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Future consequences of decreasing marginal production efficiency in the high-yielding dairy cow

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ABSTRACT

The objectives were to examine the gross and marginal production efficiencies in high-yielding dairy cows and the future consequences on dairy industry profitability. Data from 2 experiments were used in across-treatments analysis (n = 82 mid-lactation multiparous Israeli-Holstein dairy cows). Milk yields, body weights (BW), and dry matter intakes (DMI) were recorded daily. In both experiments, cows were fed a diet containing 16.5 to 16.6% crude protein and net energy for lactation (NE_L) at 1.61 Mcal/kg of dry matter (DM). The means of milk yield, BW, DMI, NE_L intake, and energy required for maintenance were calculated individually over the whole study, and used to calculate gross and marginal efficiencies. Data were analyzed in 2 ways: (1) simple correlation between variables; and (2) cows were divided into 3 subgroups, designated low, moderate, and high DMI (LDMI, MDMI, and HDMI), according to actual DMI per day: ≤26 kg (n = 27); >26 through 28.2 kg (n = 28); and >28.2 kg (n = 27). The phenotypic Pearson correlations among variables were analyzed, and the GLM procedure was used to test differences between subgroups. The relationships between milk and fat-corrected milk yields and the corresponding gross efficiencies were positive, whereas BW and gross production efficiency were negatively correlated. The marginal production efficiency from DM and energy consumed decreased with increasing DMI. The difference between BW gain as predicted by the National Research Council model (2001) and the present measurements increased with increasing DMI (r = 0.68). The average calculated energy balances were 1.38, 2.28, and 4.20 Mcal/d (standard error of the mean = 0.64) in the LDMI, MDMI, and HDMI groups, respectively. The marginal efficiency for milk yields from DMI or energy consumed was highest in LDMI, intermediate in MDMI, and lowest in HDMI. The predicted BW gains for the whole study period were 22.9, 37.9, and 75.8 kg for the LDMI, MDMI, and HDMI groups, respectively. The present study demonstrated that marginal production efficiency decreased with increasing feed intake. Because of the close association between production and intake, the principle of diminishing marginal productivity may explain why increasing milk production (and consequently increasing intake) does not always enhance profitability. To maintain high production efficiency in the future, more attention should be given to optimizing rather than maximizing feed intake, a goal that could be achieved by nutritional manipulations that would increase digestibility or by using a diet of denser nutrients that would provide all nutritional requirements from lower intake.
Key words: dairy cow, production efficiency, gross efficiency, marginal efficiency

INTRODUCTION

Feed costs constitute 50 to 60% of the overall costs in dairy production; therefore, increasing feed efficiency has a major effect on dairy industry profitability. Feed efficiency in the dairy industry also has consequences for environmental issues such as greenhouse gas production, carbon footprint, methane emission, nitrogen excretion, and so on (Connor et al., 2012; Reed et al., 2015). Capper et al. (2009) estimated that, because of improvements in the modern dairy cow, the carbon footprint associated with production of 1 kg of milk was 63% less in 2007 than in 1944.

Intensive selection and improvements in nutritional and management techniques have markedly increased milk yields of dairy breeds worldwide and this, in turn, has increased their gross production efficiency. Simultaneously, however, feed intake was increased; Veerkamp (1998) reviewed several studies and found that the genetic correlation between yield and intake ranged from 0.46 to 0.65. The rate of passage of digesta increases as feed intake increases, and decreasing the retention time of digesta in the rumen decreases feed digestibility (Colucci et al., 1982) and, consequently, the energy derived from feed. Gabel et al. (2003) found reductions of 4.1% in energy digestibility and 1.6% in diet NE_L content

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for each increase in multiple of maintenance unit (total ME/ME for maintenance).

Efficiency of conversion of feed into yields (mainly of milk and body mass) comprises maintenance cost and production cost. Although we deal with a biological system, these terms could be treated as economic concepts, with maintenance cost considered as fixed cost and production cost a marginal cost. According to a basic principle in production economics, although increasing one input (production cost) while keeping other inputs (maintenance cost) constant may initially increase output, further increases in the variable input will have increasingly limited effects, and eventually no effect or a negative effect on output. In light of the decreasing digestibility associated with increasing yields and intake, the premise in the present study is that the principle of diminishing production efficiency also applies to the high-yielding cow that consumes a large amount of feed. Therefore, the present objectives were to examine the gross and marginal efficiencies for producing milk traits in high-yielding dairy cows, and to assess future consequences for dairy industry profitability and development.

