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HERBAGE MINERAL NUTRITION INDEXED AS TOOLS FOR RAPID MINERAL STATUS DIAGNOSIS IN TROPICAL PASTURES

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ABSTRACT

The animal production sector in the tropics is increasingly becoming challenged with the limited availability of pastures. There is need therefore to explore other options to suppliment the available pastures. The objectives of this study therefore was to understand how herbage mineral dilution indices used in developed countries as tools for controlled fertilisation, could be adapted in a tropical environment where high seasonal variations with regard to availability occur in pastures. A 3-year study was carried out in La Réunion Island, Indian Ocean. Forty nine farms, with swards made of either temperate or tropical grasses, grazed or mowed, were visited between four and five times a year. Dry biomass and dry matter contents were reported at each sample collection; whereas mineral indices were calculated from chemical analysis with a view to generate relevant fertilisation recommendations. Although the dry matter (DM) values of less than 20% indicated a better stage of exploitation for the grasses, the data consistently indicate a decrease in the seasonal differences of dry biomass for grazed species. The use of indices, which combine both plant mineral status and pasture biomass, appeared relevant indicators for farmers and for pasture experts in tropical countries, and can be predicted through near infrared spectroscopy with an acceptable precision (R^2 = 0.80, 0.60 and 0.91, for nitrogen , phosphorous and potassium, respectively). With reduced cost of pasture feed analysis using the NIRS, farmers can be able to make informed decisions based on scientific data. Fertilisation is one of the potential options to improve pasture management as indicated by findings of this study. This is useful evidence-based information that could be incorporated in extension packages and resource materials for dissemination and subsequent adoption by livestock farming communities to improve produtivity.

Key Words: Dairy cattle, France, near infrated sepectroscopy, La Réunion Island

RÉSUMÉ

Le secteur de production animal sous les tropiques fait de plus en plus face au défi de la disponibilité limitée de pâturages. Il y a le besoin donc d'explorer d'autres options pouvant suppléé les pâtures disponibles. Les objectifs de cette étude étaient donc de comprendre comment index de dilution minéraux de l'herbage utilisé dans les pays en voie de développement comme outil de fertilisation contrôlé, pourrait être adapté dans un environnement tropical où une variation saisonnière élevée en ce qui concerne la disponibilité des pâturages existe. Une étude de 3 années a été exécutée dans L'Ile de la Réunion dans l'Océan indien. Quarante neuf fermes, avec swards fait d'herbes modérées ou tropicales, broutées ou fauché, ont été visitées quatre à cinq fois par an. La biomasse séchée et le contenu de la matière ont été rapportés à chaque collection d'échantillon ; tandis que les index minéraux ont été calculés à partir de l'analyse chimique avec une vue pour produire les recommandations de fertilisation pertinentes. Bien que la matière sèche (DM) de moins que 20% a indiqué une meilleure étape d'exploitation pour les herbes, les données indiquent régulièrement une diminution dans les différences saisonnières de biomasse sèche pour l'espèce broutée. L'usage des 'indices, qui combinent à la fois le statut de la plante et la biomasse de pâturage, apparaît comme indicateurs pertinents pour les fermiers et pour les experts de pâturages dans les pays tropicaux, et peut être prédit par la spectroscopie infrarouge avec une précision acceptable (R^2 = 0,80, 0,60 et

0,91, pour l'azote, phosphore et de potassium, respectivement). Avec le coût réduit de pâture nourrit l'analyse utilisant le NIRS, les fermiers peuvent pouvoir faire des décisions informées sur basé des données scientifiques. La fertilisation est une des options potentielles pour améliorer la direction de pâturages comme indiqués par les conclusions de cette étude. Cette information est beaucoup plus utile et peut être incorporée dans les packets d'extension et les matériels -ressource de diffusion et l'adoption subséquente de la communauté d'agriculture pour améliorer productivité des bétails.

