ANIMAL PRODUCTION

Nutrient fluxes and environmental performance indicators for a pasture-based dairy system

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ABSTRACT. The aim of this study was to evaluate the nutrient fluxes for lactating cows in a pasture-based dairy system and the impact of a nutritional management strategy on the environmental performance indicators. Fourteen lactating cows were divided into two experimental groups with seven animals each. The nutritional managements were a diet containing 20% crude protein (Group 1) and a diet with adjusted protein (Group 2). The nutrient budget was calculated on a monthly basis for nitrogen, phosphorus, and potassium. The nutritional strategy of adjusted protein reduces the total surplus in the lactation period for nitrogen by 7.6% and for phosphorus by 6.3%. The total potassium surplus of the adjusted protein group was 8.5% higher. The average nitrogen use efficiency was 21% for group 1 and 22.7% for group 2. Phosphorus use efficiency ranged from 13.4 to 35% for group 1 and from 15.5 to 34% for group 2 and potassium average use efficiency was 14.2% for group 1 and 12.6% for group 2. Nutritional management reduced nitrogen and phosphorus surpluses as well as the values of the environmental performance indicator. Based on this, it is possible to improve the environmental efficiency of dairy systems through improved nutritional management.

Keywords: nitrogen; lactating cows; phosphorus; potassium; protein.

Introduction

Intensive livestock production is common in many countries, with advantages such as economic gains, but also disadvantages, e.g., excessive inputs (nutrients, water, energy, etc.), posing a potential environmental risk. Wood et al. (2018) state that increased farming intensification can increase food and nutrient supplies, but could also lead to environmental damages. According to White (2016) states that, given that dairy producers often operate on tight profit margins and that the long-term viability of their businesses relies on ensuring costs are kept to a minimum, improving energy and protein use efficiency should be a primary objective of dairy producers. A relatively low nitrogen proportion (15-35%) is converted into products in intensive pasture-based livestock production systems, revealing the relatively low overall N use efficiency of these systems (Burchill et al., 2016).

Nutrient budget calculation is a valuable tool to understand the nutrient cycling in agroecosystems, mainly because such an approach summarizes large amounts of data in transparent and easy-to-understand input/output diagrams (Oenema et al., 2012). A better understanding of nutrient use at the farm level is necessary because it considers animal nutrient-transformation processes (Jan et al., 2017). Studies on dairy nutrient budgets have been performed previously (Aarons et al., 2017).

Optimizing animal nutrition is one approach to make ruminant production systems sustainable (Sotomayor-Ramirez et al., 2003; White et al., 2015). Powell et al. (2017) state that the type, amount, and quality of feeds offered to livestock greatly impact whole-farm N use efficiency. White et al. (2016) report that animal nutrition research has focused on improving energy and protein use efficiency; however, the potential environmental benefit of these research avenues has not been well investigated.

In this context, the aim of this study was to evaluate the nutrient fluxes for lactating cows in a pasture-based dairy system and the impact of a nutritional management strategy on the environmental performance indicators.

Material and Methods

The nutrient budget was used to evaluate the nutrient flows of two groups of lactating cows in a cradle-to-farm gate perspective. The study considered inputs and outputs, which were calculated from primary data related to feed, fertilizer, irrigation, and milk production, prioritizing a bottom-up approach. The experiment was conducted during the wet-dry season on a monthly basis (273 days of lactation). Fourteen lactating cows were divided into two experimental groups with seven animals each. The stoking rate was 5.7 cows ha^{-1}.

Group 1 (fixed protein) was fed with a diet containing 20% crude protein. This percentage was considered as being used in commercial dairy diets. The crude protein content of Group 2 (adjusted protein) was determined according to the milk production during the lactation period.

The diets of both experimental groups are presented in Table 1. Cows had access to food and water *ad libitum*.

The cows were fed TMR between the two daily milkings. The two groups remained separated in the remaining area in which they received TMR. Each area had 0.37 ha.

During the night, from 17:00 PM to 07:00 AM, the 14 animals had access to paddocks to feed on 'Tanzania' grass (*Panicum maximum* Jacq.). The grazing system consisted of 32 paddocks ranging in size from 0.04 to 0.07 ha, with a total area of 1.7 ha.

Total N application in the grazing system was 330 kg, applied as three splits of 46 kg per month in winter (July, August, and September) and three splits of 64 kg per month in summer (November, December, and January).

