Intake Based Milk Allocation Improves Health and Growth of Calves

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Abstract: *The problem:* The same feeding plan can be applied to all animals with individual differences rarely considered. On the contrary, individual intake-based feeding regime claims that if a calf has missed meals and therefore could not consume its daily milk allocation, it should be compensated.

Methods: The objective of this study was (1) to compare 'age-based milk allocation' with calf individual 'intake-based milk allocation' (milk amount depending on the actual consumption). The study achieved its objective through the following phases (2) to design a real-time algorithm, (3) to embed the algorithm in the feeder's control software, (4) unique mechanical design capable of the computer-controlled feeder.

One hundred and fifty male calves were fed. If a calf has not consumed its accumulated milk allocation from birth to date it receives an additional 1.5 liters (L) per day until it has consumed the entire planned amount.

Results: Daily weight gain was 691 g/day in the age-based group vs. 794 g/day (SE = 36) in the intake-bared group. The average body weights (BW) at weaning were 76 kg vs. 82 kg. The indicator of health 57% vs. 66%.

Keywords: Precision livestock farming, calves, computer controlled milk feeder, individual milk allocation, feeding behavior.

INTRODUCTION

In Europe, group housing with computer-controlled milk feeders are used increasingly for calves, but knowledge about how to best manage these systems is still all too limited. The same feeding plan is applied to all animals, with individual differences in feeding behavior rarely considered [1]. Already proposed Concentrate-Dependent Weaning but found that "Health status, weight gain, and rumen development did not differ in calves weaned by the intake-based method and the conventional method". Cross-sucking phenomena in group-housed dairy calves fed by computer-controlled milk feeders have being investigated by [2-4] studied the feeding method vs feeding behavior, [5] measured the influence of grouping density i.e., the number of calves per drinking stall on animal drinking behavior; [6] suggested mechanical improvements such as a closed stall, like the one used in our present system, except that in our study the gate is pneumatically operated [7]. Identified Diseases By Use Of Data From Automatic Milk Feeders. Other studies considered fitted housing systems [8], feed diets [9] and several additional aspects of computer-controlled milk feeders [10-12]. With the exceptional study reported by [1], and although computer-controlled milk feeding systems have been commercially available for many years, we did not find any published intake-based milk allocation of the individual calf.

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An indication of lung diseases maybe derived from the kosher status of a calf. Immediately after slaughtered the kosher inspector blows into the lung to inflate it (like a balloon). If the lung is without any hole, injury and the lung's parts do not adhere to each other, then the calf is certified as "kosher meat". In this way, lung problems is measured in every commercial slaughter house in Israel. For example, if a calf had mild pneumonia when it was 2 weeks old, this might not be detected by the farmer or by the local vet, but since the lung had already been injured, the calf might not be classified as kosher when it is slaughtered one year later. The price to the farmer of a kosher meat is over double.

The assumptions of the present study were:

1. Lung diseases along a calf lifetime are reflected in the calf kosher status
2. The kosher status of a calf at late age is influenced also by lung diseases at early age and therefore influenced also by milk allocation at drinking period
3. A calf has individual nutritional requirements that depend upon its weight, age, heath status, and history.
4. A calf weight, age, and heath status influence its voluntarily feed intake

5. A computer-controlled feeder can automatically response, in real-time, to a change in calf individual voluntarily feed intake. Accordingly, regime 1 and 2 below were designed for *age* vs. *voluntarily intake* based feeding regimes.
6. The light weight calves are not yet ready to consume a lot at early age, they need more time while the heavy calves are ready earlier. Accordingly, regime 3 and 4 below were designed for initially lighter or heavier calves, respectively.

The hypotheses of the present study were:

1. Milk allocation at early age may influence calf's kosher status at late stage,
2. Calf body weight at early age may influence a calf's kosher status at late stage.

Therefore, t**he objective** of this study was (1) to compare 'age-based milk allocation' with calf individual 'intake-based milk allocation' (milk amount depending on the individual actual consumption). The study achieved its objective through the following phases (2) to analyze whether feed intake automatically recorded by a feeding computer is suitable input for controlling individual diets. (3) to design a real-time algorithm and to embed the algorithm in the feeder's control software. (4) to put into practice the above algorithm, it required a new mechanical design of the computer-controlled feeder.

MATERIALS AND METHODS

One hundred and fifty male calves were fed with milk by a specially designed computer-controlled feeder. The data on each calf's rewarded and unrewarded visits were collected automatically by the feeder from day 7 until weaning. A real-time algorithm was design and embedded in the feeder's software; it calculates the individual milk allocation for a calf approaching the milk feeder. It allocates milk according to the calf's previous consumption. If a calf has not consumed its accumulated milk allocation from birth to date it receives an additional 1.5 L per day until it has consumed the entire planned amount.

