrates) and reducing weight gain rate over the first 20 wk of lactation. Yet, before drawing a conclusion about superiority of one strategy over the other it must be recognized that the experimental design did not permit fluctuations in total concentrate density in the TMR fed group. In herds of this size, cows can be moved from a high (70-75%) to a lower (60-65%) and a lower yet (50%) concentrate density TMR feeding group. ISC was documented truly to be economically superior to high concentrate TMR feeding. However, in small herds (up to about 100 cows in milk) where grouping is not possible, diet changes in response to economic constraints affect all cows whether it is for the better or worse. In these cases when TMR strategy is applied with no flexibility whatsoever ISC is one answer for

economizing on grain concentrates. Even when cow grouping is available, movements from one group to another affect (at least temporarily) milk production because of the abrupt change in diet and reestablishment of social order.

Our aim by carrying out this experiment was not just to demonstrate the successful application of ISC strategy since its feasibility was already indicated (7); the main goal was to refine the flexible ISC strategy, thus indicating practical ways of carrying out an ISC strategy on one hand and pointing out the criteria for cows' movements between feeding groups when grouping is available on the other. This requires a thorough analysis of the results regarding PAR and MYP of ISC cows as well as TMR fed cows.

The significance of the contribution of TRT, PAR and MYP and any possible interaction between them in affecting the performance variables are summarized in Table 6. All performance parameters were affected by MYP and, except BW as percent of initial, also by PAR. This result directs us to the possibility that grouping of TMR-fed cows may be more efficient if it considers these two variables rather than assigning cows to feeding groups related to their stage of lactation as it is now widely practiced in many herds. These results also support earlier conclusions regarding group feeding according to production potential (3). Our study showed that BW changes (BW as percent of initial) were significantly affected by the strategy employed for ISC. It also showed that MYP had a significant effect on BW changes. There was an interactive effect of TRT (strategy employed for ISC) and PAR on MY and MY as percent of BW. Even though TRT contribution to the combined effect with parity was not large (some 10% of the combined effect), it indicates that a better result could have been achieved either by applying a more adequate ISC strategy to cows of different parities, or that the MYP criterion selected for each parity (dictating the ISC) was not adequate, thus causing a different response in

cows of different parities. To investigate this possibility, an additional analysis was conducted to focus on the effect of PAR and MYP in both treatment groups.

First parity cows

The milk yield results of 1st parity cows are presented in Table 3 and Figure 1. There was no significant difference regarding MY between the two treatments. The 20-week lactation curve was similar between ISC and TRM fed cows for all 3 MYPs. LP cows in both TRTs produced significantly less milk than the other two MYPs; the difference between MP and HP cows was not significant.

The body weight results (actual weight and percent of initial) are presented in Table 3 and Figures 4 and 7 respectively. There was no significant difference in initial body weight between LP and MP cows in either treatment, 487 ± 37 and 483 ± 34 Kg ($x \pm SD$) in ISC LP and MP cows, but initial body weight of HP TMR fed cows was significantly higher ($P < 0.05$) than that of LP and MP cows. Body weights of ISC cows were similar in absolute values and in their pattern of change to those of the TMR fed cows. Even though it seemed that TMR fed LP cows gained weight more rapidly than their counterparts in the ISC group (when body weight changes were calculated as percent of initial), statistically the difference was not significant. Only two ISC cows qualified for the HP level; therefore, no decisive conclusion could be drawn regarding this class. HP TMR fed cows appeared to differ significantly from LP and MP in the pattern of body weight changes. They maintained a constant weight for 10 weeks (between weeks 4 and 14, Figure 4) and their weight gain afterwards was more moderate than that of LP and MP cows. Thus, while LP reached $107.0 \pm 3.9\%$ and MP $104.8 \pm 3.7\%$ of initial body weight ($x \pm SD$) at week 20, HP cows reached only $99.7 \pm 5.7\%$ of initial body weight ($x \pm SD$). The similarity in performance between the two TRTs is also expressed in MY as percent of BW

(Table 3). There was no significant difference between the two TRTs. No difference could be detected between the different MYPs within TRTs except HP ISC cows (only two cows, see above).

With respect to changes of performance parameters as reflected by the slopes from week 4 onwards (Table 4), no significant difference could be detected between TRTs. However, the differences related to MYP that occurred in the TMR fed cows (BW $P < 0.08$ and BW as percent initial $P < 0.05$) diminished in the ISC cows.

The husbandry routine in Kibbutz dairy herds in Israel is that heifers are raised and bred on the farm for herd replacements. Those that fail to produce 20 Kg milk/d at the second milk test (routinely done once a month) leave the herd. All the others, everything being well, will be given an opportunity to produce during second lactation. In our experimental herd this selection was conducted at week 10 postpartum; cows culled at this point from either TRT were not included in the results. We a priori considered the possibility that 1st parity cows should be classified into 2 MYPs rather than 3. It is therefore possible that the additional supplementation of concentrates to MP cows was unnecessary to some. It is also possible that the criteria used for classifying according to MY was inadequate and that a difference classification that would express both MY and BW should have been applied.

Second parity cows

MY results for 2nd parity cows are presented in Table 3 and Figure 2. ISC cows performed better than TMR fed ones ($P < 0.05$) overall and in each MYP class. MY varied significantly ($P < 0.05$) with MYP in both treatments.

BW results (actual values and percent of initial) are summarized in Table 3 and Figures 5 and 8 respectively. The mean BW throughout the period was similar in both TRTs when

all cows were concerned. The BW increase in TMR fed cows as percent of initial appeared to be more rapid than in the ISC group; thus the TMR fed cows reach initial weight earlier and at week 20 weighed $113.4 \pm 7.5\%$ of initial weight compared to $106.6 \pm 6.6\%$ for the ISC cows ($x \pm SD$). There were some significant differences ($P < 0.05$) in initial BW and BW change along the period between TRTs of similar MYPs and among the different MYPs cows within TRTs. In LP cows mean BW as percent of initial weight differed significantly between TRTs ($P < 0.05$) although initial BWs were similar, indicating a lower weight gain. Since no significant difference in the slope of BW as percent of initial could be detected between these cows (Table 4), it is apparently a result of different weight gain rate at some stages between weeks 4-20 (Figure 8). The weight change of the HP ISC cows had a different pattern than the TMR HP group by having a greater decrease followed by a smaller gain (Figure 5). Their mean BW gain as percent of initial was also significantly ($P < 0.05$) lower than that of TMR fed HP cows. There was no significant difference between initial body weight of MP cows of the two TRTs. The weight change pattern expressed both as absolute change and percent of initial weight in MP cows were similar in each TRT. A significant difference ($P < 0.05$) in mean BW between MYPs within TRTs could be detected only in ISC cows where HP ones were heavier than the other two MYP classes. Significant differences ($P < 0.05$) were recorded in mean BW as percent of initial between MYPs within TRTs. LP cows demonstrated the greatest increase in both TRTs, while MP cows had the lowest increase within the TMR fed groups and HP had the least increase within the ISC groups (insignificantly lower than MP).

MY as percent of BW is summarized in Table 3. The significant difference ($P < 0.05$) between TRTs regarding all cows of 2nd lactation is mainly the result of significant difference ($P < 0.05$) between the MP cows. A significant difference ($P < 0.05$) could also

be observed between MYPs within TRTs. In both treatments the HP cows were higher than the two other MYPs.

As in 1st lactation cows, no difference in performance variables for persistency could be detected when comparing the overall slopes of the TMR and ISC groups between weeks 4 and 20 (Table 4). However, a different pattern of persistency ($P < 0.05$) among MYP classes was found in the TMR fed cows when compared to ISC ones. The TMR LP cows were significantly different from MP and HP cows regarding persistency whereas in the ISC cows HP cows differed significantly from MP and LP ones.

The ISC strategy applied was most successful in the 2nd parity cows. The ISC cows produced more milk and gained less weight. The ISC strategy enabled the cows of all MYP classes to exploit their performance capacity. Maybe this is because the BW changes as well as MY were strongly related to MYP. The differences found among the MYPs within the ISC TRT suggest that in second parity cows the MYP definition included the potential relating to BW and BW changes. The dependence between MYP and BW changes was best illustrated in second lactation TMR fed cows where no attempt was made to affect the cows' weight (Table 3, Figures 5 and 8). As percent of initial weight LP cows gained weight most and MP least. MY as percent of BW varied with MYP yet differently than MY and BW changes.

Important conclusions can be drawn from the performance and performance persistency results of TMR fed second lactation cows. Feeding LP cows a TMR of 65-67% concentrates resulted in a higher weight gain instead of having all the nutrients partitioned into milk yield. A similar result was found in the HP cows but they had a lower initial weight and mean BW than those in the ISC TRT (Figure 5). On the other hand, it appeared that the MP cows had the potential to produce more milk if fed a TMR with

higher density of concentrates than they actually received and some MP cows in the ISC TRT actually did (Figure 2). This suggests that a potential estimate may be beneficial not only for ISC strategy but also for TMR feeding strategy. The superior performance of 2nd lactation ISC cows could be a result of the MYP definition in the ISC cows being more closely related to BW and BW changes than in the TMR fed cows; thus the ISC strategy applied resulted in better performance (see below).

This leads once again to the possibility that the MYP definition used in this trial may not be the best possible potential indicator to be used either for ISC or for TMR grouping. The results suggest that a variable combining MY and BW may be a more efficient approach to express cow potential in order to best describe the feeding strategy that should be applied.

Third onward parity cows

Milk yield results of >2nd parity cows are summarized in Table 3 and Figure 3. ISC cows produced significantly ($P < 0.05$) less milk than TMR fed ones. Lower production was present in all MYP classes although the difference was significant ($P < 0.05$) only in HP cows. In both TRTs the average daily MY was MYP dependent.

BW changes (actual weight and percent of initial weight) of >2nd parity cows are presented in Table 5 and Figures 6 and 9 respectively. A significant difference ($P < 0.05$) in initial BW between treatments was recorded only in MP cows. Weight gains were similar between TRTs in all 3 MYPs. No significant differences in mean BW and BW changes (as percent of initial) between or within TRTs were detected. However, significant differences in mean MY as percent of BW were present within TRTs (Table 3). Insignificant differences between TRTs might be the reason for the order change in differences ($P < 0.05$) regarding mean MY as percent of BW between TRTs (Table 3). In

TMR fed cows LP ones produced less milk per BW unit than MP and HP ones, while in ISC cows there was no difference between LP and MP cows, both lower than HP ones.

In >2nd parity cows the persistency of performance parameters was affected by TRT in the same way as in the other parities, by changing the order of differences related to MYP within TRTs rather than between them (Table 7). The ISC strategy applied in this trial was inefficient for >2nd parity cows, particularly the ones in the HP group. The >2nd parity cows were expected to perform equally to the TMR fed ones. The HP group was expected to do so while consuming less concentrates (7). One possible reason for failing to perform as expected could be the difference in postpartum routine in this study. In this work the cows were moved to computerized self-feeders immediately postpartum while in the previous study (7), the cows were fed a high concentrate TMR for 7 weeks before being transferred to self-feeders. Another possibility might well be the MYP definition in these cows. This factor which dictated ISC amounts, though yielding satisfactory results in younger cows, was not sufficient in the highest yielders. The fact that only mean MY as percent of BW was MYP dependent in both treatments points out yet again the possibility that a potential ranking that considers BW and its changes might have been more successful in applying the ISC strategy. This also applied to the >2nd parity TMR fed cows. If those cows would have been grouped in different feeding groups according to MYP, the MP and HP cows would have been assigned in different groups, while the mean MY as percent of BW suggests that they be allocated to the same group.

Cow performance potential

When all cows were considered, the data analysis of TMR fed cows revealed a close relation between PAR and mean BW (Tables 3 and 4) and between MYP and BW changes

(actual values and percent of initial Tables 3 and 4). Within PAR the relations were less sharp. This leads to the conclusion that by establishing our ISC strategy on PAR and MYP we defined at least to some extent, the average BW, BW gain rate and its pattern along lactation on top of average daily milk production (Table 2). This result suggests that our ISC strategy was limited a priori in its effect over BW changes. It is possible that by incorporating a better potential definition into the decision making process, our attempt to economize on concentrates by affecting weight gain would have been more successful. The inconsistency in the differences and their statistical significance regarding performance variables within PAR in the TMR fed cows (Table 3) suggests that a performance classification that would describe MY as well as BW and its changes along lactation is needed and feasible. Such a definition of lactation potential would have improved our ability to feed cows efficiently in both strategies.

In order to test this possibility we expressed peak MY as percent of BW in the TMR fed cows. Cow potential was defined as described in Table 7. The result was that 50%, 35% and 50% of 1st, 2nd and >2nd parity cows changed their potential group comparing to MYP definition (Table 7). The average daily MY was CP dependent regarding all cows (Table 8) but a different ranking within lactation could be observed in 1st and 2nd lactation ($P < 0.05$) while no significant difference was detected among the >2nd parity cows. The CP definition classified that cows regarding initial BW (Figures 10 to 12), mean BW (Table 8), BW changes (actual values and percent of initial Figures 10 to 12, Table 8), MY as percent of BW (Table 8), and persistency of milk yield expressed by slopes (Table 8), in a way that is physiologically more consistent than that of the MYP definition. Efficiency of milk production physiologically and economically should be related to BW and to BW change during lactation; this was the result obtained with the CP definition. It is likely that

the deviation between MYP and CP definition in our previous study (7) was similar to the current one, since both works were carried out in the same herd. Therefore, assuming a similar distribution among the ISC cows, it appears that ISC was most successful in the cows where MYP definition was closest to that of CP, which were the 2nd parity cows and less so in 1st and >2nd parity ones.

CONCLUSIONS

ISC strategy when applied according to physiological and economical factors can economize on the grain fraction of the ration. This is especially true in small herds that do not have the option of cow grouping. The results of this trial do not permit a decisive conclusion regarding the superiority of ISC or TMR with grouping available as a feeding strategy. A trial in which TMR fed cows are grouped and transferred among feeding groups according to the physiological differentiation (suggested in this trial for ISC strategy) is necessary for such a comparison. Yet several points emerged in favor of ISC. This seems to be a more flexible system than TMR feeding strategy. Changes in density of concentrates can be applied gradually without moving cows from one group to another thus avoiding the negative effect caused by abrupt changes in diet (1) and social disorders (2). Computer self-feeders which can ration up to 4 ingredients separately are commercially available. This sophistication will allow: separate supplementation of energy and protein ingredients, different ratios of rumen degradable and undegradable proteins (9) according to time postpartum and the cows' response and protected fats or expensive additives feeding that are economically exploitable only by a part of the cows. The obstacle of estimating DMI when only a part of the feed ingredients are measured can be overcome by formulae that translate performance parameters and feed stuff qualities

into reliable DMI estimates (5, 8, 13). The availability and wide-spread use of electronic milk meters, personal computers for herd management, a variety of herd management software, controllers on weighing mixer wagon (12), walk-through electronic scales (10) and multichannel self-feeders make ISC an attractive research field with promising management applications. The data analysis for ISC decisions as well as the decisions themselves (that were done in this work manually) can be easily translated into software. On-farm computer software that will, when coupled with automatic data collection, perform data analysis and aid in making ISC decisions according to expected physiological and economical results can make ISC a useful feeding strategy.

The same physiological parameters that make ISC an attractive potential management system can and should be applied in TMR feeding (5). Incorporating BW and its changes into potential criteria (as described above) may improve this system that is already successfully applied in most of the herds in Israel and in many dairy herds in other countries.

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Table 2. Milk yield potential definition (MYP) according to peak production in the different parities (PAR) and individual supplementation of concentrates (ISC).

PAR	1			2			3			>3		
MYP	LP	MP	HP	LP	MP	HP	LP	MP	HP	MP	HP	HP
Milk Yield at peak (kg/d)	<30	30-32	>32	<36	36-41	>41	<41	41-44	>44	<41	41-44	>44
ISC 4 wk postpartum (Kg as fed/d) ^a		10			12			14			16	
Total concentrates after 4 wk postpartum (% of estimated DMI)	55	60	55	60	70	70	70	70	65	70	70	65

^a When byproducts concentrates do not exceed 20% of DM in bunk feedstuffs.

Table 1. Content and composition of rations fed to total mixed ration (TMR) fed and individually supplemented with concentrates (ISC) cows.

Component (% of DM)	TMR	ISC	Concentrates through self feeders ^a
	% of DM		
Wheat silage	25-26	35-45	---
Vetch hay	9-10	15.0-17.6	---
Barley	19-24	---	60
Corn	2-7	---	20
Soybean meal	7-9	3-7	1.5
Wheat bran	9-11	6-9	1.5
Cotton seeds	11-15	15-19	---
Cottonseed meal	0.2-0.3	0.1-0.3	1.5
Citrus pulp	0-15	0-20	---
Vitamin mix	1.91	1.9	1.9
Composition (% of DM)			
CP	16	14.2	18.4
NDF	31-35	33-38	12
NEL (Mcal/kg)	1.68	1.48-1.68	1.83

^a Pelleted concentrates also contained 1.5% of fish, bone and feather meal.

Table 4. Mean regression coefficients (slope) in milk weight changes (BW % of initial) and milk yield as % of body weight (MY % of BW) of cows fed 65-67% concentrates total mixed ration (TMR) and cows individually supplemented with concentrates (ISC), from 4-20 wk of lactation as expressed in the different parities (PAR) and milk yield potentials (MYP); low, medium and high potentials (LP, MP and HP, respectively).

MYP	n	TMR				n	ICS			
		MY kg/d	BW kg	BW % of initial	MY % of BW		MY Kg/d	BW Kg	BW % of initial	MY % of BW
PAR 1										
LP	6	0.09 ^a	2.89 ^b	0.62 ^a	-0.01 ^a	5	-0.03 ^a	2.44	0.51	-0.03 ^a
MP	6	-0.24	2.73 ^b	0.59 ^a	-0.02 ^a	5	-0.04 ^a	2.91	0.61	-0.04
HP	6	-0.06 ^a	1.20 ^a	0.22 ^b	0.00	2	-0.12 ^a	1.56 ^a	0.30 ^a	-0.04 ^a
ALL	18	0.13 ^a	2.27 ^a	0.48 ^a	0.00 ^b	12	-0.06 ^a	2.30 ^a	0.47 ^a	-0.04
PAR 2										
LP	6	-0.02 ^a	4.12 ^a	0.83 ^a	-0.04 ^a	10	-0.06 ^a	2.93 ^a	0.59 ^a	-0.04
MP	7	-0.33 ^b	1.71 ^b	0.30 ^b	-0.07 ^{ab}	10	-0.18 ^a	2.26 ^a	0.41 ^a	-0.06
HP	8	-0.42 ^b	1.01 ^b	0.29 ^b	-0.09 ^a	5	-0.40 ^b	0.56 ^a	0.10 ^{ab}	-0.07
ALL	21	-0.26 ^b	2.28 ^a	0.48 ^a	-0.07 ^a	25	-0.21 ^{ab}	1.92 ^a	0.37 ^a	-0.06
PAR >2										
LP	9	-0.25	2.47 ^a	0.43 ^a	-0.07	9	-0.24	1.44 ^a	0.25 ^a	-0.05
MP	6	-0.44	1.20 ^{ab}	0.32 ^b	-0.10	7	-0.34	2.24 ^a	0.36 ^a	-0.07
HP	6	-0.35	0.41 ^{ab}	0.06 ^{ab}	-0.06	6	-0.48	0.04 ^a	0.00 ^b	-0.08
ALL	21	0.35 ^b	1.36 ^b	0.27 ^b	-0.07 ^a	22	-0.35 ^b	1.22 ^b	0.20 ^b	-0.06
ALL PARs										
LP	21	-0.06 ^a	3.16 ^a	0.63 ^a	-0.04	24	-0.11 ^a	2.27 ^a	0.45 ^a	-0.04
MP	19	-0.18 ^{ab}	1.88 ^b	0.41 ^b	-0.05	22	-0.19 ^{ab}	2.47 ^a	0.46 ^a	-0.06
HP	20	-0.24 ^b	0.87 ^c	0.19 ^c	-0.05	13	-0.33 ^b	0.69 ^{ab}	0.13 ^b	-0.06
ALL	60	-0.16	1.97	0.41	-0.04	59	-0.21	1.81	0.35	-0.06

^a Pooled SD values for MY, BW, BW % of initial, MY % of BW are 3.53, 1.76, 0.29 and 0.06, respectively.

