DOI: 10.5433/1679-0359.2019v40n6Supl2p2917

Nitrogen variable rate in pastures using optical sensors

Taxa variável de nitrogênio em pastagens utilizando sensores ópticos

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Abstract

The use of optical sensors to identify the nutritional needs of agricultural crops has been the subject of several studies using precision agriculture techniques. In this work, we sought to overcome the lack of research evaluating the use of these techniques in the management of nitrogen (N) fertilizer in pastures. We evaluated the methodology of the nitrogen sufficiency index (NSI) in N management at variable rates (VR) using a portable chlorophyll meter. In addition, the use of color vegetation indices generated from a digital camera was evaluated as a low-cost alternative. The work was conducted in four management cycles at different times of year, evaluating the productivity and quality of *Brachiaria brizantha* cv. Xaraés grass. Three NSIs (0.85, 0.90 and 0.95) were evaluated, applying complementary doses of N according to the response of monitored plots using a chlorophyll meter and comparing the productivity and leaf N content of these treatments to the reference treatment (T_{REF}), which received a single dose of N (150 kg ha^{-1}). Together with these treatments, plots without N application (control) were analyzed, totaling five treatments with six replications in a completely randomized design. The dry mass productivity and N leaf concentration of the VR treatments were statistically equal to T_{REF} in all management cycles ($P < 0.05$). Most color vegetation indices correlated significantly ($P < 0.05$) to the chlorophyll readings. The use of NSI methodology in pastures allows the same productivity gains, with significant input savings. In addition, the use of digital cameras presents itself as a viable alternative to monitoring the N status in pastures.

Key words: Precision agriculture. NSI. Vegetation index. *Brachiaria brizantha*. Xaraés grass.

Resumo

O uso de sensores óticos para identificação das necessidades nutricionais de culturas agrícolas tem sido objeto de diversas pesquisas empregando técnicas de agricultura de precisão. Nesse trabalho buscou-se suprir a carência de pesquisas avaliando o emprego dessas técnicas no manejo de adubo nitrogenado (N) em pastagens. Avaliamos a metodologia do índice de suficiência de nitrogênio (NSI) no manejo de N a taxa variada (VR) com o uso de um medidor de clorofila portátil. Além disso, avaliou-se o uso de uma câmera digital como uma alternativa de baixo custo. O trabalho foi conduzido por quatro ciclos de manejo em diferentes épocas do ano, avaliando a produtividade e qualidade do capim *Brachiaria brizantha* cv. Xaraés. Foram avaliados três NSIs (0,85; 0,90 e 0,95), aplicando doses complemantares de N de acordo com a resposta da planta monitorada com o medidor de clorofila, comparando a produtividade e teor

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Received: Aug. 17, 2018 - Approved: Mar. 07, 2019

de N foliar desses tratamentos com o tratamento de referência (T_{REF}), que recebeu uma dose única de N (150 kg ha^{-1}), conforme recomendações tradicionais. Junto com esses tratamentos foram analisadas parcelas sem aplicação de N (controle), compondo assim cinco tratamentos, com seis repetições, em delineamento inteiramente casualizado. A produtividade de massa seca e de N foliar dos tratamentos a VR foi estatisticamente igual a T_{REF} em todos os períodos avaliados ($P < 0,05$). A maioria dos índices de vegetação aplicados às imagens obtidas com a câmera digital se correlacionaram significativamente ($P < 0,05$) com as leituras realizadas com o clorofilômetro portátil. O uso da metodologia do NSI em pastagens permite os mesmos ganhos de produtividade, com economias significativas de insumo. E o uso de câmera digital apresenta-se como uma alternativa viável ao monitoramento do status de N em pastagens.

Palavras-chave: Agricultura de precisão. NSI. Índice de vegetação. *Brachiaria brizantha*. Xaraés.

Introduction

Brazil has one of the largest cattle herds in the world, with 171.9 million head of cattle, and a pasture area equivalent to 158.6 million hectares. Of these, 11.8 million hectares are in unproductive conditions (IBGE, 2017), representing a challenge to the development of the activity, regarding the recovery and pastures management.