Animals and Housing

In order to avoid seasonal effects, all treatments were performed simultaneously in parallel. The experiment began at the winter, February 2002, and lasted one year, until the calves were slaughtered at the age of 1 year. On arrival at the research farm, the medium weight calves were allocated to pairs, matched in age and weight. One member of each pair was randomly allocated to the treatment l (group 1 received feeding regime 1, so called "regime 1") and the other member of the pair was allocated to regime 2. Regime 1 and 2 were balanced in terms of weight and age. The pairs and groups were virtual, with their members designated only in the feeder's computer, so that the farm workers could not know which calf belonged to which group. Thus, the experimental design included 'double-blind randomization' which means that – (a) calves assigned randomly to treatments, regime 1 or 2 (b) all the calves received the same handling from the farm workers and were subjected to the same climatic conditions, management practices, etc. If a calve was light weight he was assigned feeding regime 3, and if the calve was heavy weight he was assign feeding regime 4.

The research was conducted at the ARO northern research station, Newe Ya'ar which is located about 10 km west to Nazareth, The Jezreel Valley, the Lower Galilee of Israel. All the calves were kept in the same cowshed, exposed to the same environmental conditions and treated in the same way. In addition to the milk replacement the calves were offered concentrates and hay ad libitum from d 12 and throughout the experimental period. The experimental cowshed had two straw-bedded pens (6 × 25 m each) each with room for more than 30 calves. However, the number of calves per pen never exceeded 25 at any given time. The calves were Holstein–Friesians, born on commercial neighbouring farms. Newe Ya'ar buys male calves from about 30 small commercial dairy farms. The calves were not selected, all the calves that were born at a collection day – arrived. No calf was rejected from the experiment. If a calf died, his member-pair was excluded from the database as well. Four calves did not finish the experiment. Two died and two excluded. One died in regime 1 and one died in regime 2 Four out of 150 is the regular mortality rate at the experimental farm (ARO northern research station).

In their origin farms, after birth, all calves were moved to individual straw-bedded indoor pens and fed milk from open buckets. They were fed colostrum, gradually replaced with whole milk. All the calves were 1 week old when they were transferred to our research institute in a light vehicle with closed sides, and they were then equally familiarized with their automatic drinking machine. In Newe Ya'ar, the calves were assigned to one of the treatments until they were gradually weaned off milk between days 57 and 65. The powdered milk concentration was 125 g/liter in all groups. After the wining period the calves were mixed in one single group, i.e., they offered the same total mixed ration (TMR), the same housing, climate and handling conditions. any difference among treatments, were treated identically, until they were slaughtered at the age of 1 year.

Feeding Methods

A calf belong to feeding regime 1 received milk according to the conventional age-dependent feeding - gradual increase up to 6 L by day 10, and gradual decrease down to a zero milk quota by the age of 57 days (Fig **1**, Table **1**, regime 1 wining age is 57 days). The other three groups (feeding regimes 2-4 in Fig. **1**) received intake-based milk allocation i.e. according to the calves' individual, voluntarily feed-intake (regime 2). The intake-based means that if a calf hasn't consumed its accumulated allocations of milk, the system compensates it with 1.5 additional liter/day in the following days. For example, if a calf was slightly ill (as in a mild case of diarrhoea or pneumonia) and drank 3 l less milk than its accumulated allocation, it will be allowed 3 L more which it is probably consumed as soon as the calf feels better. The intake-based algorithm will allow one and half liter per day in addition to the calf's regular daily allocation until the animal has actually consumed its allowed accumulated quota (from birth to date).

The 24-h period was divided into two feeding sessions, started at 0100 and 1500 h daily. Within its feeding session,

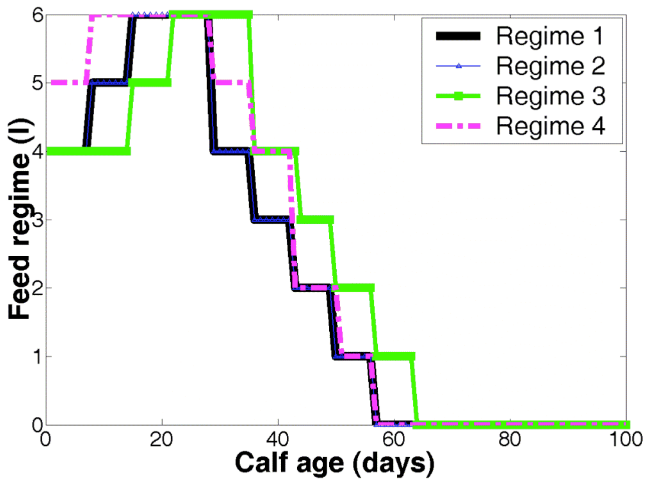

Fig. (1). Materials and methods - feeding regimes. Regimes 1 and 2 were identical (the wider line over laps the narrow line); regimes 3 and 4 were for initially lighter or heavier calves, respectively. Regime 1 is age-based while regimes 2-4 were intake-based milk allocation. Regime 1 differ from regime 2 in one parameter – time or intake based allocation. Regime 3 and 4 fit the maximum milk allocation of the intake-based method to the calf's individual physiology; the light weight calves are not yet ready to consume a lot at early age, they need more time while the heavy calves are ready earlier.