^a Slope does not differ from zero (P>0.05).

^a Significant difference (P<0.05) within rows.

^{a,b,c} Significant difference (P<0.05) within columns.

Table 3. Mean^a daily milk yield (MY), body weight (BW), body weight changes (BW % of initial) and milk yield as % of body weight (MY % of BW) of cows fed 65-67% concentrates total mixed ration (TMR) and cows individually supplemented with concentrates (ISC), during 20 wk of lactation as expressed in the different parities (PAR) and milk yield potentials (MYP); low, medium and high potentials (LP, MP and HP, respectively).

MYP	n	TMR				n	ICS			
		MY kg/d	BW kg	BW % of initial	MY % of BW		MY Kg/d	BW Kg	BW % of initial	MY % of BW
PAR 1										
LP	6	24.9 ^b	482	102.1	5.16	5	24.5 ^b	485	99.7	5.05 ^b
MP	6	28.9 ^a	487	100.7	5.93	5	26.2 ^a	478	98.9	5.49 ^b
HP	6	30.2 ^a	517	97.7	5.84	2	31.4 ^a	499	96.3	6.29 ^a
ALL	18	28.0 ^c	495 ^c	100.2 ^b	5.65 ^b	12	26.4 ^b	484 ^c	98.8	5.45 ^b
PAR 2										
LP	6	27.2 ^c	535	108.5 ^a	5.08 ^b	10	30.4 ^c	531 ^b	101.9 ^a	5.72 ^b
MP	7	32.4 ^b	579	98.9 ^c	5.59 ^b	10	34.8 ^b	543 ^b	98.5 ^b	6.41 ^a
HP	8	36.2 ^a	540	102.2 ^b	6.70 ^a	5	39.6 ^a	607 ^a	95.8 ^c	6.52 ^a
All	21	32.4 ^b	552 ^b	102.9 ^a	5.86 ^b	25	34.0 ^a	484 ^c	98.8	5.45 ^b
PAR > 2										
LP	9	33.8 ^c	586	101.1	5.77 ^b	9	31.4 ^c	601	100.8	5.22 ^b
MP	6	37.2 ^b	590	99.6	6.31 ^a	7	35.8 ^b	631	97.2	5.67 ^b
HP	6	41.0 ^a	631	98.9	6.66 ^a	6	38.8 ^a	611	98.4	6.35 ^a
All	21	37.1 ^a	600 ^a	100.0 ^b	6.18 ^a	22	34.8 ^a	613 ^a	99.0	5.68 ^b
ALL PARs										
LP	21	29.3 ^c	542	103.5 ^a	5.37 ^c	24	29.5 ^c	547	101.0 ^a	5.39 ^c
MP	13	32.8 ^b	553	99.7 ^b	6.40 ^a	22	33.2 ^b	556	98.2 ^b	5.90 ^b
HP	20	36.1 ^a	560	99.9 ^b	6.40 ^a	13	37.9 ^a	592	97.0 ^b	6.42 ^a
ALL	60	32.7	552	101.1	5.93	59	32.7	560	99.1 ^a	5.87

^a Pooled SD values for MY, BW, BW % of initial and MY % of BW are 2.62, 49, 4.2, 0.64, respectively.

^a Significant differences (P<0.05) within rows.

^{a,b,c} Significant differences (P<0.05) within columns.

Table 6. Significance (P value) of treatment (TRT), parity (PAR) and milk yield potential (MYP) and any possible interaction between them on performance parameters (milk yield-MY, body weight-BW, body weight as % of initial-BW % of initial, milk yield as % of body weight-MY % of BW) during 20 wk of lactation of cows fed total mixed ration and individually supplemented with concentrates.

	M.Y.	B.W.	B.W. % of initial	M.Y. % of B.W.
TRT	n.s.	n.s.	0.0059	n.s.
PAR	0.0001	0.0001	n.s.	0.0285
MYP	0.0001	0.0393	0.0001	0.0001
TRT*PAR	0.0001	n.s.	n.s.	0.0090
TRT*MYP	n.s.	n.s.	n.s.	n.s.
PAR*MYP	n.s.	n.s.	n.s.	n.s.
TRT*PAR*MYP	n.s.	n.s.	n.s.	n.s.

Table 5. Mean daily feeds intake (kg DM/d) per cow calculated over 5 months for total mixed ration (TMR) fed and individual supplemented with concentrates (ISC) cows.

TRT	n	Grain concentrates	Cottonseeds	Citrus pulp	Miscellaneous concentrates	Silage	Hay	DMI	Concentrates-forage ratio
ISC	60	7.1	3.0	1.8	1.4	5.3	1.8	20.4	65:35
TMR	63	7.9	2.8	1.7	0.8	4.8	1.7	19.7	67:33

Table 8. Mean[†] daily milk yield (MY, kg/d), body weight (BW, kg), body weight as % of initial (BW % of initial), daily milk yield as % of body weight (MY % of BW) and their regression coefficients (slopes) of cows fed 65-67% concentrates total mixed ration between 4-20 wk. Expressed according to parity (PAR) and cow potentials (CP, peak milk yield as % of body weight). Low (L), medium (M) and high (H).

CP	n	Means wk 1-20				Slopes wk 4-20			
		MY Kg/d	BW Kg	BW % of initial	MY % of BW	MY Kg/d	BW Kg	BW % of initial	MY % of BW
PAR 1									
L	5	25.5 ^b	500	102.1	5.07 ^b	0.12 [*]	2.79	0.59	-0.01 ⁺
M	7	27.6 ^b	508	100.2	5.43 ^b	0.07 ⁺	2.05	0.41	-0.01 ⁺
H	6	30.7 ^a	476	98.6	6.44 ^a	0.22 ⁺	2.10	0.46	0.02 ⁺
ALL	18	27.9 ^c	495 ^c	100.3	5.65 ^b	0.14 ^{*,a}	2.32	0.49 ^a	0.00 ^{+,b}
PAR 2									
L	6	27.1 ^b	590 ^a	104.2	4.58 ^b	-0.43 ^b	4.03 ^a	0.74 ^a	-0.10 ^a
M	9	33.8 ^a	530 ^b	103.1	6.36 ^a	-0.01 ^{+,a}	1.73 ^b	0.43 ^a	-0.03 ^{+,b}
H	6	36.0 ^a	548 ^b	100.1	6.57 ^a	-0.59 ^b	0.81 ^{+,b}	0.18 ^{+,b}	-0.12 ^a
ALL	21	32.3 ^b	556 ^b	102.5	5.84 ^b	-0.35 ^b	2.19	0.45 ^a	-0.08 ^a
PAR >2									
L	7	35.3	638 ^a	101.5	5.53 ^c	-0.32	2.57 ^a	0.42	-0.07
M	8	37.3	592 ^b	99.7	6.32 ^b	-0.22	1.44 ^a	0.25	-0.05
H	6	38.8	564 ^b	98.8	6.79 ^a	-0.50	0.40 ^{+,b}	0.21 ⁺	-0.10
ALL	21	37.2 ^a	598 ^a	100.0	6.21 ^a	-0.35 ^b	1.47 ^a	0.29 ^b	-0.08 ^a
ALL PARs									
L	18	29.3 ^c	576 ^a	102.6 ^a	5.06 ^c	-0.21 ^{ab}	3.13 ^a	0.58 ^a	-0.06 ^{ab}
M	24	32.9 ^b	543 ^b	101.0 ^{ab}	6.04 ^b	-0.05 ^{+,a}	1.74 ^b	0.36 ^b	-0.03 ^b
H	18	35.2 ^a	530 ^b	99.2 ^b	6.60 ^a	-0.29 ^b	1.10 ^b	0.28 ^b	-0.07 ^a
ALL	60	32.7	552	101.1	5.93	-0.16	1.97	0.41	-0.05

[†]Pooled SD values for MY, BW, SW % of initial and MY % of BW are 3.7, 39, 5.0 and 0.48, respectively. Pooled SD values for slopes of MY, BW, BW % of initial and MY % of BW are 0.32, 1.82, 0.32 and 0.06, respectively.

^{abc}Significant differences (P < 0.05) within columns.

Table 7. Cows of different parities classified into potential groups according to peak milk yield as % of body weight (cow potential) and peak milk yield (milk yield potential).

Cow potential	Peak milk yield % of body weight	n	Milk yield potential		
			nLow	nMedium	nHigh
Parity 1					
			<30	Peak milk yield kg/d 30-32	>32
Low	<6	5	4	1	--
Medium	6-7	7	2	2	3
High	>7	6	--	3	3
Parity 2					
			<36	Peak milk yield kg/d 36-41	>41
Low	<6.5	6	3	3	--
Medium	6.5-7.5	9	2	4	3
High	>7.5	6	--	--	6
Parity 3					
			<41	Peak milk yield kg/d 41-44	>44
Low	<7	7	5	1	1
Medium	7-8	8	3	3	2
High	>8	6	1	2	3

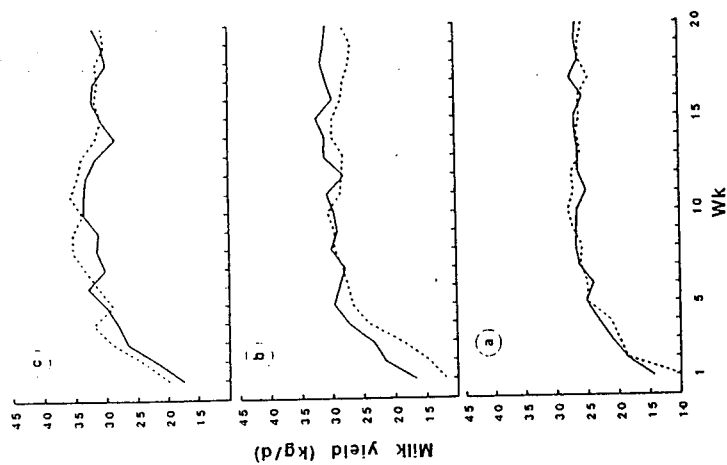


Fig. 1 Average daily milk yield of 1st parity cows fed 65-67% concentrates total mixed ration (—) and individually supplemented with concentrates (---) expressed according to milk yield potential determined at peak production. Low (a, <30 kg/d, n=6), medium (b, 30-32 kg/d, n=6) and high (c, >32 kg/d, n=6) during 20 wk of lactation.

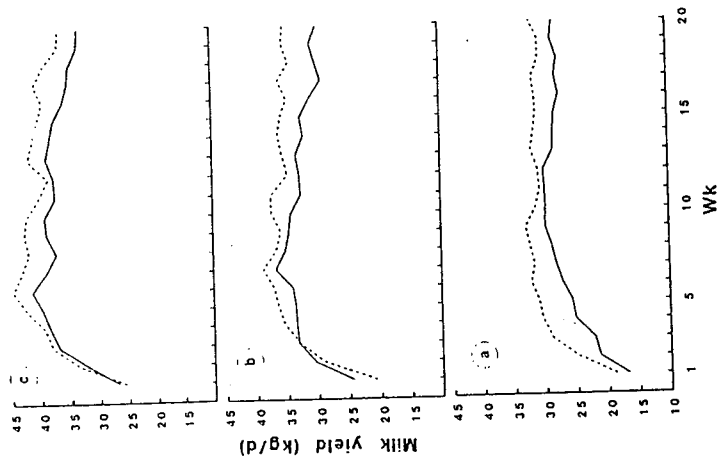


Fig. 2 Average daily milk yield of 2nd parity cows fed 65-67% concentrates total mixed ration (—) and individually supplemented with concentrates (---) expressed according to milk yield potential determined at peak production. Low (a, <36 kg/d, n=5), medium (b, 36-41 kg/d, n=7) and high (c, >41 kg/d, n=9) during 20 wk of lactation.

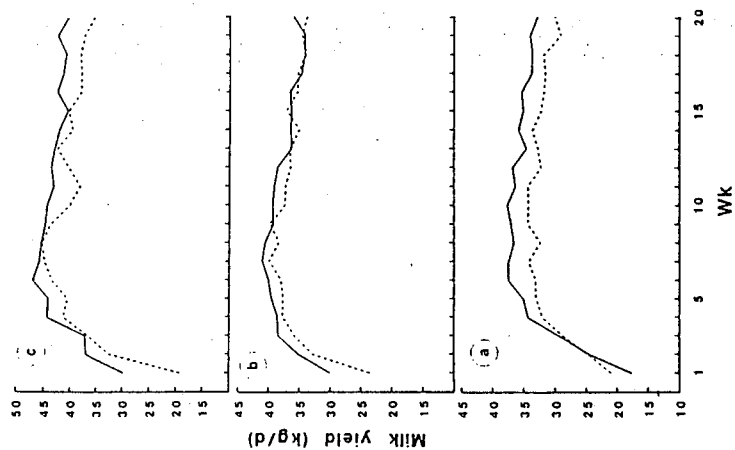


Fig. 3 Average daily milk yield of >2nd parity cows fed 65-67% concentrates total mixed ration (—) and individually supplemented with concentrates (---) expressed according to milk yield potential determined at peak production. Low (a, <41 kg/d, n=9), medium (b, 41-44 kg/d, n=6) and high (c, >44 kg/d, n=6) during 20 wk of lactation.

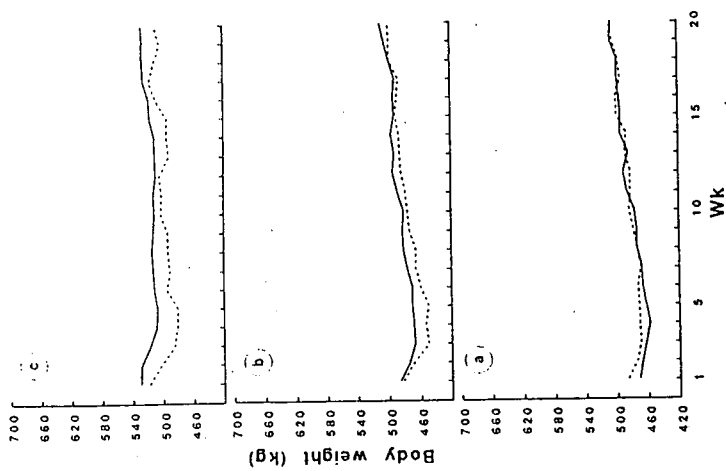


Fig. 4 Average body weight of 1st parity cows fed 65-67% concentrates total mixed ration (—) and individually supplemented with concentrates (---) that have different milk yield potentials determined at peak lactation. Low (a, <30 kg/d, n=6), medium (b, 30-32 kg/d, n=6) and high (c, >32 kg/d, n=6) during 20 wk of lactation.

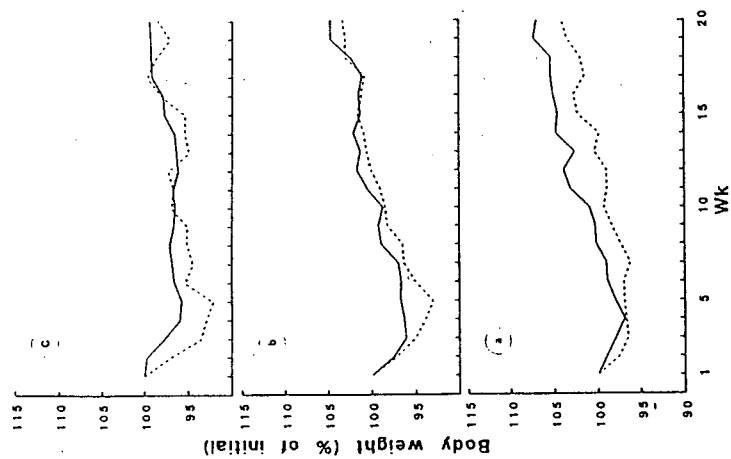


Fig. 7 Average body weight as % of initial body weight of 1st parity cows fed 65-67% concentrates total mixed ration (—) and individually supplemented with concentrates (---) that have different milk yield potentials determined at peak lactation. Low (a, <30 kg/d, n=6), medium (b, 30-32 kg/d, n=6) and high (c, >32 kg/d, n=6) during 20 wk of lactation.

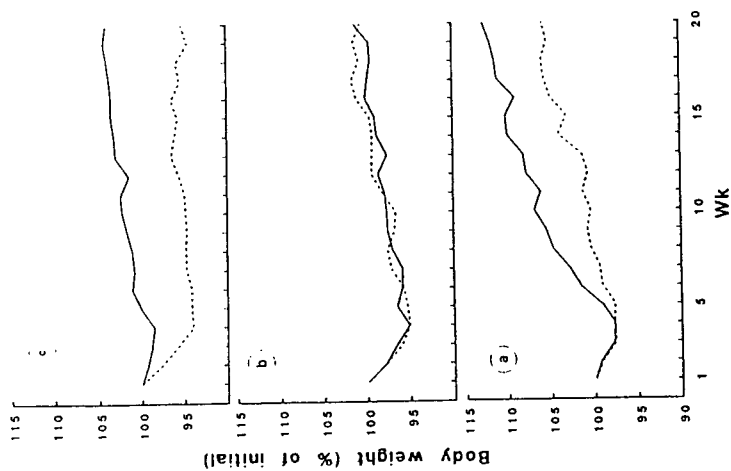


Fig. 8 Average body weight as % of initial body weight of >2nd parity cows fed 65-67% concentrates total mixed ration (—) and individually supplemented with concentrates (---) that have different milk yield potentials determined at peak lactation. Low (a, <36 kg/d, n=5), medium (b, 36-41 kg/d, n=7) and high (c, >41 kg/d, n=9) during 20 wk of lactation.

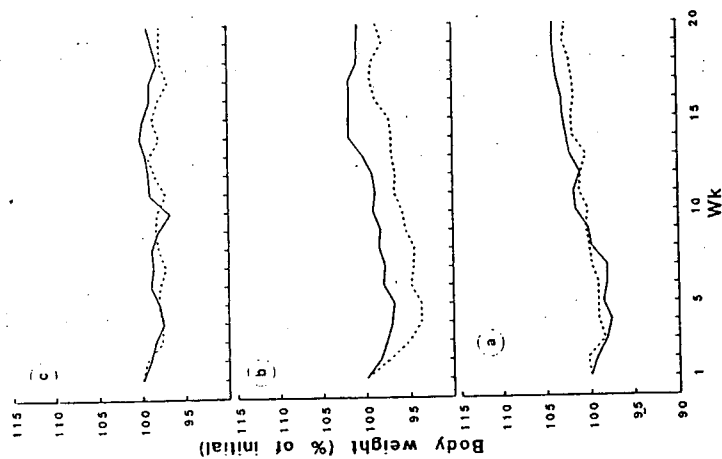


Fig. 9 Average body weight as % of initial body weight of > 2nd parity cows fed 65-67% concentrates mixed ration (—) and individually supplemented with concentrates (---) that have different milk yield potentials determined at peak lactation. Low (a, <41 kg/d, n=9), medium (b, 41-44 kg/d, n=6) and high (>44 kg/d, n=6) during 20 wk of lactation.