Mots Clés: Les vaches laitières, France, approchent spectroscopie à infrarouge, L'Ile de la Réunion

INTRODUCTION

Swards in La Réunion Island, an oceanic tropical zone in the south-west India Ocena, are used for domestic herbivores, mainly dairy and suckling cattle, and pasture management is a major concern as the grass appears to be in excess in hot season with a drop in nutritive value, while there is a shortage in quantity the rest of the year (Blanfort *et al.*, 2000; Grimaud and Thomas, 2002). Like in many tropical countries, cattle farmers have to adapt various practices to overcome challenges of seasonal growth of the grass. Such practices as reflected in terms of stocking rate methods of grass exploitation - grazing or mowing -, field patterns - surface, shape and number of paddocks - , of fertilisation. Controlled mineral fertilisation practices are an important component for a sustainable management of grasslands but are not a common practice in Africa. For instance on the La Réunion Island, cattle farmers fertilise their pastures based on formulations designed for sugarcane, the first cultivated crop on the island, and also apply fertilisers in their pastures during the dry season (Grimaud and Thomas, 2002).

In developed countries, the assessment of available nutrients for the plants and the general recommendations on the level of phosphorus and potassium to apply on grasslands are based on classical soil analysis and average regional levels. Nitrogen is rapidly leaching in the soil and mid- or long-term recommendation cannot be easily derived from sole soil composition. Studies showed that sward management in these northern countries lean on the use of nutrient combined indices for nitrogen (IN) (Lemaire *et al.*, 1997), phosphorus (IP) and potassium (IK) (Duru and Thelier-Huché, 1997). These indices combine herbage mineral analysis and actual biomass measurement; compared with a standard optimum, they indicate a limiting factor or an eventual excess in the mineral feeding of the grass that the farmers can easily correct (INRA, 1997).

Agronomic studies have recently validated, in tropical conditions, the dilution process for N, P, and K established in temperate climate (Blanfort *et al*., 2000). The differences in dry biomass among pastures between seasons observed in La Réunion Island, compelled the local agricultural organisations to use herbage mineral nutrition index which are as easy to handle tools for better sward management. This study aimed at indicating that mineral nutrition index of pastures obtained with near infrared spectroscopy (NIRS) could be an important tool for rapid mineral status diagnosis and relevant fertilisation at least cost in tropical countries.

MATERIALS AND METHODS

Study area. La Réunion Island is a French overseas department located in the Indian Ocean at latitude of 21° South and longitude of 56° East, and lies East of Madagascar, and is 252, 200 ha in size. The island experiences two distinct seasons, namely, a cool season (CS) with some precipitation from mid-May to mid-November, and a hot season (HS) characterised by strong hurricanes the rest of the year. The island is volcanic, with several mountains higher than 2,500 m; these mountains cause increased precipitation on the eastern side of the island. Rainfall is irregular throughout the island for example, the south-west receives an annual average rainfall of 1000 mm, while the east cost receives 10 000 mm. Average minimum and maximum temperatures range from 17 to 20° C in CS, and 28 to 31° C during the HS. Nevertheless, differences in daily temperatures never vary by more than 10° C. Cadet (1980) defined four different land use types from the littoral to the top of mountains, namely (i) the urban areas, (ii) sugarcane plantations, (iii) orchards, market gardens and pastures, and (iv) forests. From the littoral to the highlands, pastures cover up 10250 ha and vary from tropical forages to temperate grasslands (Grimaud and Thomas, 2002). The nature and plant covers of these pastures are tropical: *Chloris gayana* (rhode grass), *Pennisetum purpureum*, *Setaria anceps*, and *Brachiaria decumberns*. Only one tropical grass, namely kikuyu (*P. clandestinum*) grows at altitude over 1,000 m. Pastures in the high altitudes are temperate, and were recently improved with introductions of *Lolium perenne* and *Dactylis glomerata*.