Table 1. Materials and Methods; Design of Experiment[1] - Timing of Allocating the Maximum Milk of 6 Liter Per Calf per Day According to the Initial Body Weight

Treatment Diet	Number of Calves (N)	Milk Allocation Method	Days to Reach Maximum Milk Allocation	Initial[2] Body Weight
Regime 1	38	Age based	15 days	Medium weight (40<BW<44kg)[a]
Regime 2	38	Intake based	15 days	Medium weight (40<BW<44kg)[a]
Regime 3	37	Intake based	22 days	Light weight (BW<40kg)[b]
Regime 4	37	Intake based	8 days	Heavy calves (44kg<BW)[c]

[1]Intake based allocation (regime 2, 3, and 4) took into account the calf individual physiology by means of (a) calf initial body weight (b) the amount of voluntarily milk intake. Statistical comparison can be made between regime 1 and regime 2 (both are medium weight, but one is age based and the second is intake based), or between regime 2,3,4 (intake based, varying weights). Otherwise, more then one parameter is being altered.

[2]measured at the age of exactly one week. The initial weights were: 42.2(SE=0.13), 41.9(0.15), 37.7(0.15), 46.5(0.18) kg. No significant difference between regime 1 & 2 (One Way ANOVA, Bonferroni, Sig=1.000) was found. The mean difference between regime 2&3 was significant at the 0.05 level (Bonferroni, Sig.=0.000). The mean difference between regime 2&4 was significant at the 0.05 level (Bonferroni, Sig.=0.000). Significance was tested by using SPSS, One Way ANOVA, Bonferroni post-hoc multiple comparison where the initial body weight is the dependent variable and the regime number is the factor.

each individual calf was offered one-half of its daily milk allowance; it could take its first milk portion when a new feeding session started but at least 120 min had to pass before it could take its second portion. If a calf consumed 0.2 L of a portion or less, the intake was not recorded, and the calf was allowed to receive the whole portion later. If a calf consumed more than 0.2 L but less than the whole portion the remainder could be consumed later in the session. Had the calf not consumed its ration within its feeding period, a maximum of 1.5 L would be transferred to its next feeding period.

Physiology Considerations

The physiology considerations include that a lightweight calf needs a sort of "phase delay" since until its rumen is further developed. Thus, feeding regime 3 included a "phase delay", reaching its peak later. Regime 4 used intake-based adapted for heavier calves that were able to accept the peak allocation earlier (assuming their rumens were already developed when arrived to the farm). Therefore, the experiment involved three timings of intake-based allocations: (Regime 2) A calf reach its pick allocation, 6 l per day after 15 days. Regime 2 suppose to fit an average calf in our herd population. Regime 3 has "phase delay", it reach the 6 l/day allocation after 22 days. Regime 4 aiming for faster rumen developed calves, reach its 6 l/day allocation already after 8 days.

Mechanical Design and Calves Traffic Control

In order to allow full control and flexibility required in this research, the mechanical design, the control system and the software were all specially developed in-house. The basic