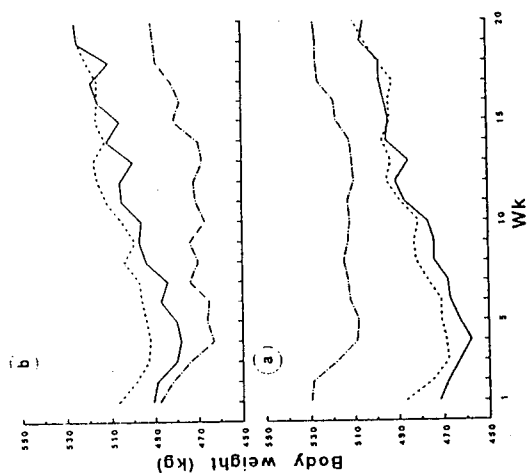


Fig. 10 Average body weights of 1st parity cows fed 65-67% concentrates total mixed ration that have different milk yield potentials determined at peak production (a). Low (—, <30 kg/d, n=6), medium (---, 30-32 kg/d, n=6) and high (---, >32 kg/d, n=6) and the same cows when classified according to peak production expressed as % of body weight (b). Low (—, <6%, n=5), medium (---, 6-7%, n=7) and high (---, >7%, n=6) during 20 wk of lactation.

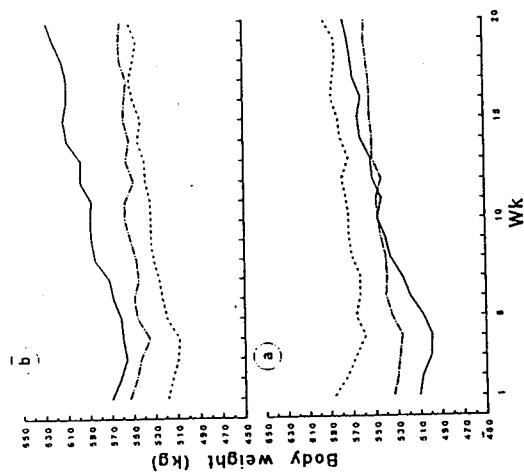


Fig. 11 Average body weights of 2nd parity cows fed 65-67% concentrates total mixed ration that have different milk yield potentials determined at peak production (a). Low (—, <36 kg/d, n=5), medium (---, 36-41 kg/d, n=7) and high (·····, >41 kg/d, n=9) and the same cows when classified according to peak production expressed as % of body weight (b). Low (—, <6.5%, n=6), medium (---, 6.5-7.5%, n=9) and high (·····, >7.5%, n=6) during 20 wk of lactation.

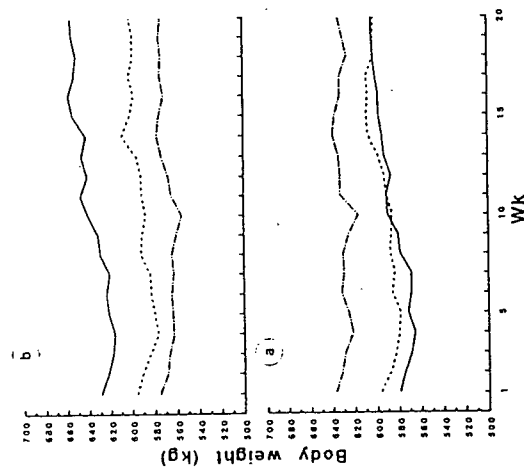


Fig. 12 Average body weights of >2nd parity cows fed 65-67% concentrates total mixed ration that have different milk yield potentials determined at peak production (a). Low (—, <41 kg/d, n=9), medium (---, 41-44 kg/d, n=6) and high (·····, >44 kg/d, n=6) and the same cows when classified according to peak production expressed as % of body weight (b). Low (—, <7%, n=7), medium (---, 7-8%, n=8) and high (·····, >8%, n=6) during 20 wk of lactation.

rate as large cows are stressed more to meet their nutrient requirements than are large cows, and therefore should receive a TMR with a higher nutrient density than larger cows. It also follows that, with individual feeding, small cows should, within the physiological limits associated with metabolic disorders, receive a higher proportion of their total ration as concentrates than should large cows at the same milk yield potential.

It was concluded that while several points favor individual supplementation of concentrates (avoid abrupt changes in diet and recurrent establishment of social order, opportunity for needed feed ingredients that are economically advantageous to only by a part of the cows), a ration balancing program that accurately predicts intake and considers a cow's likelihood of partitioning nutrients into body weight gain at the expense of milk yield was needed to fully exploit individual feeding (as with a computer feeder) relative to the Israeli system of TMR group feeding. Frequent body weights were shown to be important to 1): fine tune nutritional requirements and 2) modify feeding strategies based on body weight change. Thus the concept of every-milking weights obtained automatically was shown to be a substantial technological advancement.

Trial II, dealing with lactation potential was conducted at Urbana to 1) further test the concept of daily milk yield per unit body weight, as indicated in the results of the Alumim trial; 2) test the additional variable of body

condition score for its relation to animal performance, especially body weight change and the partitioning of nutrients into milk or body weight gain.

One hundred twenty eight cows (Ayrshire, Brown Swiss, Holstein and Jersey) were divided into three lactation potential groups based on yield of 3.5% fat milk per unit body weight at week 6 and 7 of lactation. Cows were assigned to be moved from a high energy ration to a medium energy ration alternately within potential group and parity number of each breed at either 12, 18 or 24 wk into lactation.

The technique of expressing daily yield of 3.5% fat-corrected-milk during week 6 and 7 as a % of body weight was successful. Almost all cows were appropriately identified. Low potential cows were especially well identified; they produced less milk in later lactation, gained more weight, reached higher body condition scores, and retained higher body condition scores in early lactation the cows identified as medium or high potential animals.

The technique of body condition scoring was found to be particularly useful as a stand alone indicator of lactation potential. Body condition scores reflected changes in body weight and were found to be surprisingly repeatable from week-to-week.

Trial II also showed the need for individualizing the decision concerning movement of individual animals from one TMR to another to adjust nutrient intake (and feed cost). The results indicated that all low lactation potential cows should

TRIAL II

Lactation Potential as a Grouping Strategy for Cows Fed Total Mixed Rations

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ABSTRACT

Jersey, Ayrshire, Brown Swiss and Holstein cows which calved in the University of Illinois herd during a 6-month period received a standard feeding regimen for the first 84 days of lactation. The regimen consisted of an "early lactation" total mixed ration (TMR) (19% crude protein (CP), 38% of CP as undegraded intake protein (UIP) and 1.67 MCAL/Kg NEL) which was fed ad libitum from approximately 7 to 10 days postpartum until Tuesday following 21 days postpartum. At that time all cows were placed on a "high" TMR (17.5% CP, 35% of CP as UIP, 1.72 MCAL/Kg NEL). Cows were divided into high, medium or low lactation potential based on mean 3.5% fat corrected milk during week 6 and 7, expressed as % of body weight. Cows were shifted from the high TMR to a medium TMR (16% CP, 35% of CP as UIP, 1.65 MCAL/Kg NEL) at 84, 126 or 168 days. Cows were shifted in order of calving within lactation potential, parity and breed. Thus all cows were on early TMR through 21 days postpartum, followed by 9 wk on high TMR. The feeding regimen (treatment) between wk 12 and wk 30 was determined by the treatment assignment. The trial ended when the cows completed 30 wk of lactation.

Almost all cows were appropriately identified for lactation potential by wk 6 and 7 by expressing daily yield of 3.5% fat corrected milk as a % of body weight. Cows designated as low potential at wk 6-7 produced lower yields of milk, fat-corrected-milk, milk protein and fat-corrected-milk per unit body weight than did cows designated as medium and high lactation potential. Low potential cows generally were the heaviest, gained more weight, reached higher body condition scores and retained substantially higher body condition scores than medium or high potential cows even during early lactation. Body condition scoring was a reliable indicator of lactation potential by itself. Body weight changes were reflected in changes in body condition score. The results indicated that all low lactation potential cows should have been moved to the medium TMR by at least wk 13. Body weight changes suggested that many of the low potential cows could have moved directly from the early TMR to the medium TMR. High and medium lactation potential cows in 2nd and later lactation benefitted from staying on the high TMR until wk 25; their high daily production was maintained for a longer period of time without excessive weight gains.

First lactation cows that underwent an early change to the medium TMR performed as well as those that changed later. It appears that first lactation cows, because of their tendency for peak production to be lower and to be more persistent in maintaining peak production than older cows, were less sensitive to the time when a change was made to a medium TMR than were older cows.

Table 1. Production responses of Holsteins by lactation potential groups.

Potential group	No. of obs.	-----Week of lactation-----			
		7 to 12	13 to 18	19 to 24	25 to 30
		Milk, Kg/d			
High	14	36.7	31.9	29.0	25.5
Med	19	35.1	31.4	27.9	24.4
Low	20	32.8 ^a	28.6 ^a	24.9 ^a	21.3 ^a
		3.5% FCM, Kg/d			
High	14	35.3 ^a	31.2	29.7 ^a	26.8
Med	19	33.0	30.4	28.1	26.2
Low	21	31.0 ^b	27.7 ^a	26.1 ^b	23.3 ^a
		Body weight, Kg			
High	14	571	578	593 ^a	615
Med	19	599	610	621 ^b	629
Low	21	644 ^a	653 ^a	666 ^c	682 ^a
		Body condition score			
High	14	1.63 ^a	1.68 ^a	1.74 ^a	2.00
Med	19	1.81 ^b	1.93 ^b	2.08 ^b	2.28
Low	21	2.15 ^c	2.30 ^c	2.43 ^c	2.84 ^a

a, b, c = P<.05 within columns

Table 2. Production responses of holsteins by stage of lactation move from high to medium energy TMR.

Stage of lactation move	No. of Obs.	-----Week of Lactation-----			
		7 to 12	13 to 18	19 to 24	25 to 30
		Milk, Kg/d			
Early	18	35.3	29.6	26.8	23.6
Med	20	33.6	30.6	26.6	23.7
Late	16	35.0	32.0	28.3	23.8
		3.5% FCM, Kg/d			
Early	18	33.8	30.1	29.0	26.6 ^a
Med	20	31.5	28.5	26.2 ^a	23.9 ^b
Late	16	33.2	30.7	28.8	25.8
		Body weight, Kg			
Early	18	607	611	620	635
Med	20	609	612	621	634 ^a
Late	16	613	627	639	658 ^b
		Body condition score			
Early	18	1.84	1.83 ^a	1.96	2.23
Med	20	1.97	2.09 ^b	2.18	2.39
Late	16	1.85	1.97	2.12	2.49

a, b = P<.05 within columns

have been moved to the medium TMR by at least wk 13. Body weight changes suggested that many of the low potential cows could have moved directly from the early TMR to the medium TMR. High and medium lactation potential cows in 2nd and later lactation benefitted from staying on the high TMR until wk 25; their high daily production was maintained for a longer period of time without excessive weight gains.

First lactation cows that underwent an early change to the medium TMR performed as well as those that changed later. It appears that first lactation cows, because of their tendency for peak production to be lower and to be more persistent in maintaining peak production than older cows, were less sensitive to the time when a change was made to a medium TMR than were older cows.

The results of Trial I and Trial II were used as the basis for the development of a knowledge-based algorithm for ranking cows concerning the adequacy of their current feeding program and as a management aid for grouping (see section V). The algorithm is yet to be tested with an independent group of animals due to the timing of its development (at the end of the project).

c. Body weight changes. As a result of the marked results obtained in Trial I (Section B.1.b) we proposed that a prediction of expected body weight changes at various stages of lactation was an essential element to making an accurate prediction of a cows response to a possible ration change at a specific stage of lactation. A trial was conducted with

A MODEL PREDICTING BODY WEIGHT
OF DAIRY COWS BASED ON
PHYSIOLOGICAL TIME SCALE

Research Thesis

Submitted in Partial Fulfilment of the
Requirements for the Degree
of Master of Science
in Agricultural Engineering

by

Sharon Devir

Submitted to the Senate of the
Technion - Israel Institute of Technology

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Abstract

A model was developed in order to evaluate dairy cows body weight changes during lactation based on available data in a commercial dairy farm. The model was calibrated with data of cows randomly selected from a commercial herd, served by controlled insemination service, under intensive husbandry condition and ration composition typical for Israel.

The model is based on the assumptions that the cow's body weight has typical characteristics affected by lactation number, calving times and seasons. The cows used for calibration, were divided into groups sharing common characteristics of lactation number and calving season. The dependant variable in the model was body weight. Fat corrected milk yield, time of conception, time from calving, initial body weight after calving and seasonal weeks remaining were selected as the independent variables. The physiological time scale was based on lactation cycles with basic time step of one week from calving. The typical behavior of body weight curve along the lactation, enables deviation of the physiological time scale into sub-periods characterized by constant slopes.

Using multiple linear regression methods, sets of empirical coefficients were computed for each of the independent variables in each of the sub-periods.

A single weighing of the cow after calving is a crucial input for operating the model. The other inputs used by the model, which are available on the farm, are: periodic milk test by the Cattle Breeders Association, lactation number, calving season and date.

The ability of the model to predict cow weights during lactations was tested on different cows from the same commercial herd. Results of these tests indicate that mean cow's body weight prediction had a deviation of 1-2% between measured and predicted data in most of the cases and maximal deviation of about 5%.

Prediction of body weight changes was better for the winter calvers than for the summer ones. Periodical milk tests introduce inaccuracy especially during the summer.

The accuracy of body weight prediction was somewhat reduced because of the lack of data on minimal body weight and the week minimal weight was recorded. This effect was especially evident after the fourth week post partum.

The model provides mean cow's body weight prediction for any group of cows for any given calendar time, with an accuracy of 2% along the year.

Cows were scored visually with independent scores once weekly using a scale of 1 to 5 (1 = very thin, 5 = very fat) with 0.5 unit intervals according to the body condition scoring system which has recently evolved in the US (Patton et al., 1988). Body condition scores were shown to be highly repeatable, to be highly correlated with body weight changes, and to be a good predictor of the partitioning of nutrients into milk yield or body weight change later in lactation. Body condition scores in early lactation were highly correlated with lactation potential.

The results indicated that a definition of cow potential could be made more accurate by considering the body condition of the cow at the time a decision was being made as to how long she should remain on a high energy TMR which was designed for cows at approximately peak lactation. While this general result is not new, the large magnitude of the effect and its level of significance relative to other factors known to affect the shape of the lactation curve were unexpected. These results indicate that an automated method, or at least one that does not require a high degree of training and skill, for body condition scoring is a highly important feature needed in an individual animal performance model.

2. Personal computer techniques.

Several advanced personal computer-based techniques were tested for potential application as knowledge based methods for incorporation into dairy herd management. These techniques may be divided into two groups: 1) traditional personal computer

programming languages; these include dBASE and C; and 2) artificial intelligence approaches, particularly those that deal with expert systems, embedding knowledge or information retrieval.

The investigations carried out in this phase of the project were primarily by graduate students as independent research projects for the completion of the requirements of The Technion and University of Illinois for graduate degrees.

a. Database management. A number of knowledge based features were added to the DAIRYBASE Herd management program at Illinois. These include:

Routine inclusion of mean daily milk yield during wk 6 and 7 of lactation as a measure of approximate peak daily milk yield.

Conversion to Predicted Transmitting Ability for production and linear scores for type traits.

Routine incorporation of previous 52 wk of mean daily milk yield from milk meters each week into the database.

Incorporation of previous 12 months of DHIA test day data for milk yield, protein %, fat %, somatic cell count into the database.

Application of FLIPPER to produce graphs of test day milk yield, protein %, fat % and somatic cell counts during previous 12 months for individual cows.

Application of FLIPPER to produce graphs of weekly milk yield for individual cows.

Revision of individual cow ration balancer to reflect 1990 NRC Nutrient Requirements for Dairy Cows and new prediction of dry matter intakes.

Reports of the current status of all animals at a specific location.

b. Data acquisition from electronic scale. Independent programs to collect cow weights, match them with cow IDs obtained automatically, and to determine which weights were valid for an individual animal were developed. The base program at Alumim was developed during the previous BARD project, and was modified for the studies described in section B.1.c of the current project. The unit at Illinois was modeled after the unit at Alumim, but developed independently with different hardware. Details are in section B.3.b.

c. Natural language interface. A personal computer version, GCLISP, of the artificial intelligence language LISP was used to develop a natural language retrieval system for data in DAIRYBASE. The dBASE interface to LISP, dbLISP, was used to interface LISP with the DAIRYBASE database. The program, called IDEA, was capable of parsing sentences, recognizing dairy herd terminology, and retrieving a knowledge based answer. It could compute means about subgroups of the herd, prepare knowledge-based answers to questions about specific animals, and find animals that met specific criteria which the user would specify.

Although the system worked nicely as a true artificial intelligence system with a dairy database, it required at

A Knowledge-Based Natural-Language Approach to Retrieving Information from an On-Farm Database

L.R. Jones¹, S.L. Spahr²

Abstract

A natural-language interface (IDEA) has been developed using a knowledge-based approach for retrieving information from a dairy database (Dairybase). The system was developed on a microcomputer using LISP. IDEA contains four modules: 1) user interface, 2) syntax, 3) semantics and 4) response generator. The semantic representation differs from other systems in that it uses a "conceptual semantics" approach to representing the meaning of the query. Domain concepts are stored in the data dictionary and contain domain knowledge for conjugating information into an intelligent answer. This approach has the potential of providing flexible access to important management information in a timely manner for decision making.

Introduction

Retrieval of information from stored records is a time-consuming and necessary part of successful management. This information is the barometer by which progress, practices and ultimately profitability can be evaluated. Information retrieval is a two step process. The first step is to determine which data to retrieve and conjugate to provide a meaningful answer to the question at hand. This determination is often dynamic, depending on the status of the particular records in the database. The second step is data retrieval. This step requires an understanding of the database format and of the procedures necessary to retrieve the data. The second step has been automated by database management systems, but automation of the first step remains elusive. Until these two steps are combined, management can be frustrating and may result in suboptimal performance. Our solution to providing timely access to relevant information is to augment an information retrieval system with domain knowledge. This knowledge is used to capture the data selection expertise of experienced managers. The result is an intelligent information retrieval system that not only understands conversational English queries

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Sources: Proc. 3rd International Congress for Computer Technology, Integrated Decision Support Systems in Agriculture - Successful Practical Applications. Deutsche Landwirtschafts-Gesellschaft, Frankfurt, May 1990.

for data retrieval but also understands the domain to formulate intelligent complete answers for decision making. The system is named IDEA for Intelligent Data retrieval in English for Agriculture.

IDEA is developed for a dairy database on an 80286-based microcomputer using LISP (GCLISP 286-developer, Gold Hill, Cambridge, MA). The database is that of Dairybase, an individual animal inventory and herd management system which is in routine use at the University of Illinois. However, IDEA is modular and can be used with any database with an interface to LISP by expanding the domain specific dictionary. Since Dairybase's database is in dBase III format, a LISP-to-dBase interface (dBlisp, Chestnut Software, Cambridge, MA) is used to access the database.