Table 1. Nutritional aspects of the system for each experimental group.

Group 1 – Fixed Crude Protein (20%)								
Feed Intake (kg DM animal^{-1})	May	June	July	August	September	October	November	December	January
Corn Silage	217.8	253.1	174.0	203.5	235.3	105.8	-	-	-
Grass	15.0	9.0	139.5	139.5	135.0	149.5	285.0	295.5	294.5
Maize	231.2	223.8	229.2	200.4	194.0	200.4	194.0	200.4	200.4
Soybean meal	107.9	104.4	108.1	111.7	108.1	111.7	108.1	111.7	111.7
Total DM intake	571.9	590.3	650.8	655.1	672.4	567.4	587.1	607.6	606.6
Roughage concentrates ratio (%)	41:59	44:56	48:52	52:48	55:45	45:55	49:51	49:51	49.51
Group 2 – Adjusted Crude Protein								
Feed Intake (kg DM animal^{-1})	May	June	July	August	September	October	November	December	January
Corn Silage	217.8	253.1	174.0	203.5	235.3	105.8			
Grass	15.0	9.0	139.5	139.5	135.0	149.0	285.0	294.5	294.4
Maize	210.1	201.0	207.3	201.5	195.0	201.5	246.0	254.2	254.2
Soybean meal	132.5	129.0	129.5	74.4	72.0	74.4	60.0	62.0	62.0
Total DM intake	575.4	592.1	650.3	618.9	637.3	530.7	591.0	610.7	610.6
Roughage concentrates ratio (%)	40:60	44:56	48:52	55:45	58:42	48:52	48:52	48:52	48:52
Crude Protein	23	23	17	17	17	17	17	17	14.5

*DM- dry matter.

The animals experiment was conducted in accordance with Brazilian guidelines on animal welfare and were approved by the Ethics Committee on the Use of Animals, College of Veterinary and Animal Science, São Paulo State University under protocol n° 8510190118.

The nutrient budget was calculated as the difference between the nutrients (N, P, and K) entering the system and exiting the system, considering a farm-scale budget approach (Stott & Gourley, 2016; Mu et al., 2016). The difference between inputs and outputs was the nutrient surplus. Atmospheric deposition was not considered. Nutrient biological fixation was considered null since no legumes were used in the production system.

Nutrient inputs and outputs were calculated on a monthly basis. The fertilizer used in the production system was urea. Nutrients in feed were calculated by multiplying the measured quantity of consumed feed per month and per animal group by its nutrient content (Valadares Filho et al., 2011). Nutrients in milk were calculated by multiplying cow milk yield per group (measured biweekly) by milk nutrient concentration (measured in the laboratory). Nitrogen in milk was calculated by dividing the milk protein concentration by 6.38 (Agricultural Research Council [ARC], 1994).

The environmental performance indicators evaluated were as follows: nitrogen, phosphorus, and potassium surplus, presented per productive farm area (area used for grazing and maize silage production), 1.65 ha for group 1 and 1.66 ha for group 2) and per productive in/off farm area (area used for grazing, maize silage production, and corn and soya production), with 6.85 ha for group 1 and 6.66 ha for group 2 (Stott & Gourley, 2016); nutrient use efficiency (Godinot et al., 2014); milk production nutrient surplus (g L^{-1} milk)

(Stott & Gourley 2016; Mu et al., 2016); and eco-efficiency, defined as the amount of milk produced per kg nutrient surplus (as a measure of potential environmental damage) (Nevens et al., 2006).

Results and Discussion

Tables 2, 3, and 4 show the nutrient budgets and environmental performance indicators for the analyzed nutrients. The nutritional strategy of adjusted protein reduces the total surplus in the lactation period for nitrogen by 7.6% and for phosphorus by 6.3%. The total potassium surplus of the adjusted protein group was 8.5% higher. The highest surplus was found for nitrogen, followed by K and P.

The nitrogen surplus for group 1 ranged from 68 to 143 kg N month^{-1} (Table 2), with an average of 111 kg N month^{-1}. For group 2, the variation ranged from 63 to 136 kg of N month^{-1}, with an average of 102.5 kg of N month^{-1}. For both groups, the lowest surpluses were verified in the first 3 months (May-July) of the lactation period and in October. Production and management aspects contributed to this situation. In the first 3 months (May-July), the cows reached the lactation peak, which was June for group 1 (32.4 kg milk cow^{-1} day^{-1}) and July for group 2 (30.6 kg milk cow^{-1} day^{-1}), with a maximum output (milk production), resulting in a lower budget. May, June, and October were the months without nitrogen fertilization. The sums of inputs were lower in those months, resulting in the lowest surplus.

