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Can a “Zero Land Use” Diet Maintain Milk Production of Dairy Cows?

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Abstract

Dairy cows can convert feeds unsuitable and unpalatable for humans into milk and play a key role in food security. Feed efficiency is usually calculated as the ratio between nutrients secreted in milk and nutrient intake, but this metric does not address concerns about human/livestock feed competition. This study aimed to evaluate whether cows fed a "zero land use" diet (diet that does not affect land used for production of human food), with or without rumen-protected amino acids, can maintain milk compared to a conventional lactation diet. Twelve second-lactation dairy cows were used in a 3×3 Latin square design experiment to evaluate 1) conventional total mixed ration (TMR) for lactating cows (CON), containing 25.7% byproduct feeds; 2) a TMR comprised of zero land use feedstuffs (ZLU); and 3) ZLU with top-dressed rumen-protected amino acids (ZLU-AA). Cows fed ZLU or ZLU-AA diets consumed less dry matter ($P < 0.01$) and decreased ($P < 0.01$) milk and energy-corrected milk yield of cows. Feed efficiency was similar between cows fed CON and ZLU but it was reduced ($P < 0.01$) when cows were fed ZLU-AA. In a scenario reflecting current food system byproduct use, cows fed ZLU diets showed greater ($P < 0.01$) human-edible metabolizable energy and protein recovery in milk than cows fed CON. Zero land use diets did not maintain milk production of late-lactation cows either with or without rumen-protected amino acids.

Keywords

byproduct, human-edible food, sustainability

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Summary
Dairy cows can convert feeds unsuitable and unpalatable for humans into milk and play a key role in food security. Feed efficiency is usually calculated as the ratio between nutrients secreted in milk and nutrient intake, but this metric does not address concerns about human/livestock feed competition. This study aimed to evaluate whether cows fed a "zero land use" diet (diet that does not affect land used for production of human food), with or without rumen-protected amino acids, can maintain milk compared to a conventional lactation diet. Twelve second-lactation dairy cows were used in a 3×3 Latin square design experiment to evaluate 1) conventional total mixed ration (TMR) for lactating cows (CON), containing 25.7% byproduct feeds; 2) a TMR comprised of zero land use feedstuffs (ZLU); and 3) ZLU with top-dressed rumen-protected amino acids (ZLU-AA). Cows fed ZLU or ZLU-AA diets consumed less dry matter ($P < 0.01$) and decreased ($P < 0.01$) milk and energy-corrected milk yield of cows. Feed efficiency was similar between cows fed CON and ZLU but it was reduced ($P < 0.01$) when cows were fed ZLU-AA. In a scenario reflecting current food system byproduct use, cows fed ZLU diets showed greater ($P < 0.01$) human-edible metabolizable energy and protein recovery in milk than cows fed CON. Zero land use diets did not maintain milk production of late-lactation cows either with or without rumen-protected amino acids.

Introduction
To feed the growing human population, more land will need to be devoted to the cultivation of food and cash crops. Since land is a finite resource, this will result in increasing competition for production of forage and concentrate feeds for livestock. On the other hand, increased food and cash crops will generate more crop residues and agro-industrial byproducts, many of which represent valuable feed resources for ruminants. Feeding byproducts to dairy cattle can sometimes decrease feed costs and improve the environmental sustainability of milk production. Recently, we compared a diet comprised of 95% byproducts with a typical diet for lactating cows and found a slight decrease in milk production (4.5%), without altering body weight of cows producing 88 lb of milk/day. Although not explored in our previous study, formulation software highlighted a possible deficiency of metabolizable lysine and methionine in the byproduct-based diet, which could be addressed through rumen protected amino acid supplementation.

One challenge in formulating a diet that displaces no land from food production for humans is to meet the effective fiber requirement of dairy cattle. In our previous work, this was accomplished with the use of wheat straw. However, an alternative is to utilize winter cover crop forages produced opposite a food-producing crop in a dual-cropping system. The objective of this study was to evaluate whether rumen-protected amino acids can maintain milk and component yields while improving human-edible nutrient conversion rate in cows fed a "zero land use" diet (diet that does not affect land used for production of human food) compared to a conventional lactation diet. In addition, we provide an approach to estimate the human-edible nutrient conversion rate for dairy cows.