IDEA's Structure

There are four modules to IDEA (user interface, syntax, semantics, and response generator) which utilize two rule bases (syntax and semantics) and two dictionaries (word dictionary and data dictionary). The data dictionary contains the knowledge-based information for responding to queries.

User Interface

The user interface for IDEA accepts conversational English queries from the user. It verifies that all words (or morphemes) are known to the system before passing the input to the syntax module. If a word is not known, the user interface prompts the user with a list of possible replacement words. In this case, the user can choose one of the suggested words or edit the unknown word directly. No other preprocessing is done to check the validity of the query.

Syntax

The syntax module determines the grammatical structure of the query. It uses a word dictionary and a set of syntactic rules. The word dictionary contains the syntactic form for words, while the syntactic rulebase contains the valid syntactic structures. IDEA uses an augmented transition network approach to parsing, as it is the most widely accepted procedure. In addition to determining the underlying syntactic structure of the query, the syntax module determines the grammatical subject (called the FORN) and the grammatical object (called the MESSAGE). It is these higher level structures that are passed to the semantic module.

Semantics

The feature that distinguishes IDEA from traditional natural-language retrieval systems is the semantic paradigm. The semantic module determines the meaning of the query. Traditionally, natural-language interfaces translate the query into a procedure (e.g., SQL) for retrieving information from the database. This approach is called "procedural semantics". This approach limits the ability to incorporate domain knowledge for answer formulation into the procedure, thereby resulting in a system that understands the database but not the domain. IDEA utilizes a new approach of representing the query as a series of underlying domain concepts. This new approach has been coined "conceptual semantics".

To capture the entire meaning of a phrase, a representation scheme with four elements is required. The first element represents the underlying domain concept. The second and third elements are required for phrases that have a comparison component (e.g., ... less than 3 years of age). The second component is the comparison value (e.g., 3), and the third component is the function for the comparison (e.g., 'LESS'). Except for when a negation is used, this was a sufficient representation. For negations, a fourth element is included that signifies if the concept and comparison should be inverted. The complete semantic representation for the query, "not less than 3 years of age", is (AGE 3 'LESS 'NOT). Once semantic analysis is completed, the identity of the original query is lost. Only the meaning of the query is retained. Consequently, related queries will result in the same semantic representation and the same answer.

Phrases relating to the form and the message are both translated into this style of semantic representation. There are two forms of semantic analysis: explicit and implicit. Explicit analysis occurs by a series of rules attached to significant words - the major word of the phrase. These words examine the remainder of the phrase for words that influence the meaning of the word. For example, the word "bred" refers to (BREEDING DATE) unless the word "to" is present. In the latter case, it refers to (SERVICE SIRE). These rules are responsible for building the semantic representation. Implicit analysis occurs when there are no words which influence the meaning of the original word and the major word of the phrase relates directly to a domain concept. This word is then taken as the concept and no explicit rules are required.

Response Generator

The response generator for IDEA determines to which items in the database the query refers and formulates a response. The semantic representations from the above module serve as input to this module. The response generator also uses a data dictionary that contains representations of high-level domain objects. These objects contain database information and rules for calculating its value and printing a response.

Every query contains two portions: a phrase describing the items in the database to which it refers (called the form) and a phrase describing the nature of the query (called the message). The name of these phrases arise from the frame-based technology on which this system originated. Since the query can be thought of having two parts, the response generator first determines a list of items in the database to which the query could refer. For example, a list of cows is determined for the query "Which cows are in the north barn?" The second step is to calculate the specific answer to the query for each of these items. In this example - the location of each animal. For those that satisfactorily fulfill the query, a complete response is formulated.

Each domain concept contains two sets of rules for printing an answer. The first set generates a complete natural-language response using domain knowledge to formulate it. For concepts whose answers are dependent on the state of the database (see Table 1), rules contain knowledge to sense the state of the database and to conjugate the pertinent data into an answer. Objects also have the capability of requesting other objects to print out their information. This method of control is referred to as delegation. As shown in the example in Table 1, a farmer can expect a different response when querying if a cow is pregnant depending on if the answer is YES or NO. A YES answer should result in a response aimed at preparing for the pregnancy while a NO answer should be aimed at giving pertinent information for determining a culling decision or a plan of action to establish pregnancy. The second set of rules for printing an answer are designed to print a concise management worksheet in a tabular form. The user selects the type of answer to be printed. Because of the semantic representation used, the relationship between the query and the answer is the underlying concept. Therefore, answers are formulated for concepts as opposed to specific questions. The result is that the answer is insensitive to the manner in which the question was asked. Also since the

representation of concepts is knowledge-based, responses to queries can mimic those of an intelligent database manager.

Table 1: Example of knowledge-based answers for decision making

>> is 5239 pregnant?

YES

5239 was bred to TOPBRASS on 06/20/1988
and is due to calve on 03/19/1989
Projected calving interval: 466 days

>> is 5449 pregnant?

NO

5449 calved on 12/11/1987 with a heifer calf - #5478
The calf was in good condition
Gestation length = 283 days
5449 is 282 days in milk

least 4 M bytes of RAM to operate efficiently, and it required at least 286 level CPU to limit its routine application as a practical system. It also operated slower and required more time to enter queries on the keyboard than was required with database management routines.

d. Machine learning. A research, mainframe version of a machine learning program, Programmable Learning System (PLS) was converted to operate on a personal computer and tested as a technique to create expert system rules by analyzing the thought process of an expert. The conversion to a personal computer was successful, and its potential application to a dairy problem (modeling the appraised value of individual animals) was demonstrated. It was successful in sorting the most important factors out of 118 possible variables to describe how values of individual animals sold at public auction in the U.S. could be derived. The techniques for converting real-world dairy events into a system suitable for modeling on a personal computer were demonstrated for the first time in this study.

e. Expert System development. An expert system was written in the language c to interpret the results obtained from an electronic activity tag (see section B.3.c). The expert system considered the magnitude of increase in activity, the time increment of increased activity, the date of previous estrus and the time since the previous estrus to provide an estimate of the probability that an individual cow was in estrus on a specific day. Thus the program used data acquired

at each milking from the activity tag and historical data from a dairy database to arrive at its interpretation of the data.

3. Hardware subsystems

a. Electronic identification. Electronic animal identification is the key to an automated data acquisition system with knowledge based analysis. Previous research on this topic by the authors included interfacing a system with neck-mounted ID units and a portal reader (Boumatic) with an electronic scale at Alumim (Peiper et al., 1987 Symposium on Automation in Dairying) and comparison of an early 1980s neck mounted passive system (Surge) with a battery-powered ear-mounted system for in-parlor ID at each stall (Spahr et al., 1987 Symposium on Automation in Dairying).

The research on electronic animal ID during the current project was in two areas: 1) extending the range of interrogation and interfacing an ear-mounted system with an electronic scale at Urbana; and 2) moving implantable electronic identification (EID) toward a practical, (inter) national system for identification of dairy cattle.

A study was conducted at Urbana to characterize the limitations of an-ear mounted ID system¹ for identifying cows automatically as they walked single file from the milking parlor in a return alley to their feeding area. After the limitations were characterized, an antenna system was designed, installed and tested to provide identification of all cows. Initially, two factory - supplied antennae were

¹(Eureka Systems, Englewood Cliffs, NJ and Slough, England)

DRAFT

2

TITLE: Translation of a machine learning program for use on a personal computer

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RUNNING HEAD: Porting machine learning program to DOS

ABSTRACT

1 A machine learning program was modified to function on a personal computer and
2 was evaluated for use with on-farm applications within animal agriculture.
3 The machine learning program, Probabilistic Learning System, was obtained for
4 this purpose from an active machine learning research program. It was first
5 translated from Berkeley Pascal to Microsoft C. Necessary modifications for
6 on-farm use included improving memory management to allow program operation
7 with 640 kilobytes RAM, supporting use of extended memory for larger
8 applications, implementing a user interface to reduce application development
9 time, and adding dBASE III+ data file support. After modification, the
10 machine learning program was usable on a commonly configured personal computer
11 for applications with up to 100 attributes or 500 examples.
12

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Machine learning is a discipline that has developed out of the broader field of artificial intelligence. One of the objectives of machine learning is to develop an alternative, automated method of knowledge acquisition. One approach uses examples which contain the information an expert used to solve a specific problem and the conclusions the expert derived from the information to generate rules best describing how the expert arrived at the conclusions -- hence, learning by example. The rules generated by the machine learning program can then be used directly by an expert system. A number of different systems that learn by example have been developed including AQ15 (Hong et al. 1986), I03 (Quinlan 1983) and PLS1 (Rendell 1983).

These programs, or derivatives thereof, remain active research projects. A criticism of machine learning and the entire field of artificial intelligence is that the emphasis is either on developing conceptual or theoretical models of some aspect of intelligence or is on developing algorithms that behave according to a narrowly defined aspect of intelligence. Validation of models or application of the technology to real problems is largely undone (** Cohen reference **).

The objective of this research was to develop a version of a machine learning program that: 1) was suitable for application to on-farm problems within animal agriculture; 2) would operate efficiently on an IBM-compatible personal computer (PC); and 3) was easy to use. The specific animal agriculture application for which the development was conducted was to model the appraised value of Holstein cattle sold at public auction. Since the emphasis was on the application of the technology to animal agriculture, it was desired that computer resources commonly available on a typical dairy farm be used for the evaluation. Hence it was determined that an IBM compatible

personal computer (PC) would be used for this purpose.

METHODS

The clusterer subsystem of the Probabilistic Learning System (hereafter referred to as PLS) (Rendell 1986) was the machine learning program used for this project. PLS was selected because: 1) it was available with source code; 2) it was considered state-of-the-art technology coming from an active research program, and 3) it used a probabilistic learning algorithm.

The program, as initially received, was written in Pascal to operate on a Unix workstation. Conversion was required for it to operate on the hardware used for the evaluation. This consisted of a Zenith 248-12 personal computer with an Intel 80286 12Mhz microprocessor, an Intel 80287 math coprocessor, a 44 megabyte hard drive, 1 megabyte conventional memory, 7 megabytes extended memory using 2 Bocaram AT memory expansion boards, an extended 101 key keyboard and an Amdek 722 color monitor. The modifications included translating the code for recompilation on the personal computer, improving memory management, improving the user interface, and adding dBASE III+ file support.

Porting to MS-DOS

The first modification to PLS was to port it to an MS-DOS machine. The version of the program received ran on a Sun workstation and was written in Berkeley Pascal. Source was transferred to the analysis machine and was then rewritten in Microsoft C v5.0¹.

The data set containing the examples for learning for this research was too large to run PLS in 640 kilobytes as a regular MS-DOS program. Thus the program was modified to allow use of extended memory. A protected mode

¹ Microsoft Corp., Redmond, WA.

1 version of the analysis program was created using OS286 v2.14². The
 2 protected mode version utilized increased memory addressing available with the
 3 Intel 80286 microprocessor operated in protected mode. This modification
 4 required that all memory allocation be through calls to the C-language memory
 5 allocation function, `malloc()`. Memory management therefore became an
 6 important part of porting to MS-DOS.

7 The original version of PLS gave little consideration to the amount of
 8 memory required. Two problems were particularly troublesome when it was
 9 operated on a PC. First when nominal valued variables were included in the
 10 analysis at least 1 and often more copies of the data points were created and
 11 maintained in memory. Second, frequently memory was allocated and
 12 subsequently lost. This became a significant drain on available memory. As
 13 originally written, the program would not run using all data with 7 megabytes
 14 of extended memory. Thus several modifications were made to conserve memory
 15 usage.

16 The first memory management problem occurred when nominal valued
 17 variables were included in the analysis. Before learning examples containing
 18 nominal valued attributes could be clustered, the order for each nominal
 19 valued attribute needed to be determined. This was performed by a
 20 subclusterer which clustered only on the nominal valued attribute and then
 21 sorted the values in ascending order of utility value and error. The
 22 subclusterer continued clustering and sorting until an optimum ordering was
 23 found. With each iteration of the subclusterer, the original version of PLS
 24 created a new copy of learning examples in memory containing only the
 25 dimension of the nominal valued attribute. Memory allocated for each new copy

² A.I. Architects, Inc., Cambridge, MA.

1 of learning examples was released only after all iterations were completed.

2 To correct this problem, an array of valid dimensions to cluster was
 3 created. This array contained a flag for each dimension. When subclustering,
 4 the dimension containing the nominal valued attribute was assigned a flag
 5 value of VALID and all other dimensions were assigned a flag value of INVALID.
 6 Then subclustering was performed on the dimension with a flag value of VALID.
 7 After subclustering was completed, all dimensions were reassigned a flag value
 8 of VALID.

9 This alteration created a new problem. Data points were represented in
 10 memory as linked lists. The subclustering procedure destroyed the links in
 11 the process of determining the order of nominal valued attributes. In order
 12 to recreate the original linked list, an additional variable was added to the
 13 learning example structure which contained the original pointer to the next
 14 structure. After subclustering was performed, the active pointers were reset
 15 to the original pointers.

16 The second memory management problem involved losing memory allocated
 17 for temporary use. This problem was corrected by placing the allocated memory
 18 on a garbage list for future use. In general, throughout the PLS program
 19 whenever memory allocated for a particular purpose was no longer need, this
 20 memory was placed on a garbage list for later use. Whenever the program
 21 called for a new memory structure to be created, the structures on the garbage
 22 list were first used before new memory was allocated.

23 While it was still necessary to use extended memory for learning from
 24 many examples or from examples with many attributes, improving memory
 25 management significantly increased the size of example set that could be used
 26 for learning with 640 kilobytes RAM.

Improving user interface

The original version of PLS read all input from an ASCII file specified on the command line. The beginning of this file contained parameter names and their associated values. The rest of the input file contained the learning examples. Subsequent runs of PLS required that the input file be edited to change parameter values. This was problematic in several respects. First, the data were stored in dBASE III+ data files and were not easily converted into an ASCII text file. Second, and much more important, was that reading the data points into memory was a time consuming process requiring in excess of 5 minutes to perform. To improve this inconvenience the program was made interactive allowing the user to change parameters when desired and allowing multiple runs of the clusterer without reloading the learning examples.

The control of the program was modified to be through a single menu bar across the top of the screen. From this menu the user could select to change parameter values, change variable assignments, change filter assignments, run the clusterer, list the output, perform disk management functions, reset all parameters to default values forcing the data to be reloaded, and to quit the program. To list the output, the program shelled to DOS and a shareware program, LIST.COM³, was executed to view the output file. Similarly, to perform disk management functions, the program shelled to DOS and executed DS.COM⁴ (directory scanner).

The other menu options provided interaction with the user for changing parameter values, changing variable assignments and changing filter assignments. One screen was used to display and change parameter values.

³ Vernon D. Beurg, Petaluma, CA.

⁴ Naval Research, TX.

When this option was selected, the screen was painted with all parameters and their associated values (Figure 1). The user was then allowed to change each parameter. The user also specified on this screen the names of the input and output files.

The variables option allowed the user to select how each field associated with a particular data file was to be used. When this option was selected, the user was prompted for the number of the data file. The name, type, and length of each field in the data file was displayed (Figure 2). Then the user could set several parameters specifying how PLS was to use each data field. A scale factor was used to reduce the magnitude of values in a data field so the range of a short integer was not exceeded. The step value was a resolution parameter used by PLS. Finally PLS could be instructed to use the data field to filter records, to cluster, for regression, or as a dependent variable.

Filter variables were used to determine which records to use in the analysis. Only records that satisfied the filter conditions were used. When this option was selected, a list of variables selected as filter variables was displayed. For numeric valued variables a threshold and the logical relationship with the threshold (<, ≤, =, ≥, >) were entered. For logical valued variables a negation could be selected. An example filter screen is contained in Figure 3.

dBASE III+ file support

Another user interface modification was dBASE III+ data file support. The dBase Toolkit⁵, a commercial library of C routines, was used to provide the interface with data files. Primarily two library routines were used, one

⁵ Software Connection, Inc., Ely, MN.

1 for reading the structure of a data file and the other for reading the current
2 record in the file.

3 The dBASE III+ file interface was designed to support from 1 to 6 data
4 files. The name of each data file was entered on the parameters screen. The
5 user specified how each data field was to be used by selecting the change
6 variable assignments option from the main menu. The user was not allowed to
7 specify the relationship between the data files. The relationship was always
8 on a record number basis only. The first data file was used as the root data
9 file. All other data files were always positioned at the same record number
10 as the root data file. One learning example consisted of data for the current
11 record from all files. The total number of learning examples was determined
12 by the number of records in the root data file. If a non-root data file did
13 not contain as many records as the root data file, an error occurred. If a
14 non-root data file contained more records than the root data file, these extra
15 records were ignored.

16 RESULTS AND DISCUSSION

17 After modification the machine learning program was used to generate a
18 model to estimate the value of Holstein dairy cattle sold at public auction.
19 Improvements in the user interface decreased time for model building and
20 extended use of the technology to users with moderate computer expertise. The
21 memory management modifications increased the size of applications that can be
22 used for learning.

23 Figure 4 illustrates the relationship between the number of learning
24 examples and the number of attributes for each example that can be analyzed in
25 640 kilobytes RAM. The complexity of the model generated and the values of
26 the parameters controlling learning can significantly effect the total memory

1 required.

2 The time required to learn depending on the number of examples, number
3 of attributes and degree of output complexity is contained in Table 1. In
4 general, the learning time required, regardless of example space or complexity
5 was less than 3 minutes on an IBM-AT class machine. Faster processors will
6 decrease the learning time even further.

7 CONCLUSIONS

8 For many applications within animal agriculture, PLS can be used
9 successfully on a personal computer to learn from examples. Except for large
10 problems containing many attributes and many examples, a commonly configured
11 IBM-compatible personal computer can be used. While the user interface could
12 undoubtedly benefit from additional improvements, it is adequate for a user
13 with moderate computer skills to quickly and efficiently operate the program.
14 Other applications where PLS has or is being used include analysis of culling
15 practices and classification of Dairy Herd Improvement data to identify
16 significant management practices.

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Table 1. Learning time for varying number of examples, dimensions per example, and output complexity.

Examples (no.)	Dimensions (no.)	Nodes in output tree (no.)	Learning time (sec.)
10	2	2	7
10	5	3	7
10	4	4	8
100	10	10	13
100	25	10	44
100	10	5	10
500	10	13	21
500	25	5	19
500	25	13	44

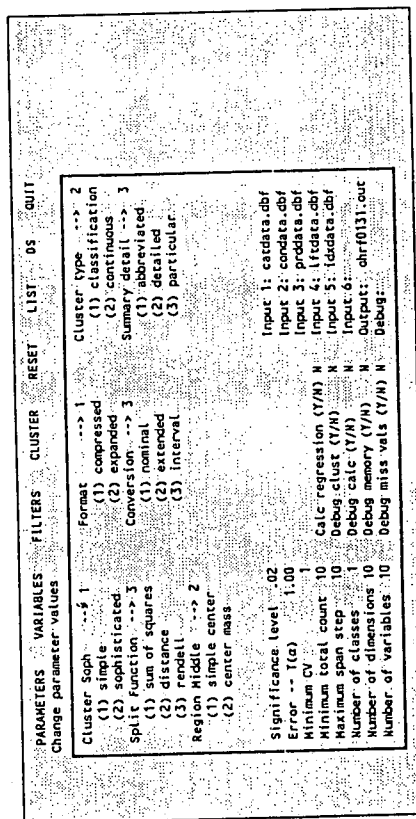


Figure 1. Example of PLS screen displayed when changing parameters.