Inadequate pasture management in Brazil, leading to abandonment of degraded areas, is an object of international concern. Among the commitments made by Brazil at COP 21 (Conference of the Parties) is the commitment to recover 15 million hectares of degraded pasture. This and other actions are aimed at meeting the global goal of reducing greenhouse gas emissions by 43% by 2030 (ONU, 2015).

Pastures are the main source of nutrition for cattle, and are the most practical and least costly system of animal nutrition (BERNARDI et al., 2016; CAMARGO et al., 2002). They are fundamental in the practice of extensive cattle raising, the predominant production system in the country. And when well-managed, mass available in the dry season may be appropriate to cattle kept in tropical grass pastures, for example (SILVA et al., 2017).

Fertilizer application is one of the most important processes in the determination of yield and quality of forage (BERNARDI et al., 2016). Among the macronutrients required for plant development, nitrogen (N) is of fundamental importance. Insufficient supply of N for crops generally leads to reduced photosynthetic capacity due to lower synthesis of chlorophyll and consequently reduces the production of biomass and crude protein (BASSO et al., 2016; WANG et al., 2014; MUTANGA et al., 2004), reducing the quality and efficiency of agricultural activity. However, excessive application of nitrogen fertilizers can lead to environmental problems, such as groundwater contamination and atmospheric pollution (BASSO et al., 2016; GRACE et al., 2011), in addition to causing economic losses and decreased application efficiency.

The identification of the variability of the nutritional needs of the plants in the field is best for the efficient application of nitrogen fertilizers, accounting the variability between organisms and the biogeochemical processes to which the N in the soil is subject. Knowing the spatial variability of this attribute, it is possible to apply precision agriculture techniques, which allow increased productivity, reducing the use of inputs and environmental impact through site-specific management (HE et al., 2016; SABERIOON et al., 2014; BASSO et al., 2013; PERALTA; COSTA, 2013; ROBERTSON et al., 2012). However, the benefits reached using precision management techniques depend on the accuracy of the variability identification (BASSO et al., 2016). In addition, traditional methods of identifying plant attributes in large areas require detailed samplings and expensive laboratory procedures (MUTANGA et al., 2004).

The spectral reflectance of leaves or the canopy has a high correlation with the foliar N status of agricultural crops (LI et al., 2014) due to its role in the formation of chlorophyll molecules. Remote sensing of chlorophyll or foliar N content can provide information on the spatial variability of plant nutrient availability, constituting a low-cost alternative to conventional analyses (BASSO et al., 2016; HUNT JR. et al., 2013; GITELSON et al., 2005).

The American Potash and Phosphate Institute (PPI) published a methodology for N prescription at variable rate by comparing the chlorophyll content of a reference plot to the chlorophyll content of the field that would receive nitrogen, using an SPAD-502 device. In the reference plot, with small dimensions and located near the field to be treated, a high dose of N is applied. This comparison is performed by calculating a Nitrogen Sufficiency Index (NSI) (FRANCIS; PIEKIELEK, 1999).

This methodology was initially proposed for grain crops (corn and wheat), but due to its practicality and low cost, it can also be presented as a viable alternative to pasture management in Brazil. Villar et al. (2015) used this methodology in crops of *Brachiaria decumbens*, obtaining satisfactory results in terms of productivity and economy of input. There is a predominance of grasses of the genus *Brachiaria*, representing approximately 80% of the total pasture cultivated in Brazil (CASTRO et al., 2013). There is a great variation of cultivars of these forages, some of which, although present morphological and structural differences, in general presenting good nutritive value and good leaf/stem ratio (FONTES et al., 2014). Among these, *Brachiaria brizantha* cv. Xaraés stands out for its high nutritional value, greater forage production, rapid regrowth after grazing, moderate resistance to grasshopper, greater support capacity during the rainy season, and higher annual productivity in low natural soil fertility compared to similar varieties (VALLE et al., 2004).