Feed was the main nitrogen input, on average accounting for 88% of group 1 inputs and 87% of group 2 inputs. On average, 80% of the two main nitrogen inflows in conventional dairy farms are mineral fertilizer and purchased feed (Einarsson et al., 2017). Fertilization in the summer (November-January) accounted for more than 20% of the inputs for both groups.

The phosphorus surplus varied from 13.9 to 21 kg month^{-1} for group 1 and from 13.4 to 19.9 kg month^{-1} for group 2 (Table 3). The averages were 17 and 16 kg month^{-1}, respectively, and the total surpluses in the lactation period were 152.8 and 142.9 kg P for groups 1 and 2, respectively. For both groups, the highest surplus was observed in the summer (November to January). This fact is related to the end of the lactation period, where milk production was reduced, with a possible excessive consumption of phosphorus, mainly via grass.

The average dietary P concentrations were higher than the recommended concentrations, namely 5.2 and 5.0 g P kg^{-1} for group 1 and 2, respectively, suggesting that dairy could excrete large amounts of P in feces, as was verified by the P surplus values.

The concentrate represented the highest phosphorus input, averaging 73% for group 1 and 70.9% for group 2. For pasture, these values were 18 and 19.3%, respectively. In the case of maize silage, average inputs were 8.7% for group 1 and 9.4% for group 2.

The total surplus of potassium for groups 1 and 2 was 488.8 and 534.4 kg, respectively (Table 4). The minimum and maximum surpluses in the lactation period were 24 to 85 kg month^{-1} for group 1 and 31.7 to 86.5 kg month^{-1} for group 2. As observed for phosphorus, the summer months presented the highest surplus values. In contrast to nitrogen and phosphorus, concentrate did not represent the highest potassium input. Here, pasture had the highest input, averaging 46.5% in group 1 and 44.5% in group 2, while concentrate had the second highest input, with mean values of 39 and 42.6% for groups 1 and 2, respectively. On average, irrigation accounted for 2.5% of the potassium inputs in both groups.

The average nitrogen use efficiency was 21% for group 1 and 22.7% for group 2. The maximum nitrogen use efficiency of group 1 was 33% (May and June), while in group 2, it was 32% (October) (Table 2). In a study by Burchill et al. (2016), the nitrogen use efficiency of dairy pasture systems varied from 29 to 37%. Gourley et al. (2012) state that the N use efficiency for Australian dairy farms ranges from 15 to 50%, with a median of 28%. The average nitrogen use efficiencies observed in this study were, however, lower. Nutrient efficiency is the result of several productive aspects such as genetics, type of nutrition, production system, and milk yield.

Maximum nitrogen efficiencies were observed in May, June, and October, where no fertilization occurred. Because efficiency is determined by outputs and inputs and, in the case of this study, the only output was milk, the higher milk production and the lower inputs, higher efficiency was observed in these months. This was verified for group 1, where in the first two months of the lactation period, we observed the highest milk yields and the lowest system inputs. In group 2, the lowest input occurred in October (93 kg N), and although the lactation curve was already descending, the total milk yield was still high (5,809 kg, 12% higher than for group 1).

Phosphorus use efficiency ranged from 13.4 to 35% for group 1 and from 15.5 to 34% for group 2, with average values of 25.3 and 26.5%, respectively (Table 3). In other studies, the values varied from 24 to 70%, depending on the system, stoking rate, milk yield, and inputs and outputs considered in the budget (Mihailescu et al., 2015).

Table 2. Nitrogen budget and environmental performance indicators for each experimental group.