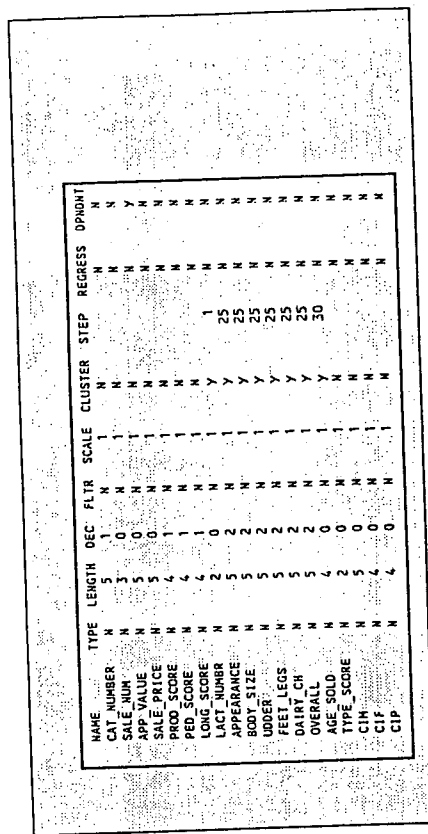


Figure 2. Example of PLS screen displayed when selecting variables.

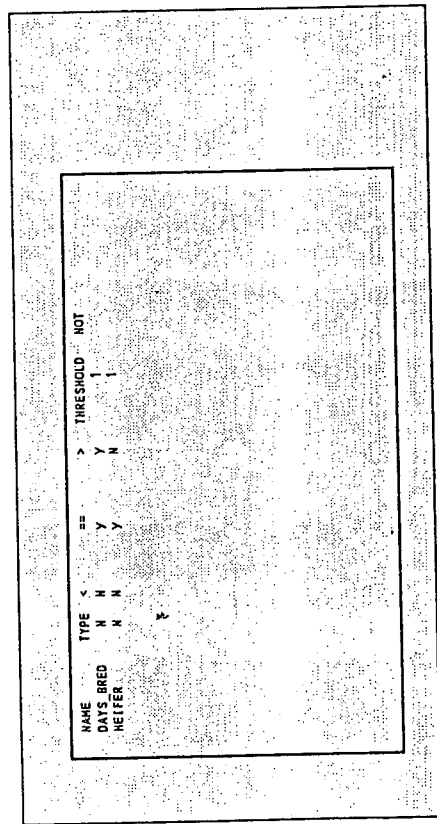


Figure 3. Example of PLS screen displayed when defining filters.

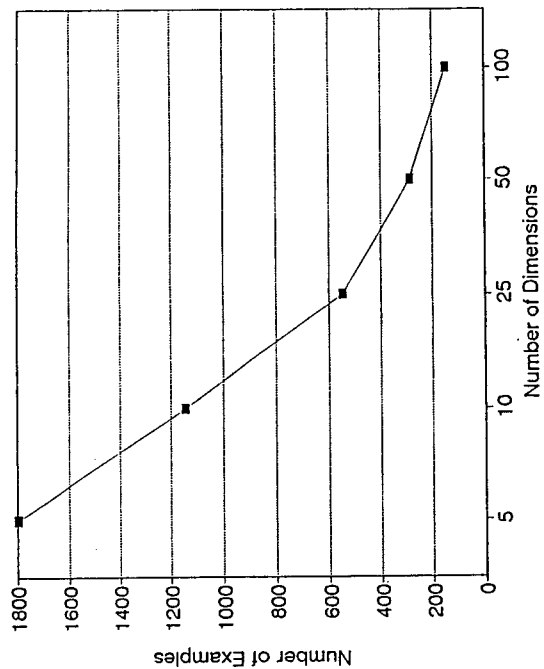


Figure 4. Relationship between number of learning examples and number of attributes per learning example for execution of PLS in 640 kilobytes RAM.

installed in a stacked array, one over top of the other and attached to the side of the alley. This resulted in a detection rate of 90.7%, significantly below the detection rate desired for automatic acquisition of body weights. An antenna system with an approximate range of 1.2 to 1.3 m was designed and installed. The antenna was .91 by .46 m. It was installed across the return alley to limit the detection of cows in front or behind the one targeted for identification. Sheet metal reflectors were installed to limit identification to cows in the return alley since cows also were in the holding area next to the return alley waiting to enter the milking parlor. A number of antenna configurations were tried, and their ranges of interrogation were characterized.

Our study demonstrated that it was possible to build an antenna with a range exceeding 1.2 m, and which would identify all of the working ID units mounted on a cow's ear as the cow passed under the antenna on her way out of the milking parlor. Orientation of the ID unit relative to the antenna significantly affected its range. Occasional low battery signals were received if the ID unit was in a fringe area of antenna activity; true low batteries were discerned by multiple low battery signals on the same ID unit for several milkings (Deligeersang et al., 1991).

The ultimate goal of electronic identification is a system that is permanent, low-cost, reliable, and safe. These features translate to an implantable system, one in which calves are implanted shortly after birth with a permanent

electronic number that is used as part of a national identification system. This technology advanced substantially during the project, but no units were available for independent research. Our activity in this area was to assist the industry in moving the technology toward practical application (Spahr, 1988).

b. Electronic scale. Hardware and software development were required to acquire body weights automatically at Urbana. The electronic identification subsystem for this purpose was described in section B.3.a. This section will describe the design and installation of the scale subsystem.

The scale system was installed in the return alley of the milking parlor and designed to operate automatically, collecting weights on every cow at every milking. a scale platform 2.1 meters in length was constructed and placed strategically under the EID subsystem. Factors found to affect the length of the scale platform included length of the cow, walking speed and degree of crowding.

The load cells were linked to an ADC-1 data acquisition device² with an integrating dual slope type A/D converter capable of sampling at 20 to 140 times per second. The ADC-1 board communicated with a PC via RS232. A program written in C running on the PC read the data from both the ADC-1 board and the identification system, and wrote the data to an output file on the hard disk.

²Remote Measuring Systems, Seattle, WA.

AN AUTOMATIC WEIGHING SYSTEM FOR DAIRY COWS

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SUMMARY:

An automatic scale for dynamically weighing dairy cows was developed and tested. Raw data were collected when cows passed over the platform in natural patterns. True weights of cows were extracted through a data processing program. Test results showed that errors for average weight were less than 2 percent.

KEYWORDS:

Weighting, Data Acquisition, Dairy, Automation, Computer

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AN AUTOMATIC WEIGHING SYSTEM FOR DAIRY COWS

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ABSTRACT

A scale for automatically weighing dairy cows was developed and tested. The scale consisted of a weigh bridge supported by two load bars placed in the return alley of a milking parlor. When a cow walked over the weigh bridge, each load bar generated an analog signal. A summing amplifier combined the signals. An ADC-1 data acquisition device transmitted the amplifier output to the serial port of a computer. A program written in C recorded the cow's weight and identification number. At the end of milking, another program processed the recorded raw data and computed the true weight of each cow detected.

INTRODUCTION

Body weight of dairy cows is a very important factor in dairy farm management. Changes in body weight supply information used by farm managers to make decisions on feed requirements. An up-to-date knowledge of individual body weight will add a considerable value to the efficiency of an individual nutrition regime (Peiper et al. 1987). Frequent body weight measurements may also indicate the health status of cows.

Old style weighing systems, both manual and electronic, require a cow to stay on the platform of a scale for a few seconds to get a stable reading. Most electronic scales will work as desired when cows are separated and stay on the scale for a short time period. For instance, the Tru-Test AG360 electronic scale¹ requires 3 seconds to get a stable reading. Human labor is required to guide the cows to the scale and keep them there for the required time. Manual weighing of many animals using a large capacity mechanical scale is more inconvenient than electronic weighing and requires extra time and labor.

An automatic weighing system ideally would require no human intervention to obtain accurate body weights for all cows. Cows would pass over it during their normal activities, and it would obtain an accurate weight in the time that a cow remains on the scale naturally. Locations suitable for weighing cows are the return alley of the milking parlor and the concentrate feeding stations (Ipema, 1987). At the dairy farm of the University of Illinois the goal is to weigh cows in the return alley.

¹Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the University of Illinois and does not imply the approval of the named product to the exclusion of other products that may be suitable.

OBJECTIVES

The objective of this project was to develop an automatic scale which could weigh dairy cows without disturbing their natural behavior as they passed through the return alley of a milking parlor. The scale was to be controlled by a computer used for dairy management programs.

DESIGN STRATEGIES

The platform of an in-line scale was installed in the return alley of a milking parlor. When the milked cows passed over the platform in their natural pattern, their identification numbers and weights were recorded. Two problems had to be solved for the system to get an accurate measurement. One was that cows were not clearly separated when they walked over the platform of the scale because they were released from the milking station in groups of four. The other was the variations in the dynamic weight readings caused by the walking movements of the cows. Sometimes these variations were very large. A typical weight versus time pattern based on the recorded weight readings is shown in Figure 1. The design approach for the system was to record many weight readings while a cow was passing over the scale. The readings indicating that all four of the cow's legs were on the platform were picked out. Then the mean was calculated to obtain the cow's approximate weight. Exact weights were not required for this application since a cow's weight varied as much as 20 to 40 kg from one day to another due to digestive fill and since weight would be obtained after every milking.

The weighing system was composed of five main parts: a scale platform, a signal amplifier, a data acquisition device, an electronic identification subsystem, and an IBM PC/AT compatible computer (see Figure 2). The scale platform included two load bars which generated analog signals proportional to the weight on the platform. The signals from the two load bars were added and amplified by a signal amplifier. A data acquisition device converted the amplifier output to digital signals and transmitted them to an IBM PC/AT compatible computer. The computer software then handled these signals according to the calibration of the signals. Simultaneously, the cow on the platform was identified by an electronic identification system, which transmitted the cow's ID number to the computer.

(1) Scale Platform

The platform was composed of a steel/wood bridge supported by two load bars (parts of the AG360 weighing system) from Tru-Test distributors, Auckland, New Zealand (see Figure 2). The length of the platform affects the performance of the weighing system. If the length is too long, it increases the chance of two cows being on the bridge at the same time. If the length is too short, a cow will not be on the bridge long enough for a sufficient number of weight readings to be collected. Fewer readings will result in lower accuracy. Factors affecting the length of the scale platform are the average length, walking speed, and crowdedness of the cows. The crowdedness is the key factor limiting the length of the scale platform. The length selected for the scale platform at the University of Illinois was 2.1 meters.

The two load bars were calibrated separately. Both load bars used a 12 VDC excitation voltage. The linear relations between weight (kg) and output voltage (mV) are shown below:

$$W1(\text{kg}) = 29.55 \cdot V1(\text{mV}) - 73.78 \quad (\text{for load bar \#1})$$

$$W2(\text{kg}) = 47.10 \cdot V2(\text{mV}) - 10.36 \quad (\text{for load bar \#2})$$

(2) Signal Amplifier and Data Acquisition Device

The selected data acquisition device (ADC-1 from Remote Measurement Systems, Inc. Seattle, WA) was equipped with an integrating dual slope type A/D converter with a resolution of 12 bits plus sign and sampling rates of 20 or 140 samples per second. The device had a ± 400 millivolts analog input range and a total of 16 analog input channels. The device communicated with a computer via an RS-232C serial port. The complete unit cost less than \$500.

The weighing system was designed for cows weighing up to 900 kg. Since the cow's weight was indicated by two load bar signals, a summation was needed to get the weight of a cow. There were two possible ways to do the summation. One was to add the analog signals from the load bars with a summing amplifier. The other was to sum them after A/D conversion by means of computer software. To obtain the fastest possible sampling speed and to avoid a time delay between the signals from the two load bars, it was decided to sum the analog signals before they reached the input of the ADC-1 data acquisition device.

The output voltage of the summing amplifier is a function of the cow's weight, which is the sum of the weights measured by the two load bars. Based on the calibrations of the load bars, the relation between output voltage and weight is given by the following formulas:

$$V_o = f \cdot WGT = f(W1 + W2) = f(29.55 \cdot V1 + 47.10 \cdot V2 - 84.14) \quad (1)$$

where WGT = complete weight (kg)

V_o = output voltage from summing amplifier (mV)

$V1$ = analog signal from load bar #1 (mV)

$V2$ = analog signal from load bar #2 (mV)

$W1$ = weight indicated by load bar #1 (kg)

$W2$ = weight indicated by load bar #2 (kg)

and f = conversion factor (constant, mV/kg)

Based on the conditions:

$$(W1 + W2)_{\text{max}} = 900 \text{ kg}$$

and $(V_o)_{\text{max}} = 400 \text{ mV}$ (ADC-1 analog input range)

the f value was chosen to be $400 \text{ mV}/900 \text{ kg} = 0.444$, allowing the system to make use of the full resolution (12 bits) of the ADC-1, and giving the complete system a resolution of 0.22 kg.

Then the formula (1) becomes:

$$V_o = 13.13 * V_1 + 20.93 * V_2 - 37.40 = A * V_1 + B * V_2 + C \quad (2)$$

where A, B = gains for each input of the summing amplifier (constant)

The offset C in formula (2), as well as the offset caused by the unloaded bridge (90 kg), was subtracted from V_o by adjusting the amplifier output offset after the installation of the weighing system was completed. This made the output voltage V_o close to zero when there was no weight on the bridge. The maximum allowable weight of the cows was thus kept at about 900 kg. The offset varied during weighing due to the excrement left on the platform by cows. It also varied with changes in the moisture content of the platform. This small offset was subtracted by the computer software to obtain the weights of the cows.

This simplified formula was realized by a summing amplifier with weighted inputs. The weights of the amplifier inputs were defined by the parameters in formula (2). The summing amplifier was constructed with two instrumentation amplifier chips, one operational amplifier chip and several resistors and capacitors (see Figure 3).

(3) Electronic ID Subsystem

To match the weights with cows, a complete electronic identification subsystem was installed with an antenna positioned over the scale platform (see Figure 2). This subsystem was an Animal Identification System Multiplex Decoder model 1200 made by Eureka Systems. It consisted of ear tags worn by the cows, each carrying a unique ID number, and a central decoder unit connected to a maximum of eight remote antennas. The antennas could be positioned up to 92 meters (300 feet) from the decoder unit. The decoder unit could communicate with a computer via an RS-232C serial port. In normal operation, each antenna was powered in turn with an activation signal. Any Eureka type tag within this antenna's field was activated and sent its data back to the activated antenna. The decoder formatted and checked the data and transmitted to the computer.

(4) Computer

An IBM PC/AT compatible computer was used to collect data and control the operation of the weighing system. Two serial ports were used to make connections with the ADC-1 data acquisition device and the identification subsystem. A program written in C running on the computer read the data from both the ADC-1 and the identification subsystem and wrote the data to an output file on the hard disk. The data in the file included the weight readings and the ID numbers detected, recorded in order of their occurrence.

OPERATION OF THE WEIGHING SYSTEM AND FIELD CALIBRATION

The control program continuously monitored the weight on the scale platform. Any weight

reading which was less than a flag value, defined to be slightly larger than the normal output of the unloaded scale, was used to update the stored offset weight of the platform. Any weight reading larger than that flag value indicated that something was on the platform. The computer wrote this weight reading to the output file. The ID numbers of the cows were also recorded in the same file at the moment they were detected. When the milking was completed, the computer automatically ran another program to analyze the data just recorded and compute the true weight of each cow being detected.

Before operation, the completed scale was field calibrated. First, the scale was balanced so a weight on the platform would cause a fixed output value regardless of its position on the platform. When the scale was first installed, the output due to a weight at one end of the platform differed from the output due to the same weight at the other end. Inaccuracies of the system components caused the imbalance. For instance, the dual power supply produced $+12.08$ and -12.45 VDC instead of ± 12 VDC. Also, the weights of the summing amplifier inputs could not be set exactly as they were defined. However, the balance was restored by readjusting the gain of one of the inputs of the summing amplifier with the scale installed in its real working environment.

Next the scale was calibrated to find the true relation between the weight on the platform and the millivolt reading displayed by the computer. Originally this conversion factor was set to 2.25 kg/mV by design constraints. After field calibration, the true factor was calculated to be 2.735 kg/mV.

RESULTS

An experiment was carried out to test the accuracy and reliability of the weighing system. Two groups of cows were allowed to pass over the scale platform via their normal route and in their natural patterns. Each group had 5 cows with different body weights. Each group of cows was guided to pass the scale 6 times within about 20 minutes. Cows were also weighed with a mechanical scale once after the first test run and twice at the end of the test. During the first three runs, some attempt was made to separate the cows by stopping them inside the milking parlor to keep a certain distance between them, but it did not help very much. Cows still got crowded upon reaching the platform.

Table 1 shows the three manual measurements of each cow's body weight. The maximum variation in the readings is less than 1% of the average value for each cow. Table 2 shows the results of the automatic weighing. A blank space indicates the measurement has less than four valid samples. If a weight was computed from eight or more valid samples, and the standard deviation was less than 5% of the computed weight, a mark "*" is shown behind it. A weight is followed by a mark "!" if it was within 5% of the cow's reference weight. The weights with mark "***" or "!" were averaged. The relative error was computed by comparing this average weight with the average from manual weighing. The results show that all the cows have a relative error between -0.44% and -1.95% except the cow with ID number 555. Cow 555 had only one computed weight within 5% of the cow's reference weight. The fact that most errors

are negative may be due to improper calibration, because the manual scale and automatic scale were calibrated using different standard references.

The results show that 34 % of the weights were accurate and reliable enough to update the table of reference weights used by the software for true weight extraction. They also show that 73 percent of the weights were within 5 % of the cow's reference weight.

Table 2 shows that the behavior of cows is a factor which affects the measurement. For some cows, like the cow with ID number 515, all 6 measurements were accurate and reliable. But for some cows, like the cow with ID number 555, only one measurement was within 5 % of the cow's reference weight and two weights had fewer than four valid samples due to her habitual quick passing mode.

The automatic scale was also operated during regular milking for one week. More than 50 percent of the measurements collected during this time had eight or more samples and a standard deviation within 5 % of the computed weight. Over 90 percent of the measurements had four or more samples and were within 5 % of the cow's reference weight.

CONCLUSIONS AND DISCUSSION

An automatic weighing system, controlled by the dairy farm management computer, was developed and installed in the return alley of a milking parlor. It could identify and weigh cows with no human intervention and without disturbing either the behavior of the cows or the normal operation of the milking parlor. The computer was able to determine the weights of the cows to within 2 % of their true values. It did so by averaging the readings from six passes of a cow over the platform, discarding those readings considered unreliable due to an excessive difference from the reference weight.

Cows are milked twice a day on a dairy farm, allowing 14 measurements each week. The weekly average will be more accurate than the values obtained from six measurements in this experiment. The accuracy of the scale can be improved if the cow movements are slowed down. If a cow walks rapidly over the platform, the variation between the samples is increased. Also, too few samples may be collected for a valid measurement. The steel/wood platform can be replaced by a complete steel platform to increase the stiffness of the platform. Thus the variation between samples can be reduced. It may be possible to improve the raw data collection program to reduce the effect of the movements of cows.