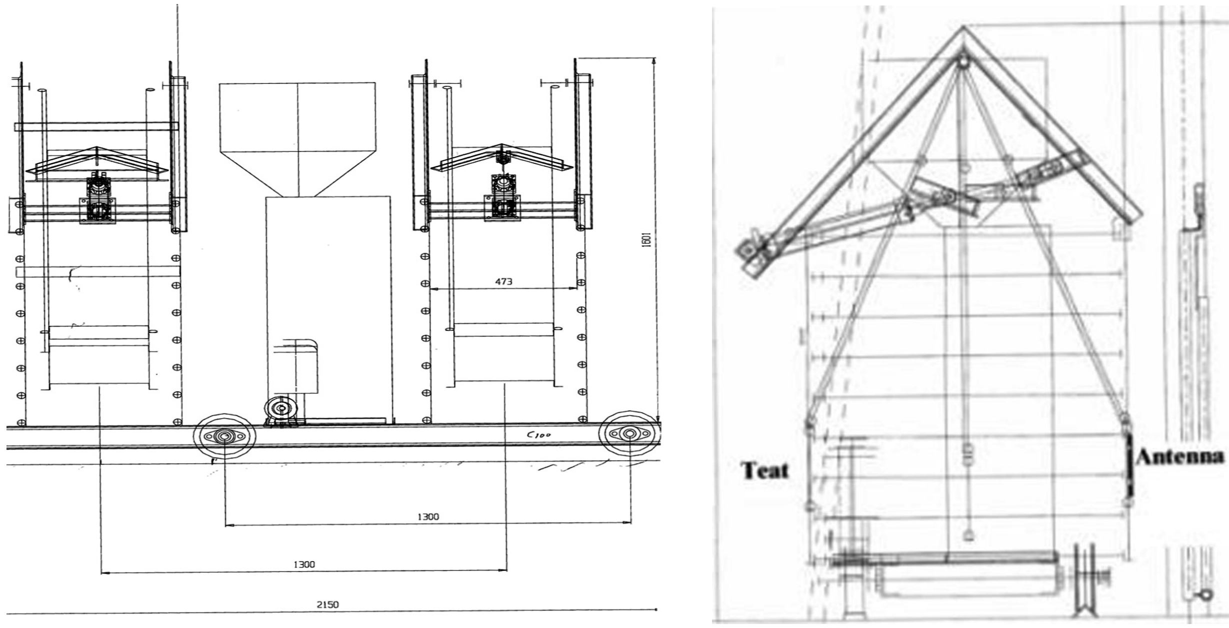

Fig. (2). Materials and methods. Mechanical design; a front view (left-side drawing) and a side view of a milk-feeder stall (right-side drawing) of the powder milk feeder and its two stalls. Each pen had one stall with one teat, connected to the computer-controlled unit that was located between the two pens. The entire system was located on four wheels and rails, it could moved automatically between the pens. During the experiment up to 25 calves was kept in each pen, but the system is capable to hold up to 50 calves per pen. When a calf feels hungry it learned to locate its neck tag near the RFID antenna. If the individual calf has granted a drinking permission from the computer, the gate moves towards the milking teat, pulled by the pneumatic cylinder. Before milk allocation and during dinking, the RFID antenna moved with the gate continuously verifies that the correct calf is still there, not replaced by another calf. Later after drinking, the pneumatic cylinder gently pushes the calf outside the drinking stall. This mechanical design of the drinking stall isolates the drinking calf from his yard mates and prevents a one calf blocking the drinking stall after he has completed his milk quota.

Forster© milk powder mixer was purchased from Shimon Ben Cnaan Ltd.. The mechanical design (Fig. **2**) allows the system to move between pens, in our experiment the system was stationary. Each pen had one milk-feeder stall with one teat, connected to the computer-controlled unit that was located between the two pens (Fig. **2**). A feeding stall floor is placed on an electronic weighing scale, connected to the feeder's computer. When a calf enters a stall and its 4 legs had stood on the stall's floor (guided by a pneumatic gate) and his ID number was recorded by the feeder's RFID (radio frequency identification) antenna and reader, its weight with the ID number are sent to the feeder computer. The accuracy of this 'built in' scale is 0.1 kg, calibrated weekly during the experiment period. Each stall had a pneumatically operated gate that protected the sucking calf from displacement and gently ejected it when it had finished drinking. The calves were assigned to treatments in groups of around 20 calves per feeder stall. The RFID antenna is built-in the pneumatic gate (Fig. **2**), when a calf feels hungry it learned to locate its neck tag near the RFID antenna. If the individual calf has a drinking permission, the gate moves towards the milking teat that is located in the drinking stall. Before milk allocation, the identity of the calf was verified again to avoid feed allocations to "pushers" that might push the permitted calf away, to get its milk. Later, after drinking, the pneumatic cylinder gently push the calf outside the drinking stall. This mechanical design was conducted by the principle author in 1996 aiming to allow many calves to be served by one stall in an experiment. The pneumatic cylinder and the drinking stall prevent one single calf to block the entire group. Since then, this design is working successfully in almost all the Israeli automatic milk feeders, it allows up to 30 calves per milking stall and up to 3 milking stalls connected to one single milk replacer powder mixer.

Software and Control Logic

The intake-based algorithm was written in-house, using Matlab software (MathWorks Inc, Natick, MA. USA). The PLC (programmer logic controller, produced by Gavish Ltd, Kibbutz Gibat Brener, Israel)'s ladder diagram stored the drinking data on the computer hard disk whenever a calf has just finished drinking. The Matlab read the date and stored drinking instruction in the PLC file ready for the next time that this specific calf approaching the drinking machine again. The implementation of the intake-based algorithm is presented in Fig. (**3**). It can be seen that the data flow is rater simple which is an advantage in such heavy loaded system.