	Group 1 – Fixed Crude Protein (20%)								
	May	June	July	August	September	October	November	December	January
Inputs									
Fertilizer (kg N)	-	-	23	23	23	-	32	32	32
Irrigation (kg N)	-	0,7	0,4	1,0	0,4	0,7	-	-	-
Concentrate (kg N)	81	79	81	74	72	74	72	74	64
Corn Silage (kg N)	18	20	16	18	17	8			
Grass (kg N)	3	3	39	39	38	29	55	57	49
Total Inputs (kg N)	101	102	158	155	150	112	159	164	145
Outputs									
Milk (kg N)	33	34	33	29	28	26	28	20	17
Indicators									
Surplus (kg N)	68	69	126	126	122	86	132	143	128
Nutrient Use Efficiency (%)	33	33	24	22	22	23	22	16	15
Surplus in productive farm[1] (kg N ha^{-1})	41	42	76	76	74	52	80	87	78
Surplus in/off productive farm area (kg N ha^{-1})	10	10	18	18	18	13	19	21	19
Milk production nutrient surplus (g L^{-1} milk)	10	10	19	22	23	17	28	40	47
Eco-efficiency (milk kg^{-1} surpuls)	97	99	52	45	43	60	36	25	21
	Group 2 – Adjusted Crude Protein								
	May	June	July	August	September	October	November	December	January
Inputs									
Fertilizer (kg N)	-	-	23	23	23	-	32	32	32
Irrigation (kg N)	-	0,7	0,4	1,0	0,4	0,7	-	-	-
Concentrate (kg N)	93	90	91	55	54	55	52	54	54
Corn Silage (kg N)	18	20	16	18	17	8			
Grass (kg N)	3	3	39	39	38	29	55	57	57
Total Inputs (kg N)	113	114	169	136	132	93	140	143	143
Outputs									
Milk (kg N)	29	32	33	29	32	30	28	25	23
Indicators									
Surplus (kg N)	85	82	136	107	100	63	111	118	121
Nutrient Use Efficiency (%)	25	28	19	22	24	32	20	17	16
Surplus in productive farm[1] (kg N ha^{-1})	51	49	82	64	60	38	67	71	73
Surplus in/off productive farm area (kg N ha^{-1})	13	12	20	16	15	9	17	18	18
Milk production nutrient surplus (g L^{-1} milk)	15	13	20	18	17	11	22	27	32
Eco-efficiency (milk kg^{-1} surpuls)	68	80	49	55	59	92	46	37	31

[1]Surplus in productive farm- considering areas in farm (grazing system, paddock, and corn silage). [2]Surplus in/off productive farm- considering areas in and off farm (grazing system, paddock, corn silage, and areas to produce maize and soya).

Group 2 presented a higher persistence of lactation and a lower P intake throughout the lactation period, with positive impacts on phosphorus use efficiency. While the animals in group 1 ingested on average 5.2 g P kg^{-1} DM, the group 2 intake was 5.0 g P kg^{-1} DM. This difference is a result of the different corn and soybean meal ratios in the concentrate.

Potassium presented an average use efficiency of 14.2% for group 1 and 12.6% for group 2, with maximum efficiencies of 30.6 and 25.2%, respectively (Table 4). The mean intake of potassium per kilogram of dry matter in group 2 was higher, namely 15.8 g K kg^{-1} DM versus 14.8 g K kg^{-1} DM in group 1. From November onwards, potassium intake was 2.1% for both groups; this value is twice the nutritional recommendations for lactating cows. From November to January, the daily grass intake was highest. As the intake was *ad libitum*, and considering that the pasture was rich in potassium, the animals ingested potassium beyond their nutritional requirements reducing the potassium use efficiency. Although potassium is not a major element when considering the potential environmental impacts of livestock, the results demonstrate that more attention should be given to the use of this element in dairy pasture systems.

Unfortunately, there are few studies evaluating the efficiency of phosphorus and potassium use in dairy systems, making it difficult to compare the results presented here. Particularly in the case of phosphorus, studies should be intensified, as this is an element responsible for the process of eutrophication in water bodies.

The nitrogen surplus in the productive area of the farm study for group 1 varied from 41 to 87 kg N ha^{-1}, with a monthly average of 67 kg N ha^{-1} and a total value in this period of 605 kg N ha^{-1}. In group 2, the monthly average was 62 kg N ha^{-1} (Table 2), with a variation from 38 to 82 kg N ha^{-1} and a total value of 556 kg N ha^{-1}. Burchill et al. (2016) calculated an annual N surplus from 193 to 139 kg ha^{-1} for a dairy system, while Gourley et al. (2012), for Australian dairy farms, presented whole-farm N surpluses from 47 to 601 kg ha^{-1}, with a median of 193 kg ha^{-1}.

Table 3. Phosphorus budget and environmental performance indicators for each experimental group.