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Table 1. Results of Mechanical Weighing

ID Num	Cow Num	WGT(1)	WGT(2)	WGT(3)	AVG	Max(WGT-AVG)/AVG
515	5051	698	697	697	697	0.14%
536	5157	738	738	739	738	0.14%
555	5129	741	738	738	739	0.27%
559	5339	431	428	427	429	0.47%
561	5307	650	645	645	647	0.46%
602	5018	450	449	449	449	0.22%
605	5045	667	662	662	664	0.45%
631	5381	678	675	675	676	0.30%
637	5268	720	718	718	719	0.14%
639	5397	705	700	699	701	0.57%

Table 2. Results of Automatic Weighing

ID Num	WGT(1)	WGT(2)	WGT(3)	WGT(4)	WGT(5)	WT(6)	AVG	Error
515	691.4*	688.7*	691.0*	696.4*	681.9*	690.5*	690	-1.05%
536	743.7!	725.9*	736.4!	726.4!	743.2!		735	-0.44%
555	751.4!	590.2	683.3			780.4	751	1.68%
559	419.0!	421.8*	425.9!	433.1!	461.3	422.7*	425	-0.97%
561	629.7!	634.7*	646.0!	634.2*	622.4!	637.4*	634	-1.95%
602	444.0*	446.3*	307.8		501.2	423.6	445	-0.93%
605	658.8*	655.6*	678.3!	644.2!	660.1!	638.3!	656	-1.17%
631	671.5*	675.1*	663.7*	650.6!	660.1*	669.2*	665	-1.62%
637	706.0!	713.7!	691.0!	714.6!	646.0	710.5!	707	-1.60%
639	711.9!	647.9	659.7	674.6!	698.7!		695	-0.89%

Notes: * -- 8 or more samples and STD < 5%
! -- less than 8 samples and error within 5%
all weights in kilograms

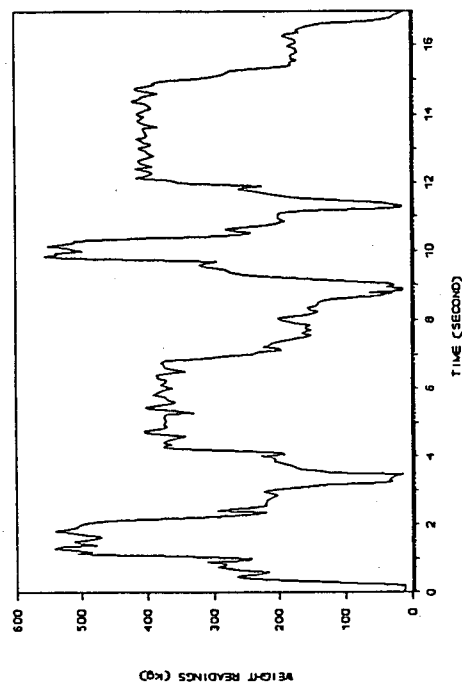


Figure 1. Typical pattern of weight readings vs. time.

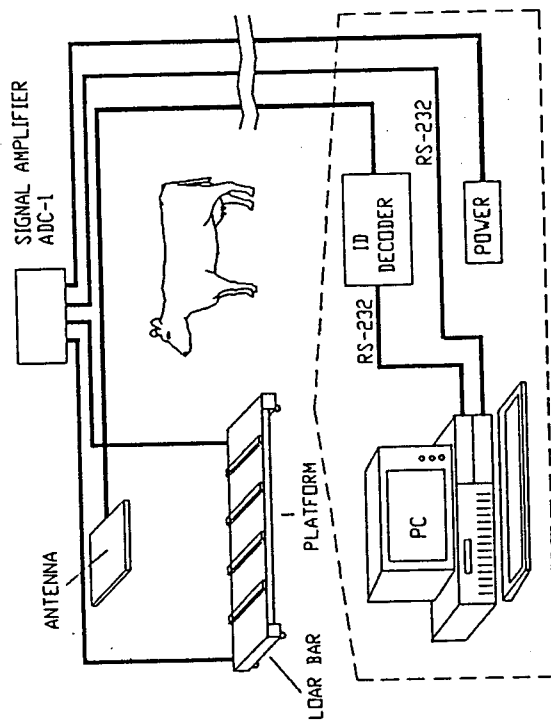


Figure 2. Overall design of the weighing system which include a scale platform, a signal amplifier, a data acquisition device, an ID subsystem, and an IBM PC/AT compatible computer.

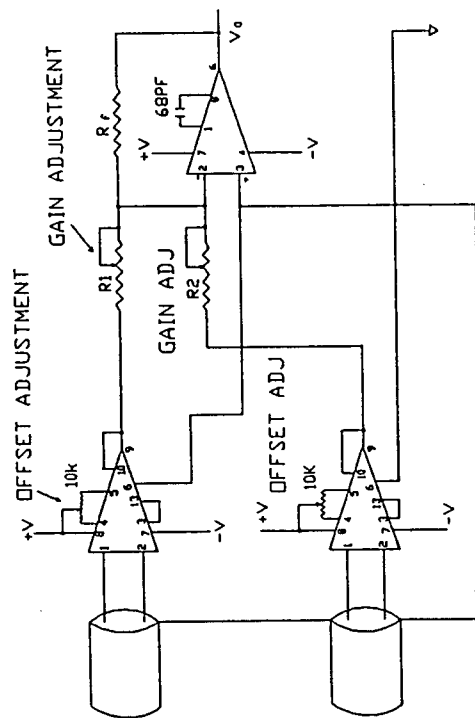


Figure 3. Construction of the summing amplifier.

DEVELOPMENT OF SOFTWARE FOR A COW WEIGHING SYSTEM

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SUMMARY:

A program written in C for an IBM/AT compatible computer was developed to operate a scale that automatically weighed dairy cows. The program read the instantaneous weights and the electronic ID numbers of cows passing over the scale and continually updated the tare weight of the platform. Another program identified the readings taken while a cow had all four legs on the platform and obtained the average weight of that cow.

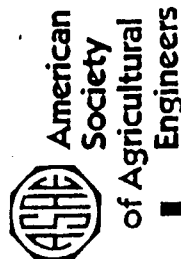
KEYWORDS:

Weighing, Data Acquisition, Dairy, Data Processing, Computer

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DEVELOPMENT OF SOFTWARE FOR A COW WEIGHING SYSTEM

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ABSTRACT

A program written in C for an IBM/AT compatible computer was developed to operate a scale that automatically weighed dairy cows as they left a milking parlor. The program read the instantaneous weights and the electronic ID numbers of cows passing over the scale and continually updated the tare weight of the platform. Another program was developed to identify the readings taken while a cow had all four legs on the platform and average them to obtain the weight of that cow. A third program generated a weekly weight report on each cow for management purposes.

INTRODUCTION

An automatic scale was developed at the University of Illinois to weigh dairy cows as they left the milking parlor (Ren et al., 1990). The weighing system consisted of five main parts: a scale platform, a signal amplifier, a data acquisition device, an electronic ID subsystem, and an IBM PC/AT compatible computer (Figure 1). The platform was placed in the return alley of the milking parlor. During milking time, cows were released from the milking parlor in groups of four. As they passed over the platform in their natural patterns, their identification numbers and weights were recorded. An ideal weight versus time pattern is shown in Figure 2. The pattern for each cow has three levels. Level 1, approximately half the cow's weight, occurs when the cow has her front legs on the scale. Level 2 is the cow's complete weight and occurs when all four legs are on the scale. Level 3, also approximately half the cow's weight, occurs when the cow has her rear legs on the scale. Sometimes the divisions between these levels are not clear, especially when cows follow each other closely. Also, when cows pass quickly over the scale few data points are collected and the variation between the data points is large.

OBJECTIVES

The objective of this study was to develop computer software to collect and process data from the automatic scale. The software was to determine a weekly average body weight for each cow to be used for farm management purposes.

DEVELOPMENT OF COMPUTER SOFTWARE

The software was divided into a data collection program and a data processing program.

(1) Data Collection Program

The task of the data collection program was to read the ID numbers and instantaneous weights of the cows, subtract the weight of the unloaded platform, and write the weights and ID numbers to an output file on the hard disk of the computer. To save time and disk space, each weight written to the disk was the average of three consecutive readings from the scale.

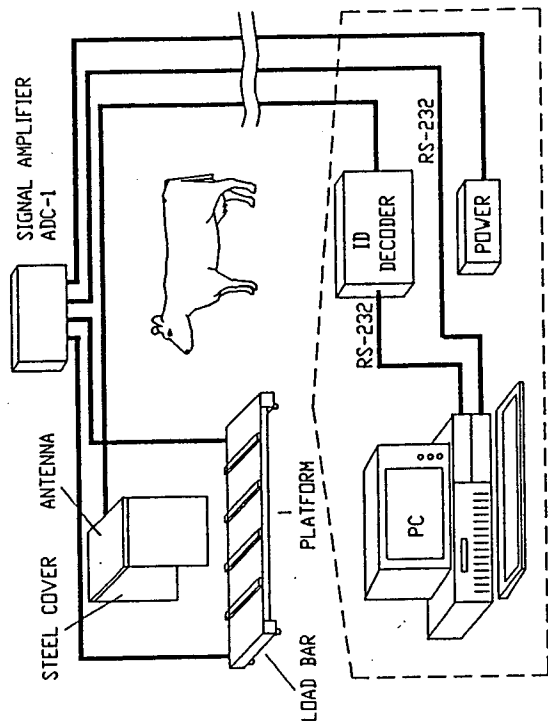


Figure 1. Overall design of the weighing system which included a scale platform, a signal amplifier, a data acquisition device, an ID subsystem, and an IBM PC/AT compatible computer.

The analog output signal produced by the scale was digitized by an ADC-1 data acquisition

device from Remote Measurement Systems, Inc.¹. The ADC-1 could digitize the signal to a resolution of 11 bits plus sign in 8.3 milliseconds or to a resolution of 12 bits plus sign in 50 milliseconds. It communicated with the computer at 9600 baud via an RS-232C serial port. To read the scale, the data acquisition program sent a command to the ADC-1 to begin an analog-to-digital conversion, then received the weight as a two-byte reply after the conversion was complete. With the ADC-1 on the higher speed, lower resolution setting, the program was able to collect 48 weight readings (16 data points of three readings each) every second. As most cows passed over the platform in less than two seconds, the lower speed setting would not have provided enough data points. The system thus configured had a maximum capacity of 907kg and a resolution of 0.44kg.

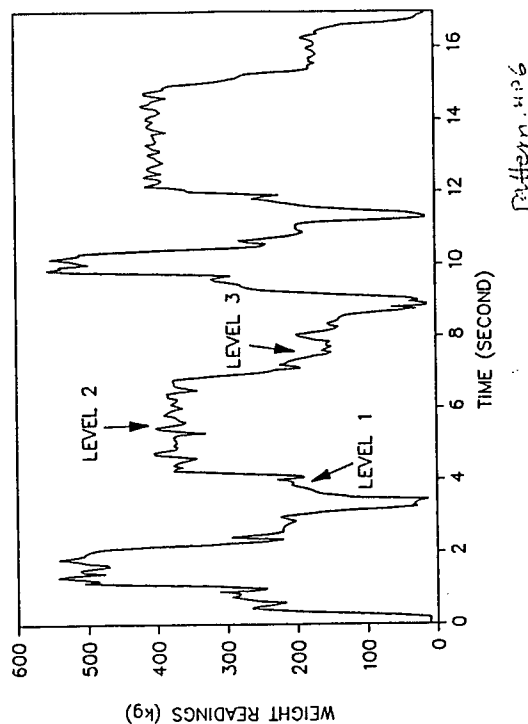


Figure 2. Typical pattern of weight readings vs. time.

¹Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the University of Illinois and does not imply the approval of the named product to the exclusion of other products that may be suitable.

the output of the unloaded scale (about 2 to 5 kg). A weight reading less than the flag value was taken as an indication that nothing was on the platform. If the program encountered 100 consecutive readings less than the flag, it averaged them to calculate the tare weight of the platform. This tare weight was updated during the entire data collection period and written to the output file, prefixed by the letter "O" (for "offset"). Up to three consecutive offsets could be written to the file. A weight reading larger than the flag value meant that something was on the platform. The program computed the weight of the object on the platform by averaging three consecutive readings and subtracting the current tare weight of the platform, then wrote the result to the output file, prefixed by the letter "W" (for "weight"). The program then checked the status of the ID port. If an ID was detected by the decoder, the program wrote the ID number to the same output file, prefixed by the letter "I" (for "ID").

The raw data sets for most cows were clearly separated by one to three offset weights. Occasionally one cow stepped on the platform before the preceding cow left, in which case the two sets of weights were not separated. After each group of four cows passed over the scale, there would be a period of about 5 seconds before the next group reached the platform. After performing the tare weight update four times in a row, the program decided that it was between groups of cows and executed the TIME_CHECK subroutine. This subroutine determined whether the current milking was over by comparing the current time with the known end time of milking. If the milking was over, the output file was renamed according to the current date and whether the milking was in the morning or afternoon. The date information was also written into the output file. A new output file was then opened for the next milking. An example of the recorded data file is shown in Figure 4.

```
O 2
O 2
O 2
W 350
W 465
W 1302
W 2865
W 3546
I 566
W 4323
W 6522
.
.
.
O 4
D date: 07/15/90 AM
```

Figure 4. The format of the recorded data file showing weight (W), offset (O), ID number (I), and date (D).

The cows were identified by an Animal Identification System Multiplex Decoder model 1200 made by Eureka Systems, which also communicated with the computer via an RS-232C serial port. To match weights with cows, the hardware was set up to detect and record the ID number at the time just before the cow placed all four legs on the scale. This was achieved by placing the antenna off center in the forward direction. The field of view of the antenna was confined to a limited distance along the platform, less than one cow length, by a steel cover. Thus there was no chance of two IDs being detected at the same time. The decoder of the ID subsystem was set to automatic mode. In this mode, whenever the decoder detected a cow ID tag it automatically transmitted its antenna number and the ID number and battery status of the tag to the computer three times. As the program could not read both a weight and an ID number at the same time, the data transmission rate of the ID subsystem was set to its maximum value of 9600 baud. Thus the time lost from reading weights was minimized.

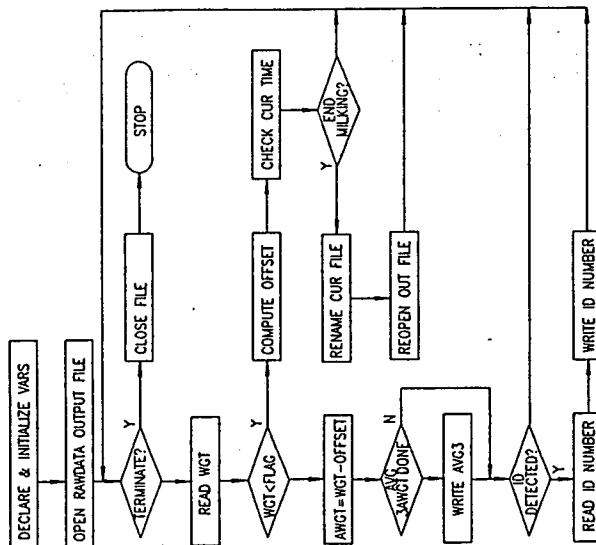


Figure 3. Flow chart of data collecting program.

The flow chart of the data collection program is shown in Figure 3. The program read weights continuously and compared them to a flag value (10 kg) which was slightly larger than

(2) Data Processing Program

A typical pattern of recorded weight data, as shown in Figure 5, matches the ideal pattern. Most data sets had three clear levels for each cow, with the cow's ID number being detected near the end of the first level. In more complicated cases, as shown in Figure 6, the cows were not clearly separated. Part 1 of Figure 6 shows two half weights of two consecutive cows. Part 2 of Figure 6 shows one cow's weight plus half of another cow's weight (six legs on the scale). An intelligent program was needed to analyze the recorded raw data and extract the true weight for each cow.

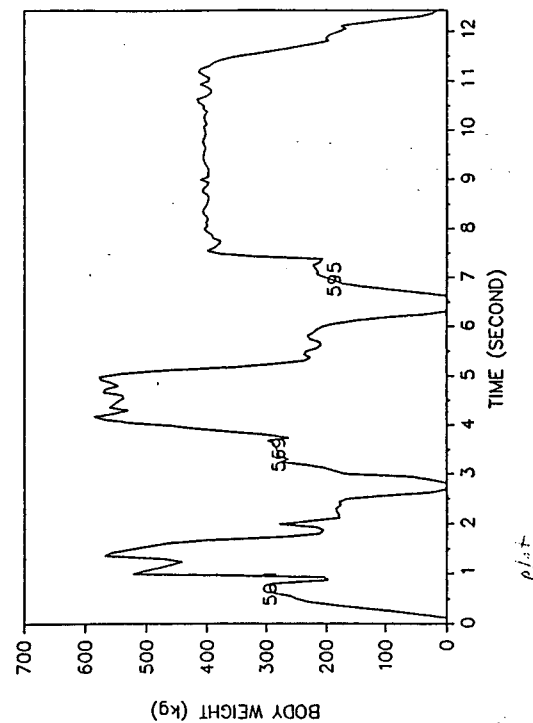


Figure 5. Raw data plotting with ID numbers being inserted.

The average of the data points representing a cow's four-leg weight is an acceptable value for the true weight of the cow. The problem is how to locate the starting and ending points of the data set. The computed weight is very sensitive to this decision, especially when there are only a few data points in the set. The body weights of the cows in this study ranged from 350kg to 800kg. However, a cow's weight usually cannot change more than 5% from one day to another (Maltz, 1990). Therefore a reference weight for each cow was used to locate the starting point of the data set. Since a cow's body weight changes much more from mornings to evenings

than from day to day (Maltz, 1990), two reference weights were used: one for the morning milkings and one for the evening milkings. The reference weights were stored in a reference table along with the ID numbers of the cows.

The data processing program read the recorded weights point by point starting from the beginning of the raw data file. When an ID number was read, the program would retrieve the reference weight for that cow from the reference table. The program then compared the following recorded weights to the reference weight. When a current weight reading was within certain limits, a data set (array) would start from this point. All succeeding data points were put into the array until the stop point was found.

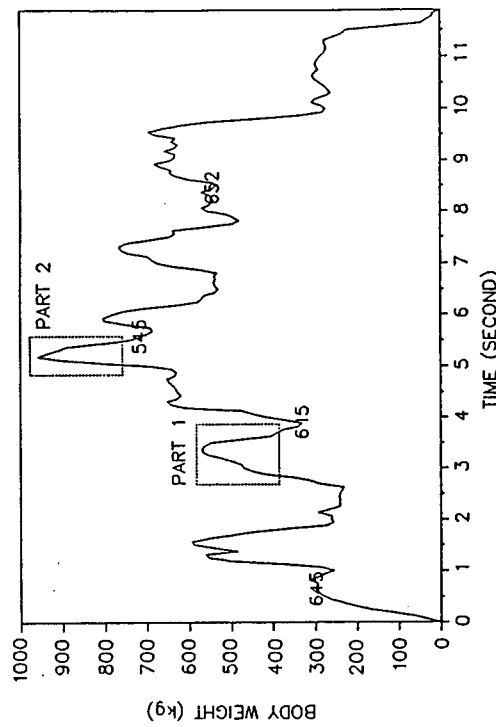


Figure 6. Raw data plotting a complicated case showing that the cows were not clearly separated.