Farmers' practices and samples collection. On a voluntary basis, a selection of forty nine cattle farms, representing about one-third of the inventoried farms in La Reunion island and scattered in the whole island, were used in the study and these included both Midlands (altitudes ranging from 800 to 2000 m) and the littoral, over a period of 3 years from the year 1 when pastures recommendations were made. These farms were representative of the geographical relief and climatic conditions prevailing on the island. All the farms in Midlands were organised in paddocks made of either kikuyu grass or improved temperate grasses. They were all fenced and rotationally grazed. On the littoral, rhodes grass was mainly used to conserve forage in the form of hay or silage; it was hardly grazed and its management was different from other grasses. Quite often, it was also organised in irrigated paddocks, and farmers harvested it 6 to 9 times a year. For both pastures and *C. gayana* plots, the average size of paddocks was close to 1 ha. On each paddock, four to five times a year - 2 minimum per season - grass sampling was done 6-10 times depending on total area and sward homogeneity, using a metallic quadrant of 50 cm^2. The quadrants were located in areas of pure grass. The grass was cut at an average height of 5 cm, representing the forage part eaten by the animals or cut for fodder conservation. The harvested fresh grass from each paddock was weighed using a Salter balance, England, 2000 ± 20 g and a representative sample of approximately 1 kg of green grass was taken to the laboratory for further analysis. The grass was categorised into three types and these included (i) improved temperate grasses consisting mainly of *L. perenne* and *D. glomerata*, (ii) kikuyu grass, and (iii) rhodes grass. The season of sampling was referenced as either CS or HS, depending on the period of collection. A total of 682 samples was collected of which, 57% was obtained in the cold season and 43% in hot season.

Chemical analysis. Dry matter contents of forage in the laboratory was determined by drying at 80^o C for 48 h, while phosphorus and potassium were determined using both the atomic absorption spectrophotmetry and continous flow colorimetry. Nitrogen (N) was determined by the Kjeldal method on dry samples (AOAC, 1990). The whole collection of dried samples was sent Cirad in Montpellier for analysis using a near infrared reflectance spectroscopy method (NIRS system 6500, 400-2492.8 nm).

Data management and statistical analysis. The dilution indexes for N, P and K mineral elements in forage were calculated following procedures described by Salette and Lemaire (1981) for N, and Duru and Ducroq (1997) for P and K, and as validated on La Réunion Island by Blanfort (1998) and Blanfort *et al.* (2000), and based on equations described in Table 1. According to NIRS calibration models (Lecomte *et al.*, 2003), IN, IP, and IK indexes were predicted based on the whole set of samples. Spectral and reference data were calibrated with Modified Partial Least Squares procedure and analysed using SAS (2000). The data (i) collected on the fields (dry biomass), (ii) obtained in laboratory (dry matter contents), and (iii) calculated (IN, IP, and IK), were subjected to analysis of variance (ANOVA) following the GLM procedure of SAS (2000).

RESULTS

DM contents and dry biomass. Data on dry matter contents and dry biomass are presented in Figure 1. They were both significantly influenced by the year, the season, and the nature of the grass (P <0.001). The availability of swards made of

TABLE 1. Calculation of nitrogen (IN), phosphorus (IP) and potassium (IK) indexes, according to the nature and the productivity of the forage

Nitrogen (IN)	Forage in C_3, with DM productivity > 1 t ha^{-1}	100 x (4.8 - 4.8 x $DM^{-0.32}$ + N) / 4.8
Nitrogen (IN)	Forage in C_3, with DM productivity < 1 t ha^{-1}	100 x (N / 4.8)
Nitrogen (IN)	Forage in C_4, with DM productivity > 1 t ha^{-1}	100 x (3.6 - 3.6 x $DM^{-0.4}$ + N) / 3.6
Nitrogen (IN)	Forage in C_4, with DM productivity < 1 t ha^{-1}	100 x (N / 3.6)
Phosphorous (IP)	-	100 x 4.17 P x $N^{-0.64}$
Potassium (IK)	-	100 x 0.62 K x $N^{-0.48}$