	Group 1 – Fixed Crude Protein (20%)								
	May	June	July	August	September	October	November	December	January
Inputs									
Irrigation (kg N)	-	0,2	0,1	0,2	0,1	0,2	-	-	-
Concentrate (kg N)	18	17	18	16	16	17	16	17	14
Corn Silage (kg N)	3	4	3	3	3	2	-	-	-
Grass (kg N)	0	0	3	3	3	4	8	8	7
Total Inputs (kg N)	21	21	24	23	23	22	24	25	21
Outputs									
Milk (kg N)	8	7	8	7	5	6	5	4	3
Indicators									
Surplus (kg N)	14	14	16	16	18	17	19	21	18
Nutrient Use Efficiency (%)	35	32	35	30	22	25	21	15	13
Surplus in productive farm[1] (kg N ha^{-1})	8	9	9	10	11	10	11	13	11
Surplus in/off productive farm area (kg N ha^{-1})	2	2	2	2	3	2	3	3	3
Milk production nutrient surplus (g L^{-1} milk)	2	2	2	3	3	3	4	6	7
Eco-efficiency (milk kg^{-1} surpuls)	472	470	422	353	298	307	252	169	150
	Group 2 – Adjusted Crude Protein								
	May	June	July	August	September	October	November	December	January
Inputs									
Irrigation (kg N)	-	0,2	0,1	0,2	0,1	0,2	-	-	-
Concentrate (kg N)	17	16	17	14	13	14	15	16	16
Corn Silage (kg N)	3	4	3	3	3	2	-	-	-
Grass (kg N)	0	0	3	3	3	4	8	8	8
Total Inputs (kg N)	21	21	23	20	20	19	23	24	24
Outputs									
Milk (kg N)	6	7	8	7	5	6	5	4	4
Indicators									
Surplus (kg N)	15	14	15	13	15	14	18	19	20
Nutrient Use Efficiency (%)	27	32	34	34	27	29	22	18	16
Surplus in productive farm[1] (kg N ha^{-1})	9	8	9	8	9	8	11	12	12
Surplus in/off productive farm area (kg N ha^{-1})	2	2	2	2	2	2	3	3	3
Milk production nutrient surplus (g L^{-1} milk)	3	2	2	2	2	2	3	4	5
Eco-efficiency (milk kg^{-1} surpuls)	384	468	440	443	402	421	289	229	190

[1]Surplus in productive farm- considering areas in farm (grazing system, paddock, and corn silage). [2]Surplus in/off productive farm- considering areas in and off farm (grazing system, paddock, corn silage, and areas to produce maize and soya).

The advantage of calculating the surplus by area per month makes it possible for farmers and researchers to make better decisions regarding the fertilization regime, because it allows to take into account the surplus of the previous month. This results in a lower acquisition of chemical fertilizers, thereby reducing production costs, optimizing the use of animal waste as fertilizer, enhancing the environmental security of dairy, facilitating an adaptation to environmental legislations.

On a monthly basis, the surplus of phosphorus per area varied from 8 to 13 kg P ha^{-1}, with a total value of 93 kg P ha^{-1}, for group 1 and from 8 to 12 kg P ha^{-1}, with a total value of 86 kg P ha^{-1}, for group 2 (Table 3). Gourley et al. (2012) verified a P surplus of 26 kg P ha^{-1}. Mihailescu et al. (2015) calculated a mean P surplus of 5 kg P ha^{-1} for a grass-based milk production system with low use of imported feeds and identified stocking rate, chemical fertilizer application, and season of P manure application as the factors determining these differences.

The monthly variation for potassium in group 1 ranged from 15 to 51 kg K ha^{-1}, with a total value of 296 kg K ha^{-1}. In group 2, the variation ranged from 19 to 52 kg K ha^{-1}, with total value of 322 kg K ha^{-1} (Table 4). As already pointed out, potassium was the only element in which the surplus of group 2 was higher than that of group 1; consequently, this element is available in larger quantities.

When the surplus was related with area in/out farm, the values were significantly lower than those verified when considering only the in-farm area. In the case of nitrogen, the monthly variation in group 1 ranged from 10 to 21 kg N ha^{-1}, with a mean monthly value of 16 kg N ha^{-1} and a total value of 146 kg N ha^{-1}. In group 2, the mean was 15 kg N ha^{-1}, ranging from 9 to 20 kg N ha^{-1}, with a total value of 139 kg N ha^{-1}. In Australia, N inputs on an average dairy farm increased from 91 to 214 kg N ha^{-1} productive dairy farm area (Stott & Gourley, 2016).