For the acquisition of data in extensive areas, such as pasture areas destined for Brazilian herds, the use of SPAD, although effective, may present some limitation as to the representativeness of samplings. Several works using different crops were performed to study the use of digital domestic cameras as remote sensing tools, replacing the SPAD in the mapping of N status (COSTA et al., 2015; SABERIOON et al., 2014, JINWEN, 2014; WANG et al., 2014). However, there are neither works using conventional cameras to identify N status in pastures using the NSI methodology for application of nitrogen fertilizer at variable rates.

The information, based on spectral bands of red and green recorded with conventional cameras, is robust enough to provide information about N status in plants, even using relatively simple optics of this type of camera and automatic white balance. This information is comparable to dedicated instruments using infrared and red bands (LI et al., 2010). Gitelson et al. (2002) suggest that the intensity of reflectance in the green and red bands could be used as an alternative to red and infrared bands to measure some plant properties.

Given the importance of the application of N in pastures to provide a quality feed for ruminants and the scarcity of scientific studies addressing the application of precision agriculture techniques to the management of forage plants, this work has the following objectives: a) to evaluate the use of a portable chlorophyll meter using different NSIs for a nitrogen fertilization recommendation at a varied rate in *Brachiaria brizantha* cv. Xaraés; b) to evaluate the application of N at a variable rate in forage yield; c) to evaluate different vegetation indices applied to the RGB bands in the recommendation of nitrogen fertilization at a variable rate from images obtained with a conventional camera; and d) to evaluate the possibility of using this camera to replace the SPAD in the evaluation of N status in Xaraés pastures.

Materials and Methods

Experimental area

The experiment was implemented in the farm of EPAMIG (Agricultural Research Company of Minas Gerais State), Leopoldina City, Brazil, in a field established with *Brachiaria brizantha* cv. Xaraés, latitude 21° 28'22 '' (S) and longitude 42º43'18 " (W) and an altitude of approximately 187 m. The soil of the experimental area is classified as Red-Yellow Alfisol, terrace phase, with a loamy texture.

Characterization and preparation of the experimental area

Initially, soil sampling for fertility correction was performed on March 14, 2016. The samples were collected in the 0 to 20 cm layer at random points. The similarity between the chemical analysis of the samples allowed the experiment to be conducted in a completely randomized design.

Between March 15 and 20, the pasture was lowered by grazing, followed by a standardization cut with a tractor-cutter five centimeters from the soil, and removal of excess cut plants from the parcels.

Fertility correction was performed according to the recommendation of the 5th approximation (RIBEIRO et al., 1999), except for nitrogen. On March 21, liming was performed to correct soil acidity, with a dose of 1.3 t ha^{-1} (PRNT = 76%) applied at the beginning of the experiment. In addition, each plot received doses of 500 kg ha^{-1} of simple superphosphate and 100 kg ha^{-1} of potassium chloride.

The methodology, originally applied for corn and wheat by Francis and Piekielek (1999), determines the complementary doses of N for these crops, when the calculated NSI is less than 0.95. The NSI can vary between 0.71 and 0.99, being characteristic of each crop and even different varieties (COSTA et al., 2015; SAMBORSKI et al., 2009). Costa et al. (2015) found a critical NSI of 0.85, for which there was no response of the Xaraés pastures in increase of productivity with additional applications of nitrogen. Thus, in present study the treatments were organized as follows:

T_0: control plot, without application of nitrogen fertilizer;

T_{REF}: reference plot, with application of 150 kg ha^{-1} of nitrogen fertilizer in a single dose of urea;

T_{85}: variable rate plot with fertilization at a variable rate, using thresholding NSI equal to 0.85;

T_{90}: variable rate plot with fertilization at a variable rate, using thresholding NSI equal to 0.90;

T_{95}: variable rate plot with fertilization at a variable rate, using thresholding NSI equal to 0.95.

These were allocated in plots of 4 m x 4 m spaced 1 m apart, with six replications totaling 30 experimental plots.

At the beginning, 50% (75 kg ha^{-1}) of the single dose of nitrogen fertilizer treatment was applied to each variable rate plot.