DM = Dry matter

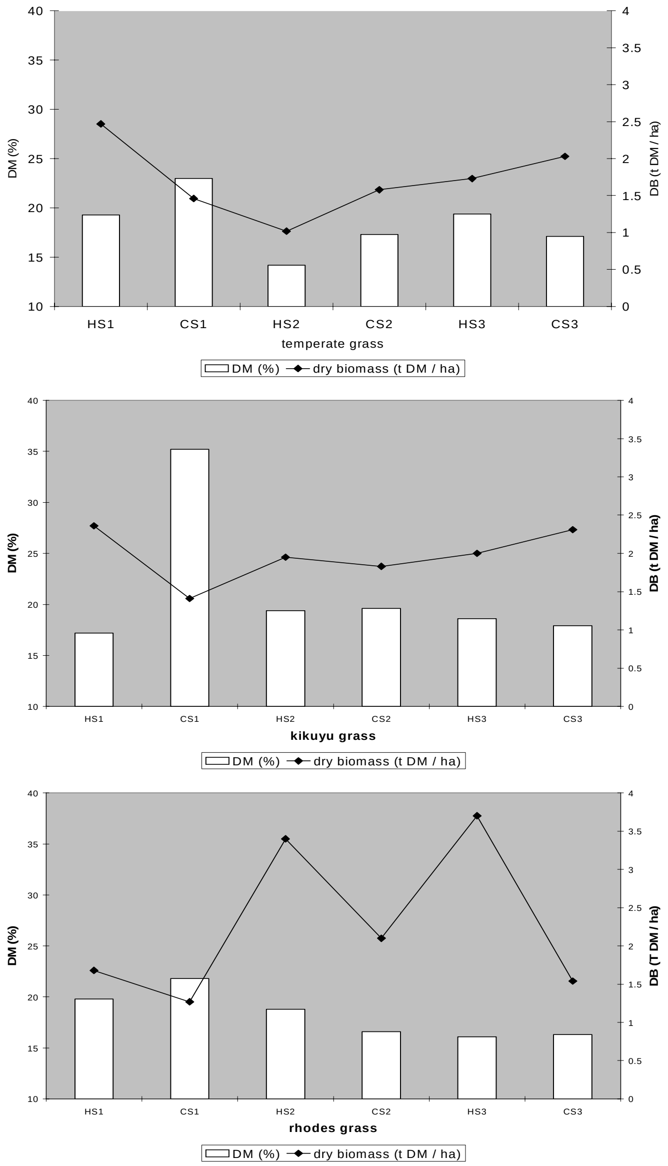

Figure 1. Dry biomass (t DM ha^{-1}) and DM (%) of temperate grass, kikuyu grass and rhodes grass. CS: cold seasons; HS: Hot season in La Reunion Island.

kikuyu and temperate grasses in terms of dry biomass were different between seasons at the beginning of the study. A lower value was observed in cold season, while plant dry matter was observed to increase; for *C. gayana*, both the decrease in dry biomass and the increase in DM contents occurring in CS were less significant. A significant interaction (P < 0.05) between the season and the nature of the grass occurring only for the dry biomass indicated a higher seasonal effect on *C. gayana* yields compared to grazed pastures. Dry matter contents were not significantly different between CS and HS for all the grasses year-2 and year 3- of the study.

Mineral dilution indexes. Calculated dilution indices of N, P, and K over the study period are presented in Table 2, and were compared to the ideal values of 80 (IN) and 100 (IP and IK) for a good herbage growth. Season (P < 0.01), nature of the grass (P < 0.001) and year (P < 0.001), significantly influenced nutrition indexes, with a significant interaction (P < 0.05) between the season and the nature of the grass also occurred for IN. Table 3 illustrates the relationships between calculated and NIRS predicted nutrition indices. A range of indexes between 19 - 106 (IN), 38 - 143 (IP), and 29-199 (IK) were obtained. The lowest correlation coefficient was obtained for IP (Table 3), although IN and IK had correlation coefficients greater than 0.8. The precision of herbage N index was higher when separate equations were used for either tropical or temperate forages (Table 3).