Experimental Procedures

Twelve second-lactation dairy cows (231 ± 40 days in milk and 75.8 ± 15 lb/day milk yield at the beginning of the experiment) were assigned to a replicated 3×3 Latin square design experiment balanced for carryover effects. Adaptation to diets was allowed for 17 days, and 4 days were used for data collection and sampling in each period. Cows were blocked according to fat-corrected milk yield and days in milk, and randomly assigned to treatment sequence within block. Treatments (Table 1) were: 1) conventional TMR containing 25.7% byproduct feeds (CON); 2) TMR comprised of zero land use feedstuffs (ZLU); and 3) ZLU with top-dressed rumen-protected amino acids [ZLU-AA; 77 g/day AjiPro-L (Ajinomoto, Chicago, IL) and 145 g /day MetaSmart (Adisseo, Antony, France)]. Cows were milked and fed twice daily. All diets were formulated to meet nutrient requirements. The chemical composition of feeds is shown in Table 2.

Feed and refusals were weighed daily, targeting 10-15% refusals. During the last 4 days of each period, TMR and refusals samples were collected to assess particle size distribution and sorting index. Milk samples were collected in every milking during the last 4 days of each period, and analyzed by MQT Laboratory Services (Kansas City, MO) for solids, urea N concentration, and SCC. Fat-corrected milk yield, ECM yield, BW, and BCS were also recorded.

Maximum human-edible metabolizable energy and protein contents were estimated based on sugar, starch, true protein, and fat concentrations in corn grain (including grains in silage), corn hominy, soybean meal products, wheat middlings, and molasses. Other feedstuffs (such as spent coffee grounds) were considered unsuitable for human consumption. We calculated human-edible nutrient recovery in milk in two scenarios: one considering hominy feed and wheat middlings suitable for human consumption (thrift scenario), and the other considering them as unlikely to be consumed by humans (choice scenario).

Data were submitted to analysis of variance using the MIXED procedure of SAS 9.4 (SAS Inst., Cary, NC) including the fixed effect of diet and the random effects of period, block, and cow within block. Least square means among diets were evaluated using the Tukey test. Significance was declared at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$.

Results and Discussion

Cows fed ZLU or ZLU-AA diets consumed less dry matter ($P < 0.01$) than those fed CON (Table 3). Feed sorting was not affected by treatments, except for greater sorting for feed particles of 4–8 mm length among cows fed ZLU compared to CON. The ZLU diets had a greater proportion of feed with long particles (>19 mm) in comparison with CON diet, which may have contributed to suppression of feed intake on these diets. The ZLU and ZLU-AA decreased ($P < 0.01$) milk and ECM yields substantially (Table 3). Feed efficiency was similar between cows fed CON and ZLU but it was reduced ($P < 0.01$) when cows were fed ZLU-AA. Feed efficiency in terms of ECM tended to decrease in cows fed ZLU or ZLU-AA diets. The huge negative impact on performance of cows can likely be attributed to the forage source used in this study. Although the triticale/clover hay used in this study had considerable amounts of crude protein and neutral detergent fiber, it also had a relatively high moisture content that favored spoilage and likely impaired palatability.

The outputs of human-edible metabolizable energy and protein in milk were decreased ($P < 0.01$) by ZLU and ZLU-AA diets (Table 4). In the thrift scenario, ZLU diets (ZLU and ZLU-AA) decreased ($P < 0.01$) human-edible metabolizable energy input but increased ($P < 0.01$) human-edible protein input. Despite lesser human-edible metabolizable energy input, recovery of human-edible metabolizable energy in milk was not affected ($P = 0.55$) by treatments. Cows fed CON had greater ($P < 0.01$) milk recovery of human-edible protein in comparison with those fed ZLU diets. In the choice scenario, cows fed CON diet had greater ($P < 0.01$) human-edible metabolizable energy and protein inputs compared to those fed ZLU diets. In contrast with the thrift scenario, cows fed ZLU diets showed greater ($P < 0.01$) human-edible nutrient (metabolizable energy and protein) recovery in milk than cows fed CON in the choice scenario. These vastly different outcomes demonstrate how impactful assumptions about human edibility are in calculations regarding the efficiency of feeding livestock.