As a nitrogen management criterion, the Nitrogen Sufficiency Index (NSI) of the T_{85}, T_{90} and T_{95} treatments was calculated when the canopy of the reference plots (T_{REF}) intercepted 75% and 85% of photosynthetically active radiation. When this was lower than the thresholding NSI, a dose of N equal to 25% of the reference portion dose (equivalent to 37.50 kg ha^{-1}) was applied. For practical management reasons, and due to the short crop development cycle, two readings were performed between the first application and harvesting. Therefore, the complementary doses were divided in 25% of the reference dose, to be applied in the two evaluation moments, according to the culture nutritional needs. At the end of the cycle, the maximum possible of nitrogen applied in the variable rate plots would be equivalent to the reference dose. The doses were always applied at the end of the day to minimize urea volatilization and leaching.

The NSI calculation was performed according to Equation 1 (FRANCIS; PIEKIELEK,1999):

$$\mathrm{NSI} = \frac{\mathrm{SM_{vr}}}{\mathrm{SM_r}} \qquad (1)$$

where:

NSI - nitrogen sufficiency index;

SM_{vr} - chlorophyll content on the area to be treated by variable rate application; and

SM_r - chlorophyll content on the reference plot.

Chlorophyll Content

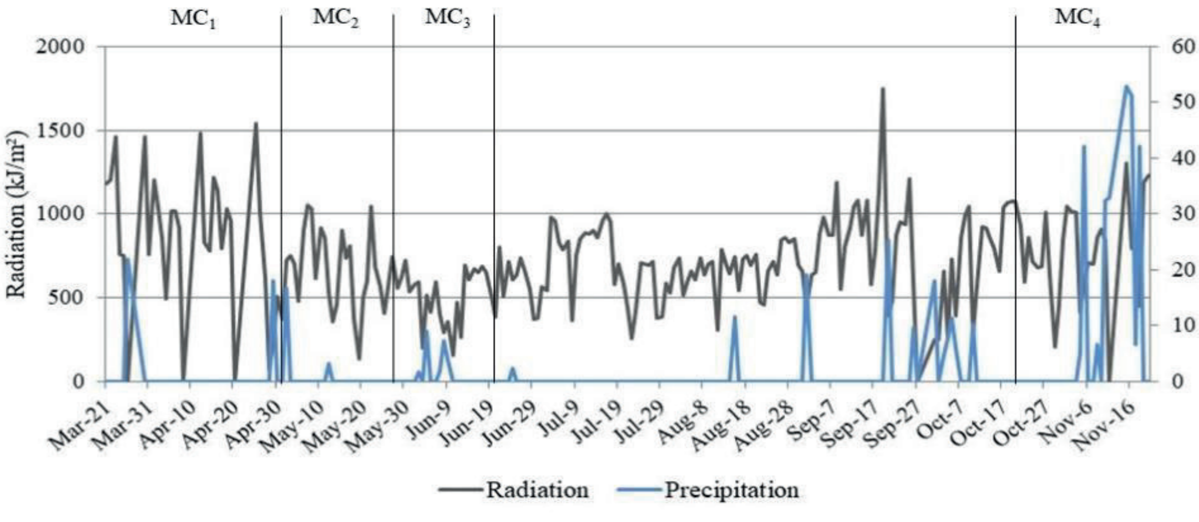
SPAD-502 (Minolta Corporation, Japan) has been used in much agricultural crop research to assist in decision-making for the application of nitrogenous fertilizers, including pastures (NETTO et al., 2005; PAGOLA et al., 2009; SABERIOON et al., 2013; VILLAR et al., 2015; WIDJAJA PUTRA et al., 2017). In each plot, 30 readings were performed by measuring different randomly selected, new and completely expanded leaves, with the equipment positioned in the intermediate portion of the leaf. After each measure, a step was taken in randomly directions along the plot, in order to selected leaves on different plant canopy. The average of SPAD 30 readings were used to calculate NSI using Equation 1.