DISCUSSION

Grass production over the year. The observation on grazed pastures (temperate and kikuyu grass) that we made at the onset of out study was in accordance with the situation in tropical countries: the cold and dry season corresponds to a decrease in forage production, despite a dramatic increase in DM contents (INRA, 1989; Minson, 1990; Brégeat *et al.*, 1994), and farmers have to cope with an excess of forage at certain periods of the year, while a lack of pastures could occur the rest of the year. Grimaud *et al*. (2001) observed that, in dryer western areas of the island, farmers must give up rotational grazing at the

TABLE 2. Evolution of nitrogen (IN), phosphorus (IP) and potassium (IK) indexes of the temperate grasses, kikuyu grass and *Chloris gauana* from year 1 to year 3

	Temperate grasses						Kikuyu grass						Chloris gayana						SE[2]	SS[3]
Year	1		2		3		1		2		3		1		2		3			
Season[1]	HS	CS	HS	CS	HS	CS	HS	CS	HS	CS	HS	CS	HS	CS	HS	CS	HS	CS		
n	21	24	23	87	55	14	51	75	41	117	57	40	11	14	22	13	10	7		
IN	37	51	68	60	53	55	37	29	40	45	41	43	52	60	33	46	31	71	8.4	S** N;Y*** NS:NY***
IP	92	83	97	90	91	86	100	73	96	92	93	97	83	89	84	80	88	79	11.2	S;N:Y*** NY***
IK	106	91	124	107	127	110	132	83	115	126	141	148	75	87	84	100	146	16.8	S;N;Y***	

[1]HS: hotseason; CS: cold season; [2]SE: standard error; [3]SS: statistical significance. S; effect of the season; N: effect of the nature of grass; Y: effect of the year; NY: interaction nature of the grass x year; *P < 0.05; ** P < 0.01; *** P < 0.001

TABLE 3. Parameters of the NIRS model predicting nitrogen (N) and dilution indexes for nitrogen (IN), phosphorous (IP) and potassium (IK)

Item	n	Mean	SD	SECV	R2
N	864	2.48	0.71	0.12	0.97
IN^1 (C3 or C4)	873	62.7	17.0	7.54	0.80
IN^2 (C3 and C4)	848	76.1	22.6	10.99	0.76
IP	880	90.5	19.2	12.17	0.60
IK	808	112.9	28.8	8.85	0.91

IN^1: Nitrogen index predicted from separate equations of forages in C3 and C4; IN^2: Nitrogen index predicted from unique equation for forages in C3 and C4; N: number of samples used in the prediction model for each parameter; SD: standard deviation; SECV: standard error in cross validation; R^2: coefficient of determination

end of cold season due to lack of roughage. Dry biomass increased during the hot season, a period corresponding to high rainfall intensities, and these first rains result in high productivity of pastures that cannot be eaten or managed by the only cattle. Consequently, farmers begin the hot season with a high plant cover in quantity but of lower quality (Blanfort *et al.*, 2000). They meet difficulties in making it totally ingested by their herd: swards are consequently often undergrazed, with consequences that could be as critical as overgrazing. Thomas and Grimaud (2002) observed that such management practices generally lead to development of invasive species, such as *Sporobolus fertilis*, a non-palatable grass which can disappear with more rational farmers' practices that must combine adequate fertilisation with intensive exploitation. *Acacia mearnsii*, an exotic shrub introduced from Australia to regenerate the fallow lands, appears to be the ultimate and non-reversible stage of this degradation (Balent *et al.*, 1998). However, at the lowest altitudes of some regions in the Midlands, swards comprise of both kikuyu grass and temperate grass and thus farmers can manage it differently while taking advantage of both forages (Thomas and Grimaud, 2002). During CS, temperate grasses are the most dominant pastures with small kikuyu cover remaining under *D. glomerata* or *L. perenne* and kikuyu grass dramatically grows on the onset of the first rains and dominants the sward.

The cut-and-carry or cut-and-conserve management of *C. gayana* makes both the decrease in dry both biomass and the increase in DM contents occuring in CS less significant. Furthermore, farmers were able to reach higher yields of forage production in HS with lower DM contents. This management of the grass through silage making has progressively been adopted with temperate grass by the farmers, and the number of silage balls has dramatically increased on the island (Grimaud and Thomas, 2002).