Data Collection and Statistical Analyses

Data were collected via the computer-controlled milk feeder. The data collected from the computer-controlled milk feeder unit were logged into a separate computer; these data included the time of the beginning and end of each rewarded visit, i.e., one in which the calf obtained milk, including time spent ingesting milk (defined by the presence of milk in the mixer bowl), and the milk intake. Data obtained on days when the feeder was out of order were deleted from the data set. Body weight was measured during the weaning period

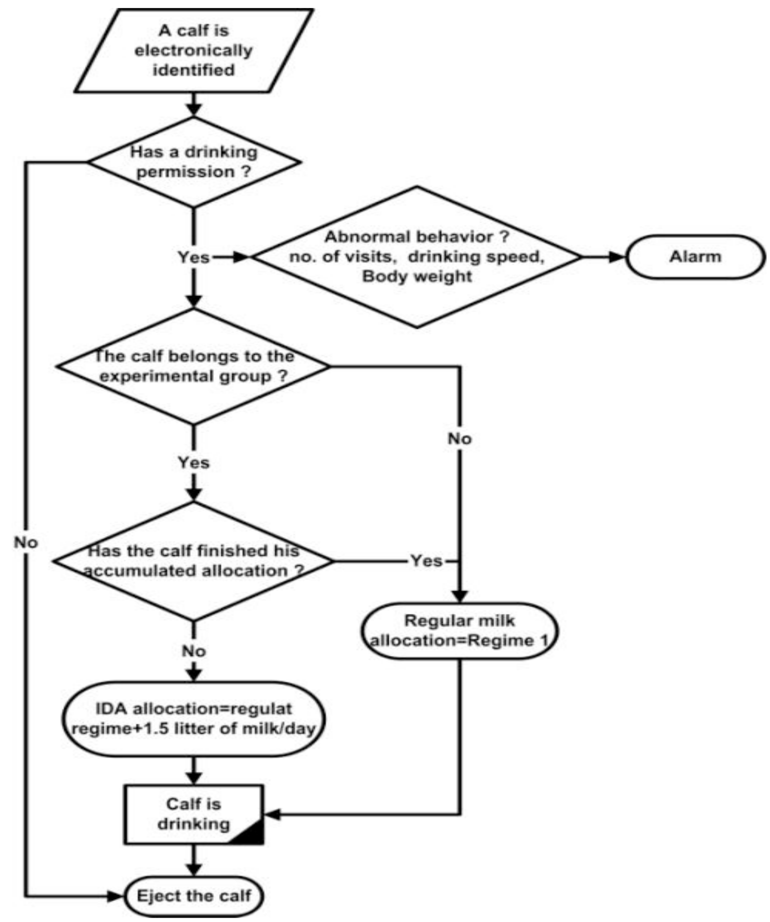

Fig. (3). Materials and methods. Control system, software implementation flowchart - from the moment a calf has identified at the drinking machine entrance till he received milk or ejected from the machine

and when the calves were 1 year old. One-way ANOVA was performed by using SPSS (SPSS Inc. Chicago, Illinois 60606). The SPSS ANOVA algorithms is a linear model with covariates, can be written in matrix notation as $Y=X\beta+ZC+e$ (1) Where, Y N×1 vector of values of the dependent variable. X Design matrix (N×p) of rank $q<p$. β Vector of parameters (p×1) . Z Matrix of covariates (N×CN) . C Vector of covariate coefficients. (CN×1) . e Vector of error terms (N×1) . N Number of cases. F Number of factors. CN Number of covariates. k_i Number of levels of factor i . Y_k Value of the dependent variable for case k. Z_{jk} Value of the jth covariate for case k. wk Weight for case k. W Sum of weights of all cases.

SE Stands for the Standard Errors

Bonferroni post-hoc multiple comparison was performed (equal variances assumed). A mean difference is significant at the 0.05 level. The measures of performance (such as kosher status, weight gain, net meat, Final BW, BW at weaning, age at weaning) were the dependent variable and the feeding regime number was the factor

RESULTS

Measures of Performance on Group Level

There was a significant effect of the treatment (age or intake based, regime 1 vs. regime 2) on the weight gain during the weaning period (g/day), on Body weight at weaning (kg), on Age at weaning (60.4 to 64.2 days) and on Kosher rate (Table **2**).

The mean difference of the number of days that the calves consumed additional milk in the three intake-based methods was significant as well as the kosher status (Table **3**)."

The findings above suggest that early-life BW and feeding regimes influence mild lungs illness. The mild illness might not be noticed during the weaning period but later on become visible via the kosher status when the calf is slaughtered. While the meat production gap (net meat and final BW) has gradually vanished during the calves entire life, an early-life damage to the lungs has not completely vanished.