Two methods of identifying the stop point were tried. Usually there was a sharp transition from level two (the four-leg weight) to level three (the rear-two-leg-weight). One approach to locating the start of this transition was to continually compare the average of three leading data points and the average of three following points of six consecutive points along the data flow. If the difference was larger than a pre-defined value (15% of the reference weight) then the

transition was considered to be found. The other approach was to compare each weight following the start of the array with the reference weight. If the recorded weight differed from the reference weight by more than 10% of the reference, the end of the array was located. The latter approach was more successful when the variation in the data was very large. It was also successful at locating both downward and upward transitions. An upward transition occurred when a cow stepped on the platform while the previous cow still had four legs on the scale. The weight reading in that case jumped from a four-leg-weight to a five- or six-leg-weight (Figure 6).

In another common case, one cow still had her two hind legs on the platform when another cow got on with her two front legs (Figure 7). The resulting weight reading was similar to a cow's four-leg weight. However, if the ID number for the second cow was detected and inserted in the data file at the right place, the beginning and end of the array for each cow could still be located correctly. Then the correct weight for each cow was computed by averaging the data points in the arrays. Figure 7 shows two occurrences of this case together for comparison. The left part shows that the ID number 552 was detected too early, causing the program to start and stop the array at the wrong places. After adjusting the relative positions of the platform and the antenna, the ID number 508 was detected at the right position (see right part of Figure 7). The following block of data indicating the cow's four-leg weight was located correctly.

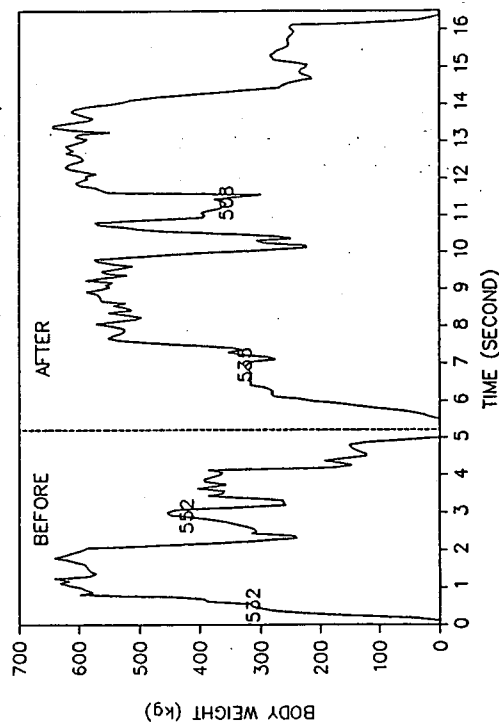


Figure 7. Raw data plotting of two cases showing the effect of the relative position of the platform and the antenna.

Several criteria were used to judge the reliability of the computed weights. One criterion was the length of time the cow stayed on the platform. At least 0.5 second on the platform was considered necessary to obtain a reliable weight, implying that at least eight data points were required to compute the average. In addition, the variation among the data points was used to judge the accuracy of the computed average. If the computed weight was based on eight or more data points, and the standard deviation was less than 5% of the computed weight, this weight was treated as reliable and accurate and was stored in the reference table, replacing the old reference weight. Weights computed from fewer than 8 data points were considered accurate if the average was within 5% of the reference weight. These weights were used later to compute a weekly average weight, but not to update the reference table.

The flow chart of the data processing program is shown in Figure 8. The main program read the data file one line at a time and took the branch specified by the letter at the beginning of that line. When an ID was found, the program looked through the reference table to find the reference weight of that cow. The program read each weight thereafter, comparing it with the reference, until the start of the 4-leg data set was located. All data points after the starting point were put into an array until the end of the 4-leg data set was located. Once the array was terminated, the program computed the average and standard deviation of the weights in the array. If there were eight or more data points and the standard deviation was no greater than 5% of the reference weight, the program updated the reference table. Finally the results, including the ID lag number, cow number, computed weight, number of samples, and standard deviation were printed to an output file. Each weight considered reliable enough to update the reference table was marked with an "x". Weights which were not considered reliable enough for the reference table but which were considered valuable for computing the weekly average weight were marked with an "i".

RESULTS

The weighing system and the data collection program were operated during the regular milkings at the University of Illinois Dairy Farm for one week. During each milking, about 65 cows passed over the scale. Cows were milked twice a day, so a total of 14 raw data files were collected. The data processing program was modified to process all 14 raw data files and write the results in a new output file.

Another program was written to read the above output file and generate a weekly weight report for each cow including the ID number, average weight, number of weights used to compute the weekly average, and the number of times the cow's reference weight was updated during the week. An example of part of the weekly weight report is shown as Figure 9.

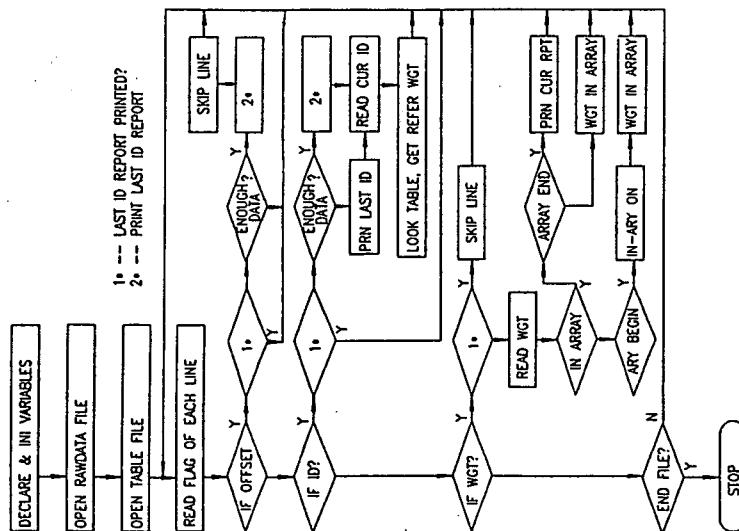


Figure 8. Flow chart of the data processing program.

DISCUSSION AND CONCLUSIONS

The software successfully recorded the raw data from the scale and was able to extract the true weight of each cow in most complex cases, even when the cows were badly crowded. During each milking, acceptable weights were obtained for more than 80 percent of the cows. An acceptable weekly average weight was obtained for 100 percent of the cows.

The results of an earlier test showed the system could come within 2% of a cow's actual weight by averaging the weight readings from six passes of a cow over the platform (Ren et. al., 1990). There were fourteen milkings during the week, and at least six weight readings were obtained for all cows. During the week, some cows dried off and were removed from the group being milked, while other cows became fresh and were added. Before the data processing program could be run, the reference weights for the new cows had to be added to the reference table. They were obtained either by estimating them from the raw data file or by weighing the cows manually.

WEEKLY BODY WEIGHT REPORT

Cow Number	AVG Weight(kg)	No. of Weight	With Mark *
5423	569.5	13	9
5429	377.0	10	3
5368	445.3	11	1
5512	487.1	12	3
5161	602.3	13	2
5276	542.2	14	8
5394	533.1	12	8
5456	520.4	11	9
5461	505.1	13	7
5413	665.1	13	4
5410	663.5	13	11
5384	608.0	13	4

Figure 9. Typical weekly body weight report.

REFERENCES

- Maltz, E. Personal Communication.
- Ren, J., N.L. Buck, and S.L. Spahr. 1990. An Automatic System for Weighing Dairy Cows. ASAE Paper No. 90-3010, ASAE, St. Joseph, MI. 4905-9659.

An analysis program considered the readings recorded concerning an individual cow and decided if a successful weight had been obtained by considering a reference weight for the cow and the average reading from eight or more data points obtained within 0.5 second. A value within 5% of the reference weight was required to be considered valid. Weekly means were computed from the milking-by-milking values to account for differences in fill.

- c. Electronic activity tag. An automated prototype electronic activity tag (Boumatic, Madison, WI) was installed and tested during a one-year period. The system was first installed so it recorded directly on a PC. A later version utilized the Boumatic 2040 processor as the initial recording site for data transmittal from the tags. With the 2040 configuration, data were recorded automatically as the cow walked through a portal antenna at milking time. The activity tag, mounted on a cow's leg, contained a memory switch which turned off and on as the cow walked. The counts per 2-hr interval were stored on the activity tag and subjected to a comparison of activity for the previous 12 hr versus activity for the same time period in the next previous 2 days. Summaries of the activity rates were transmitted to the 2040 unit at every milking, and actual counts were downloaded from the tags once weekly with a PC and an infra-red transmitter.
- d. Computer feeder. A new computer feeder system was installed at Alumim to conduct the trial described in section B.1.b. The systems was a four-stall Alfa-Laval single-feed

unit with a 6-ton concentrate storage tank. Cows were identified with neck mounted Alfa-Laval electronic ID transponders.

e. Multi-tasking operation system. Automated data acquisition was enhanced by implementation of a PC-MOS multi-tasking operating system on a PC equipped with an Intel 80386 CPU board. This system allowed multiple data acquisition programs to operate simultaneously on one PC rather than requiring a separate PC to operate each program. PC-MOS allowed up to five programs operating simultaneously. Thus a single PC could simultaneously run programs to collect every-milking milk weights from milk meters, behavioral and usage data from computer feeder stalls, operate an automated scale system with electronic ID, and still allow programming to take place.

Upon implementation we found that the speed of data transmission and the clock speed of the CPU limited the reliability of multi-tasking for automatic data collection. With all of the above named programs operating, data sometimes were lost when events occurred at almost the same time. Thus while multi-tasking on a PC was possible, the possibility of a number of events happening at almost the same time limited the practical application of multi-tasking to the operation of two programs (collection of every-milking weights from milk meters and behavioral and usage data on the computer feeder) plus programming simultaneously.

f. Mixing wagon electronics. An automated system for mixing and delivering TMRs utilizing mobile feed mixers, computerized ration balancing, and an electronic record system was installed at the Alumim test location. TMR mixtures for group feeding were prepared and distributed twice daily by a mixing wagon equipped with electronic scales. Preparation and distribution of rations were monitored by a special purpose portable controller (Anat Computers, Bror Hail, Israel) which received ration preparation "orders" from a personal computer equipped with a linear ration preparation program. The controller was transported to the mixing wagon and connected to the wagon's electronic scale daily, thus becoming an integral component of the control system to communicate ration instructions to the operator, and to monitor the actual preparation and distribution of the mixture to cow groups. The controller was then reconnected to the computer at the end of the day to feed back the actual preparation and distribution data (Spahr, 1989).

g. Milk meters. The milking recording system at Urbana was modified to reflect technology advancements. The 1980-model milk meters (6 in a double-3 side opening parlor and 16 in a 4X4 polygon parlor) were replaced with Model M+ Boumatic meters. A single Boumatic Model 2040 processor replaced the two previously-used 2020-R units. A Boumatic cow identification system via 2 portal walk-through interrogator-antennae was installed at the d-3 side opening parlor. An underground cable system was utilized to complete the link

from each parlor to the 2040 processor, and then to a personal computer.

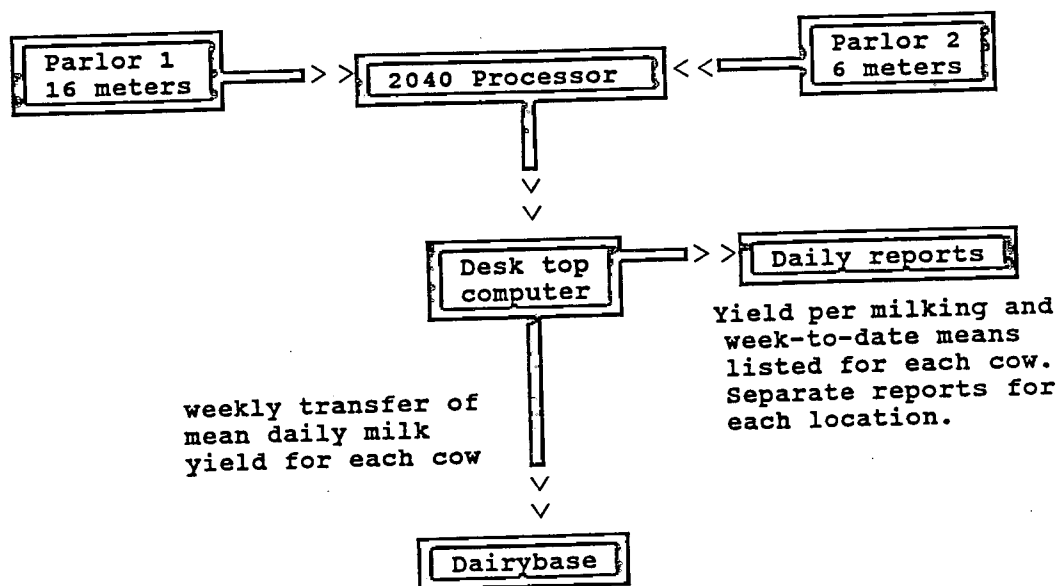


Figure 1. Collection system for electronic transfer of daily milk weights to a PC

Milk yields are received and recorded on the 2040 processor from either milking parlor at the time of milking. Cow identification is either via a neck-mounted Boumatic ID system (d-3 parlor) or via manual entry at the milking stall on a key pad (4X4 polygon parlor). Data transfer from the 2040 to the PC occurs automatically at a specific time once daily (typically 1:00 am). Updated summaries are prepared daily with data from each cow at each milking listed by location; an updated mean of daily yield is computed daily for each cow. The weekly mean daily milk yield is transferred into the permanent herd database once weekly. Weekly means

for each cow are concatenated with previously-recorded values to provide a complete electronic milk recording system.

4. Response differences, Illinois vs. Israel

It would not be appropriate, without testing, to assume that dairy cattle production models developed for Illinois or Israel necessarily could be transported unaltered from one country to the other and to work equally well both places since there are known differences in climate, feedstuffs, and other management practices. Since body weights, body weight changes and milk yield, expressed either as yield per cow or per unit of body weight, during early lactation were found to be important variables in our strategic models, we made a comparison of these variables between Illinois Holsteins and Israeli Holsteins. These results are in the report by Spahr et al., 1990 (attached).

The Israeli cows were 60 cows at Kibbutz Alumim which were assigned to the control ration for 20 weeks as part of the trial described in section B.1.b. Data from an additional 40 1st lactation cows which were on the control diet for the first seven weeks also were available.

The Illinois cows were control animals on BST trials conducted in 1987 and 1988, control animals for a feed additive trial in 1989 and all cows on a high and low protein trial with high and low rumen degradable protein concentrations in the diet all cows were fed weighed amounts of a TMR according to her individual appetite.

The Illinois cows had greater body weight in each lactation, reached peak production earlier in lactation, had higher peak yield in 1st and 2nd lactation despite the Israeli cows being milked 3X

BODY WEIGHT CHANGE, PERFORMANCE POTENTIAL AND LACTATION
NUMBER AS STRATEGY PARAMETERS FOR ADJUSTING NUTRIENT
DENSITY.

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North Carolina, June 1990.

This research report is a part of the US-Israel Binational Agricultural Research and Development (BARD) program in which we are developing knowledge-based approaches to improved management of dairy herds. In previous research (Kroll et al., 1988; Strickland and Braster, 1981) it was reported that 1) daily milk yield during early lactation has a predictable effect on the partitioning of absorbed nutrients between body weight gain and daily milk yield during mid-to-late lactation; and 2) prediction equations for diets of designated nutrient density need to include lactation number and body weight of animals. This report extends these claims by examining and contrasting the early lactation performance of Illinois and Israeli cows. An overall goal of our work is the development of a knowledge-based individual-animal prediction for partitioning of absorbed nutrients into milk or body weight gain when a TMR with a specific nutrient density is offered *ad libitum*. The specific objectives of this study were:

1. To compare the following as early lactation strategies for adjusting nutrient densities of total mixed rations (TMR) in 1st, 2nd or 3rd and greater parities for Israeli and Illinois Holsteins:
 - Daily milk yield per cow
 - Daily milk yield expressed as % of body weight
2. To compare milk yields, body weights, and body weight change during early lactation in Israeli and Illinois Holsteins.

The Israeli cows were Israeli Holsteins maintained at Kibutz Alumim in the northern Negev desert. This herd ranks in the top 1/3 of Israeli herds. A single total mixed ration (TMR) was fed to appetite; cows were milked 3X. Only early lactation data (through 7 weeks) were available for some cows that were assigned to nutritional experiments.

The Illinois cows were control animals on BST trials conducted in 1987 and 1988, control animals for a trial in which fat was added to the diet in 1989, and all cows on a trial

to test high and low rumen by-pass protein at high and low crude protein concentrations in the diet. A TMR was fed individual to each cow according to appetite. The cows were Holsteins; milking was 2X.

Table 1. Number of cows

Parity No.	Israeli	Illinois
1	18 40'	-- 22'
2	21	33 33'
3 or more	21	24 52'

'Data available from control diet for only 7 weeks

Minimum body weight during early lactation and mean milk fat percentages are shown in Table 2. The Illinois cattle weighed more in each parity than the Israeli cattle. Substantial variation was present in the milk fat percentages and no trends were evident.

Table 2. Minimum body weights and milk fat percentages

Parity No.	Mean minimum body weights		Mean milk fat %	
	Israeli	Illinois	Israeli	Illinois
1	473	496	3.07	3.37
2	521	539	3.12	3.01
3 or more	575	582	3.21	3.40

Means for body weight and for daily milk for each week in lactation are in Figures 1 and 2. Daily milk, expressed as percent of body weight for each week in lactation and a scatter diagram of daily milk expressed as a % of body weight for each cow plotted against the corresponding value for daily milk are in Figures 3 and 4.

R_s values showing the relationship between daily milk and daily milk expressed as % of body weight are in Table 3.

Table 3. R_s values, daily milk vs daily milk as % of Body Weight

Parity No.	Illinois	Israel
1	.66 (22)'	.64 (30)'
2	.61 (33)	.56 (45)
3 or more	.85 (52)	.56 (48)

'No. of observations

The higher R^2 values in the Illinois cattle, especially in 3rd and later parity, suggests that the Israeli cattle may benefit more than the Illinois cattle by considering body weight as a factor in their nutritional management.

In summary, during the first 20 weeks of lactation the Illinois cows had greater body weight, reached peak daily yield earlier in lactation, had higher peak yield in 1st and 2nd parity, and had higher daily yield as % of BW to about 12 wk in 2nd parity, and after about 6 wk in 1st parity. The Israeli cows gained more weight relative to minimum lactation weight, maintained peak daily yield with greater persistency in 2nd parity, and 3rd and later parities, and had higher daily milk as % of BW after wk 14 in 3rd and later parities.

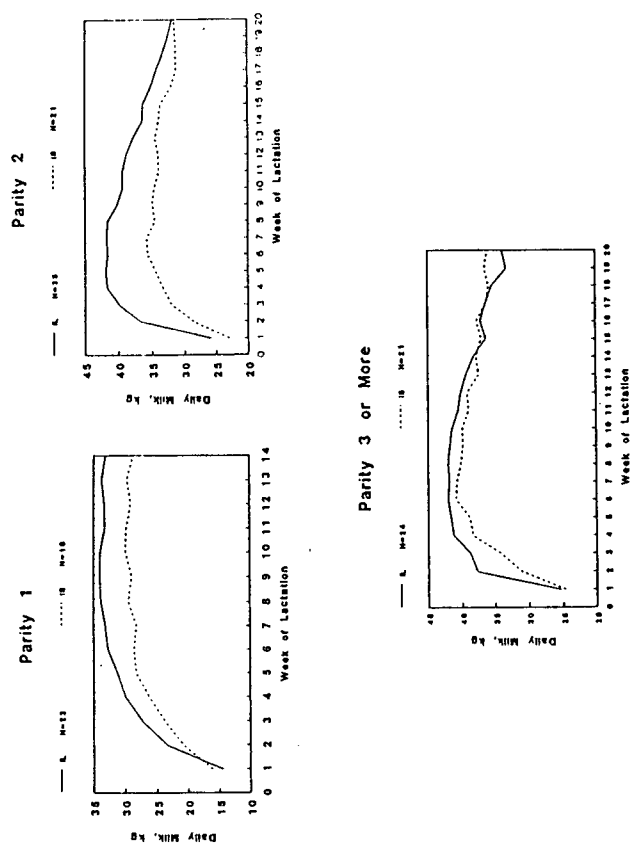


Figure 2. Daily milk yield by week of lactation for Illinois and Israeli cows.