A higher DM content of grazed tropical grasses. The increase in DM content in CS the first year of our study, was dramatically higher for kikuyu grass than temperate grasses. This increase is a function of water evaporation and is exacerbated by the physiological characteristics of this tropical and non-cespiteous grass: plants are leafy in hot and rainy season and contain a greater percentage of stems with maturity at the onset of the dry and cold season. In addition, tropical forages are known to have a lower nutritional value than temperate forages (INRA, 1989). Kikuyu DM contents greater than 30% lead to roughage utilisation at too old stages so as to guarantee an optimal nutritive value of forage, despite this grass present a compromise in the evolution of nutritional values between temperate and other tropical forages, as previously described by Grimaud *et al.* (2002), attributed to the influence of altitude. In some other tropical countries located in similar latitudes to Réunion Island, pastures made of tropical grasses during the dry season can present DM values similar to those of straw (Brégeat *et al*., 1994; Grimaud *et al*., 2006), although this does not interfere with palatability (Brégreat *et al*., 1994). Nevertheless, these high DM contents were not evidenced for *C. gayana*, another tropical grass but managed by regular cuttings, even if at the beginning of our survey a light increase was also observed from HS to CS. Grazed temperate forages, with a lower increase in DM content in CS, showed better resistance to cold and dry periods, as previously observed by Morand-Fehr and Doreau (2000).

Study benefits. Among other recommendations, like rotational grazing rhythms or stocking rates depending on the season and transfer of HS forage surpluses as silage to feed the animals during the CS, grazing management experts focused to a seasonal and sward-adapted fertilisation to cope with poor sustainability of pastures in Réunion Island. Experts principles were gathered in a technical guide distributed to the farmers (Barnet-Massin *et al.*, 2005), and throughout the survey, these recommendations led to an increase in dry biomass during CS, combined with a decrease in DM contents. Farmers progressively adapted the fertiliser quantities applied on pastures both to the season and to the animals' withdrawal, with the objective of not reaching the climatic potential of the sward but rather maintain its quality high. Rhodes grass also succeeded in increasing their biomass production, while reducing the DM contents, and consequently improving the nutritive value of *C. gayana*. The significant effect of the season on all mineral indices evidenced lower mineral dilution in grasses in CS. However, very low IN values, whatever the season in the first year of the survey can be attributed to poor fertiliser management within fields; the low IN values also suggest low availability of N, which inhibited pasture growth potential, especially in CS. The calculated IP and IK in year 1 for kikuyu and temperate grass pastures were higher during the hot season and close to the threshold values reported by Blanfort (1998) for a good herbage growth. High IK values valued registered by this study were attributed to the rapid absorption of K by the plant roots, despite all the soil analysis evidenced K deficiencies in tropical conditions (Blanfort *et al.*, 2000). These values can be considered as the climatic potential of the forage growth that can be valorised by animals. However, lower indices could meet the animals' requirements with a lower withdrawal from the sward. This phenomenon points out the need to combine the index values with the height of the grass. Our results are evidence that an adapted fertilisation was one of the potential ways to improve pasture management, and thus to take a higher financial advantage from dairy or suckling cattle exploitation.

The potential of NIRS prediction. The increase in herbage dilution indices from year-1 to 3 attests to the improvement of farmers' practices, and the support of NIRS in a rapid knowledge of these indices could allow both the farmers and the technicians to use them as tools to control the benefit of changes in farmers' practices. Although NR ability to predict direct nitrogen content is classical, its use is generally less relevant for other elements. However, as the concern is more related to the appreciation of a combined index, it was challenging to test the potential of NIRS to predict and classify these samples based on mineral levels of grasslands. Through the precision of the relationship appears lower for nitrogen and phosphorous indexes than what is generally observed when calibrating with the optimum standard of 80 (IN) or 100 (IP and IK). The low correlation observed on IP values could be attributed to the depressive effect of N supply on P contents of the forage, as Blanfort *et al.* (2000) observed that inadequate supply of phosphorous during growth and development of pastures leads to a larger probable reasons to explain this is prediction of the feeding value of the forage, as reported by Coleman et al. (1999).

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