Behavioral Observation and Analyzing the Calf Individuals

The average numbers of visits (Fig. **4**, rewarded and unrewarded) per calf per day did not differ significantly between regime 1 and regime 2: 8.4 (SE = 0.043) and 8.4 (SE = 0.039), respectively. However, heavy calves visited the feeder more often than medium- or light-weight calves: 9.78 (SE=0.21), 8.50 (SE = 0.080), and 7.76 (SE=0.082) visits/day. In Fig. (**4**) it can be seen that heavier calves (regime 4) visited the drinking machine more often, probably because they were better able to force their way to it, and no significant effects of intake/age-based treatments were

Table 2. Results. Comparing Age-Based vs. Intake-Based Feeding Regimes

Initial body Weight[2] / Measure of Performance	Treatments – Feeding Regimes[1] 1-Medium (Mean(SE))	2-Medium	ANOVA F(1,74),	p-Value
Weight gain during the weaning period (g/day)	691 (36)	794 (73)	7.32,	p =.008
BW[3] at weaning (kg)	76(2.36)	82(1.74)	14.7	p<<0.05
Age at weaning (days)	60.4(1.5)	64.2(1.09)	9.40	0.003
Net meat (kg)[4]	264 (5.5)	273(4.4)	0.195	0.660
Final BW (kg)[5]	504(11.8)	513(7.66)	1.07	0.304
Kosher status[6] (%)	57(0.66)	66(0.65)	8.40	0.04

[1]Feeding regime 1 is age based, feeding regime 2 is intake based
[2]Initial body weight was monitored at the age of exactly one week old, the herd population was divided into three weights; medium weight (40<BW<44, feeding regime 1&2), light weight (BW<40 kg, feeding regime 3), heavy calves (44<BW, feeding regime 4).
[3]BW=body weight
[4]Net meat (MISKAL TIBCHA). After deduction the uneaten parts (hooves, skin, stomach, large bones, etc).
[5]Final BW is measured in the farm before transporting to the slaughterhouse
[6]Kosher status suggests whether the calves had lung problems at an early age.
[4,5,6]Net meat production, live BW and Kosher status were measured at the slaughterhouse, the calves were 1 year old.
The mean difference was significant at the 0.05 level. Significance was tested by using SPSS, One Way ANOVA, where the measure of performance (such as weight gain, BW, age, kosher status) was the dependent variable and the regime number was the factor.
SE stands for the standard errors.

Table 3. Results. Intake Based Feeding Regime while Varying Initial Body Weight

Initial Body Weight[2] / Measure of Performance	Treatments – Feeding Regimes[1] 2-Medium (Mean(SE))	3-Light	4-Heavy	ANOVA F(2,109)	p-Value
Intake-based days[3]	11.95(0.35)[a]	9.26(0.29)[b]	10.26(0.26)[c]	30.4	p<<0.05
Weight gain during the weaning period (g/day)[4]	794 (73)	723(54)	821(51)	2.271	0.108
Net meat (kg)[5]	273(4.4)	261(4.17)	270(6.4)	2.68	0.073
Final body weight (kg)[6]	513(7.66)	493(6.75)	507(12.5)	0.744	0.478
Kosher rate[7] (%)	66(0.65)[a]	56(0.64)[b]	75(0.69)[c]	20.135	p<<0.05

[1]Regimes 2,3,4 were intake based and initial body weight dependent
[2]Initial body weight. At the age of exactly one week old, the herd population was divided into three weights; medium weight (40<BW<44, feeding regime 1&2), light weight (BW<40 kg, feeding regime 3), heavy calves (44<BW, feeding regime 4).
[3]'Intake-based days' is the number of days on which a calf actually used additional milk (1.5 additional liter/day). The mean differences were significant (P_{23}=0.000; P_{24}=0.000; P_{34}=0.002);
[4]Weight gain. A multiple comparison results with no significant comparison P_{23}=0.676; P_{24}=1.000; P_{34}=0.108);
[5]Net meat (MISKAL TIBCHA), after deduction the uneaten parts (hooves, skin, stomach, large bones, etc). A multiple comparison results with no significant comparison P_{23}=0.096; P_{24}=1.000; P_{34}=0.233);
[6]Final body weight was measured in the farm before transporting to the slaughterhouse. A multiple comparison results with no significant difference (P_{23}=0.899, P_{24}=0.899, P_{34}=1.000)
[7]Kosher status suggests whether a calf had a lung related illness at an early age. The mean differences between the feeding regimes were significant (P_{23}=0.004, P_{24}=0.004, P_{34}=0.000)
SE Stands for the Standard Errors.
[a,b,c] Significance was tested by using SPSS, One Way ANOVA. Multiple comparison was made by Bonferroni post-hoc where the measure of performance (such as kosher status) was the dependent variable and the regime number is the factor. The mean difference was significant at the 0.05 level.
[5,6,7] Net meat production, final BW and Kosher status were measured at the slaughterhouse, the calves were 1 year old.