Conclusions

This study showed no evidence that a diet composed of feedstuffs that do not affect land used for production of human food can maintain milk production of late lactation cows, even if combined with rumen-protected amino acids. We suspect that the poor quality of the winter forage used in these diets was primarily to blame for the poor feed intake and resulting loss in productivity in this study. In addition, feeding ZLU diets does not necessarily improve the human-edible nutrient conversion rate in dairy cows, as this is dependent on both the ability to maintain productivity of cows and on assumptions made in calculating the value of feed ingredients for human consumption.

Table 1. Ingredient, chemical composition, and particle size distribution of diets

	Diet[1]	
Item	CON	ZLU
Ingredient, % dry matter (DM)		
Corn silage	41.9	
Alfalfa hay	12.6	
Prairie hay	1.05	
Triticale/clover hay[2]		31.6
Corn gluten feed[3]	23.1	15.1
Whole cottonseed with lint	2.62	1.38
Ground corn	11.9	
Soybean meal[4]	4.39	
Calcium salts of long-chain fatty acids[5]	0.61	
Wheat middlings		25.5
Corn hominy		12.6
Spent coffee grounds		4.36
Molasses		5.94
Minerals and vitamins	1.72	3.4
Chemical, % DM		
Dry matter, % as-fed	58.5	54.1
Crude protein	17.1	18.0
Acid detergent fiber	19.5	20.4
Neutral detergent fiber	34.4	37.3
Non-fiber carbohydrate	34.4	25.9
Ether extract	5.07	4.73
Ash	8.95	14.0
Total digestible nutrient, %	69.0	62.7
NE_L, Mcal/kg	1.61	1.46

[1]Conventional lactation diet (CON), containing 25.7% co-product feeds, and TMR composed of feedstuffs that do not affect land used for production of human food (ZLU) – water was added to achieve similar diet DM.
[2]Hay from the winter intercropping of triticale and red clover.
[3]Sweet Bran (Cargill, Blair, NE).
[4]Soy Best (Grain States Soya, Inc., West Point, NE).
[5]Megalac-R (Arm & Hammer Animal Nutrition, Trenton, NJ).
[6]Scenario considering hominy feed and wheat middlings suitable food for humans.
[7]Scenario not considering hominy feed and wheat middlings suitable food for humans.

Table 2. Chemical composition of feeds (% DM, unless stated)

Item[1]	DM, % as-fed	CP	ADF	NDF	NFC	EE	Ash
Corn silage	35.6	9.2	21.5	39.2	41.9	3.70	6.05
Alfalfa hay	91.5	20.3	31.8	42.8	23.4	2.30	11.3
Prairie hay	93.3	5.70	43.1	68.9	14.0	2.30	9.14
Triticale/clover hay	72.3	19.1	40.9	59.2	1.55	2.23	17.6
Cottonseed with lint	88.2	22.3	44.3	57.2	0.70	15.7	4.38
Corn gluten feed[2]	61.3	23.0	8.90	31.8	43.2	5.10	7.05
Spent coffee grounds	35.1	14.2	32.3	54.7	15.2	14.2	1.78
Molasses	70.7	5.80	-	-	-	5.70	15.4
Grain mix CON[3]	86.4	16.1	6.80	19.8	45.3	5.35	13.6
Grain mix ZLU[4]	82.5	15.4	9.7	29.1	38.9	4.45	12.2

[1]Dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF) treated with sodium sulfite and alpha-amylase, non-fiber carbohydrate (NFC), and ether extract (EE).
[2]Sweet Bran (Cargill, Blair, NE).
[3]Grain mix containing (% DM): 63.9% ground corn, 23.5% bypass soybean meal (Soy Best, Grain States Soya, Inc., West Point, NE), 3.3% bypass fat (Megalac-R, Arm & Hammer Animal Nutrition, Trenton, NJ), and 9.18% minerals and vitamins.
[4]Grain mix containing (% DM): 61.4% wheat middlings, 30.4% corn hominy, and 8.22% minerals and vitamins.