Vegetal development and harvesting

Plant development was monitored using an AccuPAR LP-80 ceptometer (Decagon) by quantifying the intercepted photosynthetically active radiation (IPAR) by the plant canopy. Every two days, four IPAR measurements were performed within each reference plot at random points. When the reference plot IPAR average was 75% and 85%, the plants of treatments T_{85}, T_{90} and T_{95} could receive complementary fertilization (equivalent to 37.50 kg ha^{-1}), if necessary, according to the NSI.

The entrance of animals when plants reach 95% of IPAR is a strategy often used with tropical grasses (EUCLIDES et al., 2014; PEDREIRA et al., 2007). In addition, we monitored solar radiation and rainfall (Figure 1) with data acquired from a meteorological station of INMET (National Meteorological Institute).

Figure 1. Amount of solar radiation and rainfall during experimental period corresponding to four management cycles (MC).



Once the plants of the reference plots reached 95% of IPAR, a forage sample of 2 x 2 m was harvested by cutting at a height of 15 cm, located in the center of each plot, which simulated the forage height recommended to remove animals from the field (PEDREIRA et al., 2009). Sub-samples were dried in laboratory oven, and the dry mass yield for each plot was calculated as proposed by Detmann et al. (2012). Subsequently, the remaining vegetation was made uniform using a costal cutter, following the 15 cm height of the previously harvested crop, to restart a new management cycle.

Foliar N content, crude protein and N use efficiency

The oven-dried samples were also used to measure foliar N content using the Kjeldahl laboratory procedure and foliar crude protein (DETMANN et al., 2012).

Nitrogen use efficiency (NUE) was calculated for each treatment at the end of each management cycle, as the difference between the dry mass produced in N fertilized plots and the dry mass of the control (without application of N) plots, divided by the N rate applied (Equation 2).

$$\mathrm{NUE} = \frac{\mathrm{DM}}{\mathrm{N_{app}}} \qquad (2)$$

where:

DM - the difference between the yield dry mass of the N fertilized plot and the yield dry mass of the control plot;

N_{app} - the amount of N applied during the management cycle.

Color vegetation indices

Images were taken from plots under open-sky conditions between 12 and 14 hours using a conventional Sony Cyber-shot DSC-W710 camera attached to a frame at a height of 1.80 m that was pointed towards the vegetable canopies. The camera was to operate in automatic ISO mode and white balance in daylight mode, and the focus and exposure time functions were set in automatic mode. Three sequential images were taken from the central part of each plot, with a size of 1944 x 2592 pixels, representing an area of approximately 4.12 m^2 and a spatial resolution of approximately 1 mm $pixel^{-1}$.

The images were processed using Matlab software (version R2009b, The MathWorks, USA). Initially, the RGB bands were normalized by Equations 3, 4 and 5.

$$r = \frac{R}{R+G+B} \qquad (3)$$

$$g = \frac{G}{R+G+B} \qquad (4)$$

$$b = \frac{B}{R+G+B} \qquad (5)$$

where r, g and b are the normalized digital values of intensity of the red (R), green (G) and blue (B) bands respectively.

The mean values of digital numbers for each band were used to calculate the vegetation index (VI) (Table 1). Each VI was used as a spectral variable for NSI calculation to evaluate the best index for N status identification using a conventional digital camera.

Table 1. Color Vegetation Indices.