found. Calves at the left-hand tail of the curves (Fig. **4**) did not visit the feeder often enough, whereas those at the right-hand corner might have visited too often, so blocking the feeding stall. It can be seen (Fig. **4**) that 40% of the light or medium size calves visited a drinking stall less than 7 times per day, i.e. 60% of the calves visited a drinking more than 7 times per day. However, 40% of the heavier calves visited a drinking stall less than 8 times per day i.e. 60% of the calves visited a drinking more than 8 times per day. Sixty percents (60%) of the heavier calves visited a drinking stall less than 10 times per day i.e. 40% of the calves visited a drinking more than 10 times per day. Ninety-five percents (95%) of the calves visited less than 15 times per day, i.e. only 5% of the calves visited a milking stall more then 15 times per day.

Actual milk intakes (fill area) are compared with the planned (stairs line) regime in Fig. (**5**). It can be seen (Fig. **5**) that there was wide variation among individual calves: sometimes a calf did not consume its quota and needed extra milk in real time; in other cases an extra milk allocation was not necessary (Fig. **5**, right). The wide variation among individuals (Fig. **5**) suggests that individual treatment is needed,

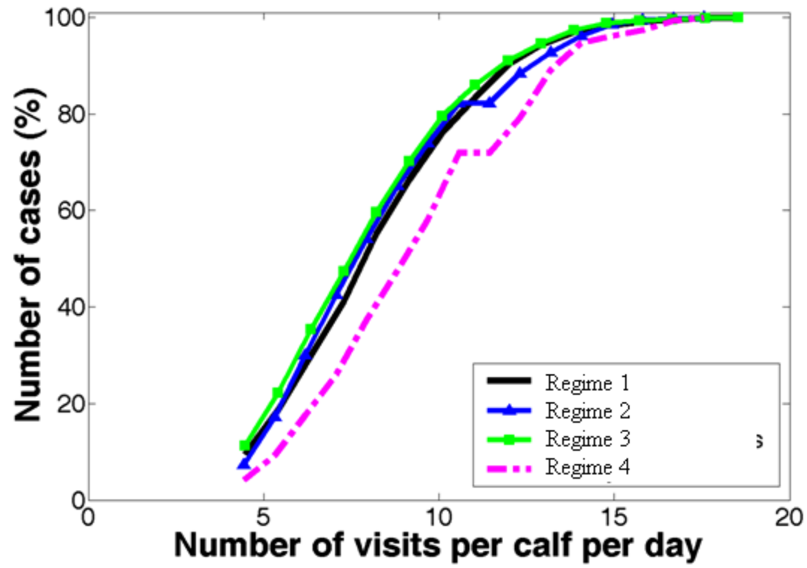

Fig. (4). Results. Number of voluntary daily visits per calf to feeder.

but that it should be applied automatically every day, in accordance with the calf's current status and previous performance, without human involvement in the real-time decision process.

General view of the mechanical system and the calves is presented in Figs. (**6**, **7**).

DISCUSSION

Comparison with Previously Published Papers

Roth [1] applied Concentrate-Dependent Weaning but found that "Health status, and weight gain did not differ in calves weaned by the intake-based method and the conventional method". In our study the health status (as reflected by the Kosher status) and the weight gain were different. The reason is that although both methods are based on voluntarily feed intake, they differ from each other in few aspects (a) [1] did not apply different feeding regime per each initial BW. (b) The mechanical system is different, in our case a calf that is not allowed to get milk is rejected from the teat area by the pneumatic cylinder so he can not block the access of the other calves, (3) Our weaning timing is based on the completeness of a predefined amount, while [1] reported that intake of 700 g of concentrate daily triggered milk reduction and 2,000 g / d defined the end of milk provision.

Physiology vs. Statistical Consideration

The physiology assumption behind this trial was that a calf has individual nutritional requirements that depend upon its weight, age, heath status, and history. The commonly used regime is based on the calf's age and does not take into account its pattern of body weight increase, decrease and fluctuation, or of reduction in its milk intake because of heath problems, being pushed away by stronger calves in the herd's hierarchy or for any other reasons. A regime that is based only on one dimension - age - prevents heavier calves with more advanced stomach development from fulfilling

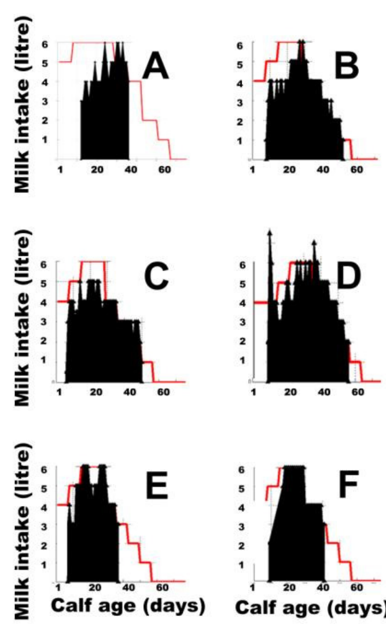

Fig. (5). Results. Actual milk intakes (fill area) are compared with the planned (stairs line) feeding regime. (**A**): a calf that has not reached its milk allocation and received compensation.