MATERIALS AND METHODS

Data from 2 experiments were used in an across-treatment analysis to examine the gross and marginal efficiencies of production. Both experiments were conducted at the Volcani Center's experimental dairy farm, in Bet-Dagan, Israel, according to protocols approved by the Volcani Center Animal Care Committee. The first study lasted 98 d and the second study 91 d. The average parity number was 2.9 ± 1.1 and 2.9 ± 0.9 in the first and second study, respectively. The average DIM during the study period were 157.3 ± 72 and 183 ± 45 in the first and second study, respectively.

In each study, 42 multiparous high-yielding Israeli-Holstein dairy cows were housed in a covered loose-housing pen with adjacent outside yards equipped with a real-time electronic individual feeding system. Each feeding station included an individual identification system (I.D. tag; S.A.E. Kibbutz Afikim, Israel) that allowed each cow to enter a specific feeding station and automatically recorded each meal.

In both studies, cows were fed a typical Israeli dairy cow ration that contained, per kilogram of DM, 16.5 to 16.6% CP and 1.61 Mcal of NE_L (Table 1). The NE_L values for feedstuffs in rations were determined according to NRC (2001) model, for cows at 4× maintenance.

Cows were fed once daily at 1000 h with 105% of the expected intake, which was adjusted daily according to the preceding day's intake. Cows were milked 3 times daily; milk yields were recorded electronically, and the cows were weighed automatically after each milking with a walking electronic scale (S.A.E. Afikim). Milk samples were collected from 3 consecutive milkings: every week in experiment 1, and every 2 wk in experiment 2. Samples were analyzed for milk fat, protein, lactose, and urea by infrared analysis (standard IDF 141C:2000; IDF, 2000) at the laboratories of the Israeli Cattle Breeders' Association (Caesarea, Israel). Somatic cell counts were determined in the same laboratory.

Calculations

Energy Calculations. Energy content in milk and energy balance (**EB**) were calculated by using the NRC (2001) equations, as follows:

$$NE_c = (NE_L \text{ per kg of DM}) \times DMI;$$

$$NE_M = BW^{0.75} \times 0.08 \times 1.1;$$

Table 1. Ingredients and chemical composition (% of DM) of the experimental diets

Item	Treatment	
	Experiment 1	Experiment 2
Ingredient		
Corn grain, ground	20.7	14.7
Barley grain, rolled	6.5	5.6
Wheat grain, rolled	4.4	2.7
Soybean meal	2.2	1.7
Rapeseed meal	6.8	6.9
Sunflower meal	—	5.7
Cottonseed	2.1	2.4
Wheat bran	0.9	9.2
Wheat silage	19.1	6.1
Corn silage	—	21.2
Oats hay	11.2	7.6
Clover hay	—	1.9
Gluten feed	13.4	0.7
Distillers dried grains	5.8	7.6
By-product of dairy industry	2.6	—
Calcium soap of fatty acids	1.9	3.4
Urea	0.1	0.3
Limestone	0.3	0.3
Calcium bicarbonate	1.0	0.8
Salt	1.0	1.2
Vitamins and minerals[1]	0.1	0.1
Chemical composition		
NE_L,[2] Mcal/kg of DM	1.61	1.61
CP	16.5	16.6
NDF	30.6	33.1
Forage NDF	17.0	18.3
Ether extract	5.1	6.6
Ca	0.9	0.8
P	0.5	0.5

[1]Contained (per kg): 20,000,000 IU of vitamin A, 2,000,000 IU of vitamin D, 15,000 IU of vitamin E, 6,000 mg of Mn, 6,000 mg of Zn, 2,000 mg of Fe, 1,500 mg of Cu, 120 mg of I, 50 mg of Se, and 20 mg of Co.

[2]Calculated using the NRC (1989) values with a few Israeli adjustments.