Name	Equation	Reference
Green Excess	$\mathrm{ExG} = 2 \times \mathrm{g} - \mathrm{r} - \mathrm{b}$	Mao et al. (2003)
Red Excess	$\mathrm{ExR} = 1.4 \times \mathrm{r} - \mathrm{g}$	Mao et al. (2003)
Blue Excess	$\mathrm{ExB} = 1.4 \times \mathrm{b} - \mathrm{g}$	Mao et al. (2003)
Green minus Red Excess	$\mathrm{ExGR} = \mathrm{ExG} - \mathrm{ExR}$	Mao et al. (2003)
Normalized Different Index	$\mathrm{NDI} = \frac{\mathrm{g} - \mathrm{r}}{\mathrm{g} + \mathrm{r} + 0.01}$	Mao et al. (2003)
Green Soil Adjusted Vegetation	$\mathrm{SAVI}_{\mathrm{green}} = \frac{(1 + \mathrm{L}) \times (\mathrm{g} - \mathrm{r})}{\mathrm{g} + \mathrm{r} + \mathrm{L}}$	Li et al. (2010)
RGB Normalized Difference Vegetation Index	$\mathrm{NDVI}_{\mathrm{rgb}} = \frac{\mathrm{g} + \mathrm{b} - \mathrm{r}}{\mathrm{g} + \mathrm{b} + \mathrm{r}}$	Widjaja Putra et al. (2017)
Green Normalized Difference Vegetation Index	$\mathrm{NDVI}_{\mathrm{green}} = \frac{\mathrm{g} - \mathrm{r}}{\mathrm{g} + \mathrm{r}}$	Gitelson et al. (2002)
Green Minus Red	$\mathrm{GMR} = \mathrm{g} - \mathrm{r}$	Wang et al. (2013)
Blue-Red Adjusted Vegetation Index	$\mathrm{BRAVI} = \frac{\mathrm{n} \times (\mathrm{g} - \mathrm{r})}{\mathrm{g} + \mathrm{r} + \mathrm{N}}$	Widjaja Putra et al. (2017)
Green Enhanced Vegetation Index 2	$\mathrm{EVI2}_{\mathrm{green}} = \frac{2.5 \times (\mathrm{g} - \mathrm{r})}{\mathrm{g} + 2.4 \times \mathrm{r} + 1}$	Widjaja Putra et al. (2017)
Green Optimized Soil Adjusted Vegetation Index	$\mathrm{OSAVI}_{\mathrm{green}} = \frac{1.5 \times (\mathrm{g} - \mathrm{r})}{(\mathrm{g} + \mathrm{r}) + 0.16}$	Widjaja Putra et al. (2017)

L = crop cover correction factor (assumed here to be 0.5); n = noise intensity, where noise intensity is equal

Data analyses

The results of the difference between the dry mass yield of the N fertilized plot and the dry mass yield of the control plot (DM) and the amount of foliar N (N_{DM}) were submitted to analysis of variance and Tukey's test for comparison of means at 5% probability, using the software Rstudio (R CORE TEAM, 2016). In addition, we evaluated the NSI thresholding that offers the best N use efficiency of N, considering the dry mass productivity and the amount of N applied.

The images were evaluated for the probability that the NSI, calculated from each vegetation index, indicates the same decision as NSI calculated from the SPAD measurements.

Results and Discussion

During four management cycles, plant development was monitored using the IPAR. The periods of each cycle, starting with cut and fertilization and continuing through the indirect evaluation of N status with the chlorophyll meter on two dates, at 75% and 85% of IPAR, until harvesting when IPAR was 95%, are shown in Table 2. After the end of the third management cycle (MC_3), it was decided to conduct the fourth management cycle (MC_4) in the rainy season, which began in October. Between MC_3 and MC_4, the plants were cut every 25 days to maintain the field in proper condition.

Table 2. Beginning and harvesting dates of each management cycle (MC) and SPAD measurement dates according to intercepted photosynthetically active radiation (IPAR) of reference plot plants.

Event	MC_1	MC_2	MC_3	MC_4
Beginning	03/21/2016	05/04/2016	05/27/2016	10/24/2016
75% of IPAR	04/14/2016	05/13/2016	06/03/2016	11/08/2016
85% of IPAR	04/21/2016	05/18/2016	06/07/2016	11/16/2016
95% of IPAR	05/02/2016	05/26/2016	06/20/2016	11/21/2016
Harvesting	05/03/2016	05/26/2016	06/20/2016	11/21/2016