(**B**): a calf that has not reached its milk allocation but was not compensated (a calf from the control group)

(**C**): a calf that has not reached its milk allocation and received compensation.

(**D**): a calf that mistakenly received too much milk on day 10, became ill and recovered.

(**E**): a calf that has not reached its milk allocation but was not compensated (a calf from the control group)

(**F**): a calf that reached its milk allocation only after 20 days, when it already decreased.

Fig. (6). The newly developed drinking machine from the calf's yard point of view.

Fig. (7). The individual calves.

their genetic growth potential. Such a regime also depresses the growth of lighter calves, because their ability to consume milk develops a few days later than average, by which time the milk allocation has been gradually reduced. Furthermore, in accordance with the minimum requirements of energy and minerals, 25 kg (125 g/L) of milk powder should be provided by the age of 50 days, but under the age-based regime less then the 25 kg minimum will usually be provided, and in some cases the amount provided might not be enough to built their rumen capabilities and to develop their immune system properly. Therefore in the light of the present study, we propose a sophisticated feeding regime which: (1) is individual, based on the dynamic response of each calf, with additional milk provided on an individual basis as needed; (2) provides more milk at an early age to heavier calves; and (3) provides more milk to lighter calves at a later age, to allow later weaning. The intake-based feeding regimes incorporate two aspects (1) initial BW, (2) time to reach maximum milk allocation. Therefore, statistical comparison between regimes 2,3,4 can not isolate which aspect has the significant difference, either the initial BW or the time to reach maximum allocation or both. However, statistical comparison between regime 1 and 2 has statistical meaning, since both are differ by only one single parameter – age or intake based allocation. The introducing of the intake-based heavy and light calves, although can not be statistically compared to the medium weight age-based calves, has it importance in reporting practical usage of the proposed methodology in commercial situation.

Body Weight (BW) Gain

The average body weight (BWs) at weaning time (76 kg and 82 kg) reflects the daily weight gain (691 g/day, SE = 36 in regime 1 and 794 g/day, SE = 73 in regime 2). The final BWs were more homogeneous in the intake based regime 2 than in the age-based regime 1 (SE = 1.7 vs 2.4 kg, respectively). In some business situations when the entire group is being sold all together, the homoganity of the group is of important, not only the average weight gain. The ages at weaning were 60.4 (SE = 1.5) and 64.2 (SE = 1.09) days in regime 1 and 2, respectively, reflects the milk distribution permitted by the behavior-based feeding algorithm during the last weaning days of those calves that had not consumed their entire share. Heavy calves (BW > 44 kg on entering the system) grew faster than light-weight calves (initial BW < 40 kg): *821 (SE = 51), and 723 g/day (SE=54), respectively. These findings are in agreement with previously published results [13, 14].

Meat Production

Final meat production can be estimated from Table **2**, which shows that after 1 year there was no statistically significant difference among treatments.

Health Measurement

Not enough health problems occurred during the drinking period to enable a statistically valid conclusion that could be attributed to the proposed new feeding methods. Applying the kosher status as an indication to historical lung health assumes that after weaning the calves suffered the same number of lung diseases. This assumption is based on the fact that after weaning all the calves were kept together in one single group, exposed to the same feeding and microclimate conditions. Table **2** presents the kosher results of each group. The preferred regime was number 2 (significant at α=0.05). In addition to the intake-based regime (2), initial heavier calves has the potential to increase kosher rate to up to 75%.

CONCLUSIONS

Daily weight gain was 691 g/day (SE = 36 g/day) in the age-based group vs. 794 g/day (SE = 36) in the intake-bared group. The average body weights (BW) at weaning were 76 kg vs. 82 kg. The kosher status 57% vs. 66%. The kosher status of the heavier calves in the intake-based group was 75% vs 56% in the lighter weight calves.

Individual intake-based feeding achieved higher daily weight gain and improved calf health. More research should be conducted with different types of feeds and other breeds.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance given by the farm staff at the Newe Ya'ar Research Center, ARO,: Mr. Ali

Zoabi, Mr. Mahush Mazarib and Ms. Ala Orlov for their careful treatment of the calves.

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Received: July 12, 2010 Revised: December 20, 2010 Accepted: February 28, 2011