Table 4. Potassium budget and environmental performance indicators for each experimental group.

	Group 1 – Fixed Crude Protein (20%)								
	May	June	July	August	September	October	November	December	January
Inputs									
Irrigation (kg N)	-	1,5	0,9	2,0	0,9	1,4	-	-	-
Concentrate (kg N)	22	21	22	20	20	23	23	23	20
Corn Silage (kg N)	10	11	8	9	11	5	-	-	-
Grass (kg N)	3	2	24	24	23	34	65	67	57
Total Inputs (kg N)	35	36	55	56	54	64	87	90	77
Outputs									
Milk (kg N)	11	11	8	7	4	8	6	5	5
Indicators									
Surplus (kg N)	24	25	47	48	50	55	81	85	73
Nutrient Use Efficiency (%)	31	29	15	13	8	13	7	6	6
Surplus in productive farm[1] (kg N ha^{-1})	15	15	28	29	30	34	49	51	44
Surplus in/off productive farm area (kg N ha^{-1})	3	4	7	7	7	8	12	12	11
Milk production nutrient surplus (g L^{-1} milk)	4	4	7	9	10	11	17	24	26
Eco-efficiency (milk kg^{-1} surpuls)	274	269	141	117	105	93	59	42	38
	Group 2 – Adjusted Crude Protein								
	May	June	July	August	September	October	November	December	January
Inputs									
Irrigation (kg N)	-	1,5	0,9	2,0	0,9	1,4	-	-	-
Concentrate (kg N)	29	28	29	23	23	23	26	26	26
Corn Silage (kg N)	10	11	8	9	11	5	-	-	-
Grass (kg N)	3	2	24	24	23	34	65	67	67
Total Inputs (kg N)	41	42	62	59	57	63	90	93	93
Outputs									
Milk (kg N)	8	11	8	7	5	8	6	7	7
Indicators									
Surplus (kg N)	33	32	53	51	53	55	84	86	87
Nutrient Use Efficiency (%)	20	25	13	13	8	13	7	7	7
Surplus in productive farm[1] (kg N ha^{-1})	20	19	32	31	32	33	51	52	52
Surplus in/off productive farm area (kg N ha^{-1})	5	5	8	8	8	8	13	13	13
Milk production nutrient surplus (g L^{-1} milk)	6	5	8	9	9	10	16	20	23
Eco-efficiency (milk kg^{-1} surpuls)	176	205	125	115	112	105	61	51	44

[1]Surplus in productive farm- considering areas in farm (grazing system, paddock, and corn silage). [2]Surplus in/off productive farm- considering areas in and off farm (grazing system, paddock, corn silage, and areas to produce maize and soya).

The phosphorus surplus and the mean value per in/out farm area presented equal monthly variations for both groups, with equal mean values from 2 to 3 kg P ha^{-1} and a mean of 2 kg P ha^{-1}. Ruiz et al. (2016) found a net P surplus in semi-confined dairy farms in Puerto Rico of 66 kg P ha^{-1}. The potassium surplus per in/out farm area ranged from 3 to 12 kg K ha^{-1} in group 1 and from 5 to 13 kg K ha^{-1} for group 2.

In terms of manure management and conservation of natural resources, the indicator that considers only the in-farm area is more suitable because it shows the potential nutrient surplus that must be managed by the farmer in his/her farm. Considering in/out areas of the farm, the indicator shows an unrealistic scenario. The greater the dependence of the outside areas to produce the feed for the cows, the greater the error in the decision making if only the in/out farm indicator is considered. The surplus of nutrients can be exported to other regions where there is a lack of these elements, depending on the available technical and economical means to collect and transport the wastes. In dairy grazing systems, this collection presents difficulties, since feces and urine will be disposed in the grazing areas.

For both groups, the highest surplus per area for the three elements was found in the months in which fertilization occurred and in the last 3 months of the lactation period. This is explained by higher inputs with lower milk output. Group 2 produced more milk than group 1 in the last three months, 7.5% in November, 24% in December, and 37% in January, with inputs being 13 12, and 2.5% lower in the respective months. Based on our findings, the strategy of adjusting crude protein levels decreases the environmental pressure per unit of area. If all cows in a production system have their dietary protein adjusted according to their milk production, this will have a positive impact on the economic dimension, with lower feed costs, and on the environmental dimension, with a lower availability of nutrients per area, resulting in a more resilient production system.

