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Knowledge-Based Information Systems for Dairy Herd Management

S.L. Spahr, L.L. Christianson, N.L. Buck, E. Maltz,
U. Peiper, O. Kroll, I. Amir

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BARD
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DAIRY HERD MANAGEMENT

Investigators' Names
(Principal listed first)

S. L. Spahr

L. L. Christianson

N. L. Buck

E. Maltz

U. Peiper

O. Kroll

I. Amir

Investigators' Institutions

University of Illinois

University of Illinois

University of Illinois

ARO The Volcani Center

ARO The Volcani Center

Hahaklait Veterinary Service

Israel Institute of Technology

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Signatures:

Principal Investigator

S L Spahr

Institute Authorized Official

J J Kameron

J J Kameron, Director
Grant & Contract Administration

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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

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

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

E. Maltz
ARO The Volcani Center
Bet Dagan 50250, Israel

S. L. Spahr
University of Illinois
Urbana 61801

R. D. Shanks
University of Illinois
Urbana, 61801

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

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 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

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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