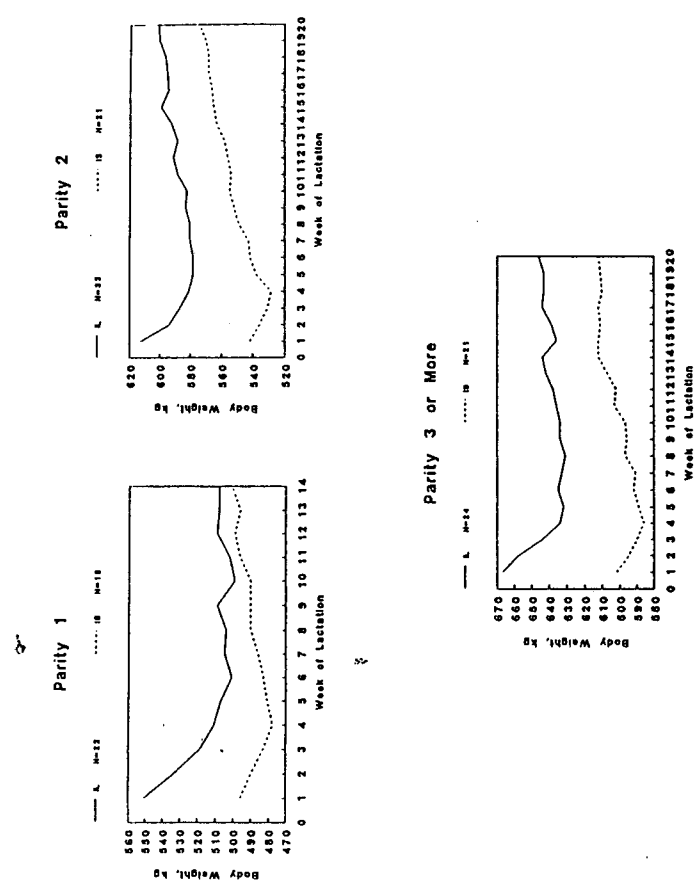


Figure 1. Body weights by week of lactation for Illinois and Israeli cows.

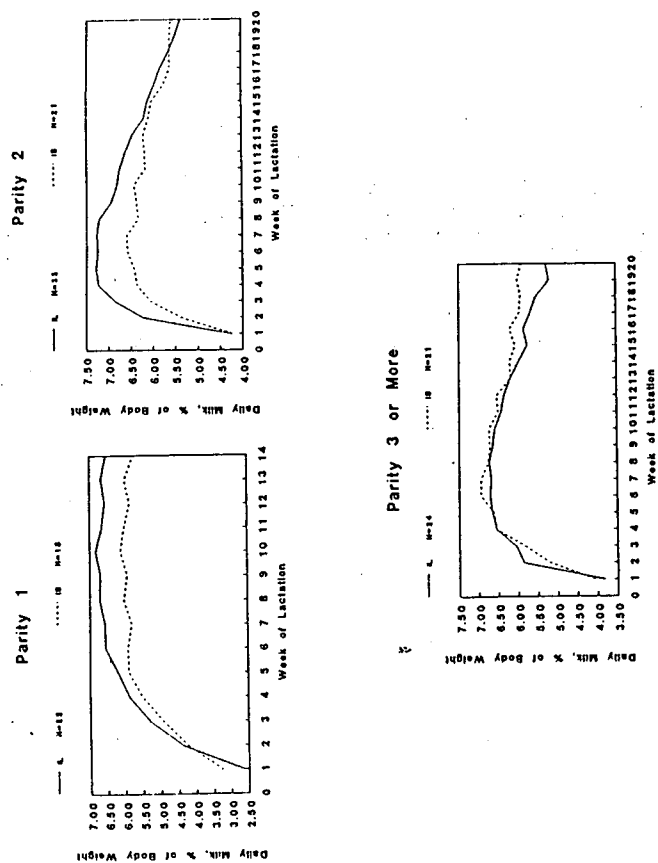


Figure 3. Daily milk expressed as per cent of body weight by week of lactation for Illinois and Israeli cows.

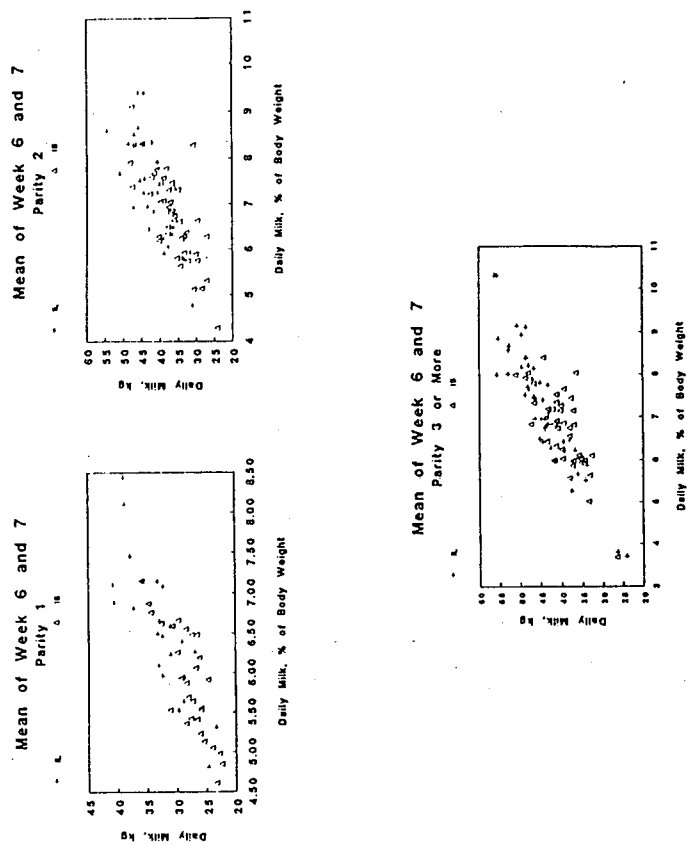


Figure 4. Individual cow means for daily milk and daily milk expressed as percent of body weight at week 6 and 7 of lactation for Illinois and Israeli cows.

The values were similar for peak daily yield during early lactation in 3rd and later parities, and for milk yield as % of body weight to wk 6 in 1st parity, after wk 14 in 2nd parity, and to wk 14 in 3rd and later parities. It is concluded that daily milk is important, but it is inadequate to use alone as a strategy for adjusting nutrient density; parity number, body weight and deviation of weight from minimum early lactation weight (degree of fleshing) are important considerations.

References

1. Kroll, O., E. Maltz and S. L. Spahr. 1988. Herd and feed management in milk production. in Knowledge Based Systems in Agriculture -- Prospects for Application. Proc 2nd DLG Congress on Computer Technology. p 492-511. Frankfurt.
2. Strickland, M. J. and Broster, W. H. 1981. The effect of different levels of nutrition at two stages of the lactation or milk production and live weight change in Friesian cows and heifers. J. Agric. Sci. Camb. 96:677-690.

and the Illinois cows 2X at 10-14 hr intervals. The Illinois cows had higher daily yield as % of body wt to about wk 12 in 2nd lactation, and after about wk 6 in 1st lactation. The Israeli cows gained more weight relative to minimum lactation weight, maintained peak yield with greater persistency in 2nd parity and in 3rd and later parities, and had higher daily milk as % of BW after wk 14 in 3rd and later parities.

The wide disparity in body weight, in milk yield and in the shape of the lactation curves suggest that both genetic and environmental differences are substantial. Models developed in one country probably will require substantial testing before being accepted in the other country.

The work from the present BARD project moved us closer to a total on-farm automatic data acquisition and analysis system. Substantial progress was made on both hardware and software systems suitable for practical on-farm applications, especially in the area of nutritional management for groups of cows. Concurrently, we tried promising new approaches with artificial intelligence techniques and prototype electronic devices which still need substantial development before they are ready for practical farm situations. While these new techniques are not ready for on-farm use today, we believe that our demonstration of their potential application to agriculture and particularly to dairy herd management has established a justification and direction for their continued development.

IV. DESCRIPTION OF COOPERATION

The mechanism for cooperation has been through a continued interchange of ideas, planning and information. Dr. Spahr visited Bet Dagan in the project preparatory stage. Dr. Maltz and Dr. Kroll met with Dr. Spahr at the National Invitational Workshop on Microcomputer Usage in Dairy Herd Management held at Dallas, TX and at Dr. Spahr's laboratory at Urbana, IL in April 1987 during the time of project review. While in Urbana Maltz and Kroll visited with Dr. Christianson and Dr. Buck. Maltz, Kroll, Spahr and Peiper reviewed project plans during the 3rd International Symposium on Automation in Dairying at Wageningen, The Netherlands in September 1987 at the start of the project. Dr. Kroll and Dr. Spahr visited at Bangor, Wales in September, 1988 as part of the International Conference on New Practices in Cattle Production.

Dr. Spahr visited Bet Dagan and the trial site at Alumim in June 1989. During this visit substantial time was spent with Dr. Maltz and Dr. Kroll reviewing progress and exchanging data concerning new feeding strategies and automatic devices for dairy cattle feeding.

Dr. Maltz spent sabbatical leave from October 1989 to August 1990 in Dr. Spahr's laboratory at Urbana. During his sabbatical leave Dr. Maltz spent substantial time conducting Trial II described in section B.1.b and studying specific evolving technologies and practices associated with the U.S. dairy industry. Dr. Maltz also spent three weeks in Urbana during April 1991 for summarization of research trial data and preparation of this report. Sharon Devir (Volcani Center) visited Dr. Maltz and Dr.

Spahr at Urbana in June 1990 for exchange of data and a review of concurrent research in Israel. The investigators have maintained a particularly strong exchange of ideas and information concerning strategies for feeding dairy cattle, automating the acquisition of body weights, and electronic devices for monitoring the state of reproduction, health and well being of dairy cattle under on-farm production conditions.

V. MAIN ACHIEVEMENTS AND EVALUATION

The main focus of the project was on the development of knowledge-based dairy herd management subsystems which were data-based and which could utilize automated data acquisition and analysis techniques. We developed PC-based subsystems for improved herd management in the following areas:

Feeding

Weighing

Automated record systems

Reproduction

Natural language interface-artificial intelligence

Machine learning-artificial intelligence

Feeding: The highest priority subsystem was for the development of a knowledge-based model for individual animal performance, as affected by nutritional allocation, with data supplied from an electronic individual-animal database and from electronic sensors which could identify animals and monitor their physiological parameters. Our trials showed that in order for performance to be optimized (achievement and maintenance of high daily yield while maintaining high

partitioning of nutrients into milk yield and low partitioning of nutrients into body weight gain), the model must include individual animal parameters for parity number, stage of lactation, body weight adjusted to a standard body condition (degree of fleshing), and a prediction of the likelihood that an individual cow would maintain or change the partitioning of ingested nutrients into milk yield or body weight change as lactation progressed. The trials conducted showed that: 1) Simply using milk yield per day or stage of lactation was an inadequate method to decide when to move cows from one nutritional regime to another; 2) First lactation cows need have different criteria applied for matching individual animals to a particular nutritional regime than do older cows; 3) a cow's potential for continuing to partition a high proportion of nutrients into milk and a low proportion into body weight gain as lactation progresses (lactation potential) may be predicted by her performance in the first 3 to 7 weeks of lactation; 4) the lactation potential estimate may be improved by expressing early lactation yield as a % of body weight; 5) additional accuracy in the lactation potential estimate could be achieved by considering minimum body condition scores in early lactation.

A "Nutritional Stress Index" model is proposed. It would evaluate quantitatively the appropriateness of an individual cow's nutritional status and to serve as a decision aid to optimize her performance by recommending changes in her current nutritional status at the appropriate time in

lactation to achieve controlled body weight changes and body condition while maintaining the highest daily milk yield that can be supported within the cow's physiological control mechanism to partition the absorbed nutrients into either milk yield or body weight gain.

The Nutritional Stress Index depends primarily on the cow's milk yield (standardized to 3.5% fat) per unit body weight in early lactation, and is affected more and more by her body condition (degree of fleshing) as lactation progresses. First parity cows have different weights than older cows at the same stage of lactation, Fig. 2, since first parity cows typically have a flatter (more persistent) lactation curve than do older cows. The weights shown in Figure 2 represent only draft values for diagrammatic purposes. Substantial refinement with additional trial is needed to fine tune the weights to various nutritional conditions and various genetic potentials.

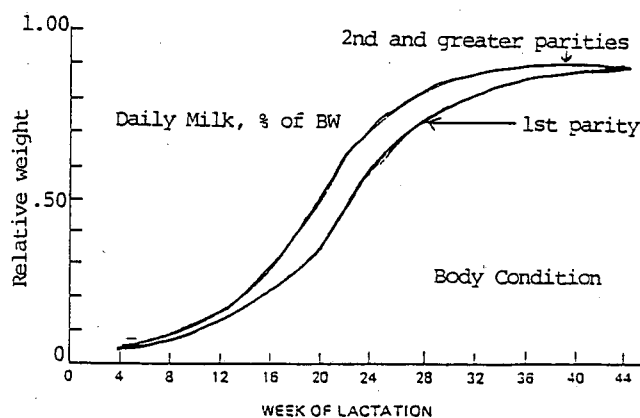


Fig. 2. Example of relative weights for daily milk and body condition scores for use in computation of Nutritional Stress Index.

The nutritional stress index computation, Fig. 3, is designed to rank the cows according to their expected deviation from the herd mean for milk yield per unit body weight and for body condition score, considering parity number and stage of lactation. The NSI value will differentiate between individual cows being underfed and those being overfed, and will serve as a knowledge-based decision aid for improving the matching of individual animals with a designated TMR or in modifying the current feeding program for cows being fed individually as with a computer feeder. Additional trials are needed to test the NSI under on-farm conditions, especially to test seasonal effects.

$$NSI = b_1 \frac{CP - \overline{CP}}{SD_{CP}} + b_2 \frac{BC - \overline{BC}}{SD_{BC}}$$

where:

NSI = Nutritional stress index for an individual cow

b_1 = weight for cow potential

b_2 = weight for body condition ($b_2 = 1.0 - b_1$)

$$CP = \text{Cow potential} = \frac{\text{daily milk, energy corrected to 3.5\% fat}}{\text{Body weight, corrected to body condition score of 2.0}} \times 100$$

\overline{CP} = Mean cow potential of other cows

BC = Body condition score

\overline{BC} = Mean body condition score of other cows

SD_{CP} = Standard deviation of cow potentials

SD_{BC} = Standard deviation of body condition scores

Fig. 3. Formula for computation of Nutritional Stress Index

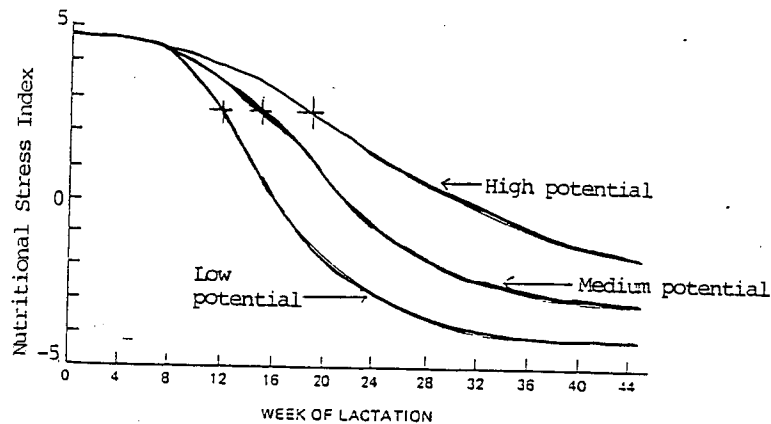


Fig. 4. Example of effect of high, medium and low lactation potential for individual cows on the stage of lactation when a specific nutritional stress index value would activate a recommendation to either move the cow to a lower nutrient density feed or administer bovine somatotropin. Example assumes second and later parity, mature cow size, and a high energy ration as common conditions for each potential group.

Weighing: A model was developed and tested using body weights which were automatically acquired at each milking. The model assumed that an individual cow's weight and weight change had characteristics that were affected by parity number and calving season. Typical behavior of the body weight curve at various stages of lactation was predicted based on fat corrected milk yield, time of conception, time from calving, initial body weight after calving and seasonal weeks remaining.

The model developed would successfully predict an individual cow's weight within 1 to 2% in most cases and within 5% in almost all cases. Body weight prediction was more accurate for cows calving in winter than those calving in summer. The accuracy of the prediction was somewhat reduced by an inconsistency in the week minimal weight was recorded.

Thus, the application of an automated weighing subsystem using a knowledge-based approach was developed and shown to be

a beneficial electronic decision aid for improved management of the dairy herd. Additional studies need to be conducted to integrate the weighing subsystem into a comprehensive herd management program.

Automated record systems: A number of advancements, some technological and some knowledge-based, were achieved toward having a PC-based on-farm record system which utilized automated data acquisition followed by a knowledge-based analysis of daily events. These included:

Integration of automatically acquired milk weights into the herd management database.

Automatic acquisition of body weights.

Automatic acquisition of animal activity data.

Graphic presentation of milk yield and milk yield and milk component values by week of lactation.

Revision of individual cow ration balancer to reflect new NRC values.

Incorporation of genetic and linear trait values into electronic database.

Utilization of multi-tasking for automated data acquisition.

The advances followed a four-stage development: 1) acquisition and/or fabrication of hardware components; 2) development of software to automate the capture of data; 3) integration of summaries of the data into the herd database; and 4) modification of the herd database to embed knowledge. Some advances were only in one or two stages; others, such as

automating milk weights, were revised from hardware through analysis and reports. Thus a number of advancements, mostly evolutionary, were achieved to automated record systems.

Artificial intelligence: Major advancements in the application of artificial intelligence to PCs were made during the period of this project. We selected two areas, natural language interface and machine learning, as areas likely to be of substantial benefit to electronic dairy herd records.

Using GCLISP, the most-widespread version of LISP used on PCs, we developed the capability to query a dairy herd database in conversational english on a PC, to have the computer understand the question or query, and to find the answer requested plus other knowledge-based information about the query from the database. This achievement resulted in receipt of the American Dairy Science Association award for the outstanding graduate student research presentation of the year; the work also was featured by Gold Hill Computers, Cambridge, MA, in their quarterly publication, The Gold Hill Standard (Fall, 1988).

We also developed the capability to utilize a PC version of an artificial intelligence approach for determining rules for expert system programs. We converted a research version of a mainframe machine learning program (PLS) to analyze the thought process of an expert, then create rules suitable for an expert system.

The natural language interface allows the user to query the database directly for whatever information is desired

instead of being constrained by the format of preprogrammed reports, as in a database management system. The use of programmed learning facilities the development of expert system rules, and provided an unbiased interpretation of the thought process of the "expert".

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