Group 1 produced on average 24 g N surplus L milk^{-1}, ranging from 10 to 47 g N surplus L milk^{-1}. In group 2, the mean value was 19 g N surplus L milk^{-1}, varying between 11 and 32 g N surplus L milk^{-1} (Table 2). Stott and Gourley (2016), evaluating Australian dairy farms, calculated a milk production surplus N from 10.2 to 17.3 g N L milk^{-1}. Gourley et al. (2012) estimated 12.1 g N L milk^{-1}. The values verified in this study are above those evaluated by other authors, probably because of the inputs and outputs considered in the budget as well as the type of production system and diet.

Phosphorus surplus values were highest in group 1, with a mean of 4 g P surplus L milk^{-1} and minimum and maximum values of 2 and 7 g P surplus L milk^{-1}, respectively. In group 2, the mean value was 3 g P surplus L milk^{-1}, ranging from 2 to 5 g P surplus L milk^{-1} (Table 3). The mean values for potassium were similar for both groups, with, 12 g K surplus L milk^{-1}. The minimum and maximum values were also similar, with 4 to 26 g K surplus L milk^{-1} and 5 to 23 g K surplus L milk^{-1} for group 1 and 2, respectively (Table 4). The results demonstrate that the applied strategy resulted in a lower amount of surplus per liter of milk produced, which means that the animals had a higher nutrient use efficiency in group 2.

Indicators that relate the environmental state with the product should be applied more frequently in the livestock sector to evaluate the environmental and productive efficiency, allow a comparison of environmental performance between farms and production systems, generate benchmarks to classify farms, identify their environmental and productive weaknesses and propose best productive practices, and support the consumer in the purchase decision, showing that it is possible to produce the same quantity of milk with lower amount of nutrients.

The average eco-efficiency in group 1 was 53 L milk kg^{-1} N surplus, ranging from 21 to 99 L milk kg^{-1} N surplus. In group 2, the average value was 58 L milk kg^{-1} N surplus, with maximum and minimum values of 31 and 92 L milk kg^{-1} N surplus (Table 2). For both groups, the highest eco-efficiencies were observed in the months when nitrogen fertilization did not occur. Nevens et al. (2006) found eco-efficiencies of top-performing European farms between 60 and 110 L milk kg^{-1} N surplus. These values are similar to the results of our study and depend on productive aspects as genetics, milk yield, and nutritional management.

The phosphorus eco-efficiency in group 1 varied from 150 to 472 L milk kg^{-1} P surplus, while that in group 2 ranged from 190 to 468 milk kg^{-1} P surplus (Table 3). For potassium, these respective values were 38 to 274 L kg^{-1} K surplus and 44 to 205 L kg^{-1} K surplus for groups 1 and 2, respectively (Table 4). For both elements, the highest eco-efficiencies were observed in the months of May and July, coinciding with the higher milk yields for both groups. Studies evaluating these indicators are non-existing, but crucial to allow a higher decision power in dairy system operation.

In production systems with inadequate or erroneous nutritional management, eco-efficiency gains are faster and more noticeable, since nutrients are used in excess. In contrast, in adequately managed systems, eco-efficiency gains occur relatively slowly. This is a challenge for present and future dairy systems, as best practices are increasingly common, making eco-efficiency gains more difficult to achieve. It is also necessary to do more studies that calculate eco-efficiency for the various production and environmental conditions of dairy production in order to establish benchmarks that allow monitoring the environmental evolution and comparing different production systems.

Conclusion

Nutritional management reduced nitrogen and phosphorus surpluses as well as the values of the environmental performance indicators. Based on this, it is possible to improve the environmental efficiency of dairy systems through improved nutritional management. The nutritional strategy evaluated in this study resulted in improved nutrient efficiency and reduced nitrogen and phosphorus losses. Future studies should evaluate the impacts on the nutrient budget of other productive improvements, such as nutrient availability in feed and nutritional supplements to increase P use efficiency, high-protein grass-clover pastures, as well as chemical fertilizer replacement by biologically fixed N and/or dairy manure and effluents.

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