Table 3. Performance and sorting index of late-lactating cows fed a conventional lactation diet or a "zero land use" diet

	Diet[1]				
Item	CON	ZLU	ZLU-AA	SEM	P-value
Dry matter intake (DMI), lb/day	57.8[a]	49.4[b]	49.6[b]	1.39	< 0.01
Sorting index[2]					
>19 mm	0.84	0.89	0.89	0.040	0.47
8–19 mm	0.96	0.98	0.95	0.015	0.73
4–8 mm	0.97[b]	1.03[a]	1.01[ab]	0.014	0.04
< 4 mm	1.04	1.04	1.04	0.008	0.89
Milk yield, lb/day	70.3[a]	50.5[b]	50.3[b]	3.28	< 0.01
ECM yield[3], lb/day	70.8[a]	51.8[b]	53.4[b]	3.04	< 0.01
ECM/DMI	1.22	1.10	1.05	0.043	0.06
Fat, lb/day	2.49[a]	1.91[b]	1.96[b]	0.108	< 0.01
Protein, lb/day	2.25[a]	1.55[b]	1.59[b]	0.094	< 0.01
Lactose, lb/day	3.37[a]	2.27[b]	2.31[b]	0.073	< 0.01
Milk composition					
Fat, %	3.60[a]	3.86[b]	3.75[ab]	0.085	0.04
Protein, %	3.22	3.15	3.18	0.044	0.31
Lactose, %	4.80[a]	4.45[b]	4.39[b]	0.049	< 0.01
Urea nitrogen, mg/dL	13.9[ab]	14.2[a]	13.7[b]	0.14	0.03
SCLS[4]	2.46[b]	3.69[a]	3.69[a]	0.25	< 0.01
Body weight change, lb/21 days	69.9	48.3	46.9	11	0.28
Body condition score change	0.04	-0.04	-0.06	0.033	0.29

[a-b]Values within rows with different superscripts differ significantly ($P < 0.05$).
[1]Conventional lactation ration (CON), containing 25.7% co-product feeds; ration composed of feedstuffs that do not affect land used for production of human food (ZLU); and ZLU with top-dressed rumen-protected amino acids [ZLU-AA; 2.72 oz/d AjiPro-L (Ajinomoto, Chicago, IL) and 1.59 oz/d MetaSmart (Addiseo, Antony, France)].
[2]Values >1.0 means that cows sorted for the specific particle size and values <1.0 means that cows sorted against the specific particle size.
[3]Energy-corrected milk (ECM).
[4]Somatic cell linear score (SCLS) = $\log_2$(somatic cell count /100) + 3.

Table 4. Human-edible (HE) nutrients conversion rate of late-lactation cows fed a conventional lactation diet or a "zero land use" diet

	Diet[1]				
Item	CON	ZLU	ZLU-AA	SEM	*P*-value
Milk metabolizable energy (ME) output, Mcal/day	22.4[a]	16.1[b]	16.2[b]	1.01	< 0.01
Milk protein output, lb/day	2.25[a]	1.55[b]	1.59[b]	0.10	< 0.01
Thrift scenario[2]					
HE ME input, Mcal/day	36.8[a]	25.6[b]	26.8[b]	1.41	< 0.01
HE protein input, lb/day	2.98[b]	3.73[a]	3.90[a]	0.099	< 0.01
Milk ME ÷ HE ME intake	0.61	0.64	0.59	0.044	0.55
Milk protein ÷ HE protein intake	0.75[a]	0.42[b]	0.40[b]	0.038	< 0.01
Choice scenario[3]					
HE ME input, Mcal/day	36.8[a]	3.92[b]	4.11[b]	1.19	< 0.01
HE protein input, lb/day	2.98[a]	0.19[b]	0.20[b]	0.15	< 0.01
Milk ME ÷ HE ME intake	0.61[b]	4.13[a]	3.84[a]	0.065	< 0.01
Milk protein ÷ HE protein intake	0.75[b]	8.21[a]	7.86[a]	0.002	< 0.01

[a-b]LSMEANS within rows with different superscripts differ significantly in LSD ($P < 0.05$).
[1]Conventional lactation TMR (CON), containing 25.7% co-product feeds; TMR composed of feedstuffs that do not affect land used for production of human food (ZLU); and ZLU with top-dressed rumen-protected amino acids [ZLU-AA; 2.72 oz/d AjiPro-L (Ajinomoto, Chicago, IL) and 1.59 oz/d MetaSmart (Addiseo, Antony, France)].
[2]Scenario considering hominy feed and wheat middlings as suitable foods for human consumption.
[3]Scenario considering that hominy feed and wheat middlings would be unlikely to be consumed by humans.