Yield and forage quality

During the first management cycle (MC_1), NSI indicated the need for N fertilization in all treatments at variable rate (Table 3). The maximum applications number of nitrogen complementary doses (Z) would be 12 (six replications and two dates), representing how many times was applied 37.5 kg ha^{-1} (25% of the reference portion dose) in each treatment. $N_{initial}$ and N_{total} describe the averages doses applied at the beginning and end of the cycle to each treatment, respectively. All the variable rate treatments received, in average, less N_{total} than the reference plot since the number of complementary N doses were less than the maximum 12. There was a predominance of dry climate and high average temperatures, which may have contributed to the volatilization of urea and negatively affected N uptake after initial fertilization. In addition, because the field had not received fertilizer management before the beginning of the experiment, soil microbiota may have consumed most of the applied nitrogen. Although T_{85} treatment received the lowest average dose of N_{total} until the end of the cycle (81.25 kg ha^{-1}), its yield dry mass (DM) was statistically similar to other treatments at 5% of probability by the Tukey test. Likewise, the amount of foliar nitrogen (N_{DM}) was statistically similar in all treatments that received N, at 5% of probabilities by the Tukey test. Nitrogen use efficiency (NUE) was equivalent for almost all treatments that received N, except for T_{85}, which presented NUE 43% greater than the reference plot NUE.

The second and third management cycles (MC_2 and MC_3, respectively) tended to show higher-yield dry masses than treatments of MC_1, although they received less N until the end of the cycles (N_{total}) and environmental conditions unfavorable to plant development, with shorter days, lower temperatures and lower rainfall. The N_{total} applied in MC_2 and MC_3 was also inferior to the first management cycle, likely because of the residual effect of fertilization performed on MC_1. At the end of these management cycles, T_{85} and T_{90} received initial N doses (75 kg ha^{-1}) with MS statistically equal to the other treatments that received nitrogen fertilizer, resulting in a savings of 50% of the nitrogen fertilizer applied to these treatments. This result led to a better NUE for treatments receiving N at a variable rate, rather than treatment with a single fixed dose (T_{REF}). For an NSI thresholding of 0.85 (T_{85}), NUE was 179% higher than T_{REF} in the MC_3, which was the management cycle with worse climatic conditions for plant development.

The fourth management cycle (MC_4) presented the highest DM relative to the previous three cycles. The average yield dry mass of MC_4 was 2164.0 kg ha^{-1}, while those of MC_1, MC_2 and MC_3 were 891.4, 1135.4 and 993.2 kg ha^{-1}, respectively. This can be explained by the climatic conditions of the experiment, favoring the absorption of nutrients by the plants. The period was characterized by the highest temperatures, relative air humidity and rainfall. As in other management cycles, there was no significant difference in DM among the treatments that received nitrogen fertilization in the MC_4, even with better environmental conditions. T_{85} received the initial dose of nitrogen fertilizer during this management cycle, with NUE 142% higher than the NUE of the fixed N rate (T_{REF}).

Table 3. Nitrogen applied at beginning ($N_{initial}$) and until harvesting (N_{total}), applications number of nitrogen complementary doses (Z), yield dry mass (DM), foliar nitrogen (N_F), dry mass foliar nitrogen (N_{DM}), crude protein (CP) and nitrogen use efficiency (NUE) for each management cycle (MC).

Treatment	$N_{initial}$ (kg ha^{-1})	Z	N_{total} (kg ha^{-1})	DM* (kg ha^{-1})	N_F (%)	N_{DM}* (kg ha^{-1})	CP (%)	NUE
				MC_1				
T_{REF}	150	-	150	1156 a	1.92	21.75 a	11.98	4.80
T_{95}	75	9	131.25	996 a	1.87	18.25 a	11.68	4.26
T_{90}	75	4	100	873 a	1.71	14.98 a	10.71	4.37
T_{85}	75	1	81.25	995 a	1.53	15.16 a	9.58	6.88
T_0	0	-	0	437 b	1.38	5.81 b	8.62	-
				MC_2				
T_{REF}	150	-	150	1351 a	2.37	31.84 a	14.84	6.40
T_{95}	75	1	81.25	1482 a	2.32	34.03 a	14.51	13.43
T_{90}	75	0	75	1305 a	2.20	28.79 a	13.75	12.19
T_{85}	75	0	75	1184 a	2.14	25.32 a	13.38	10.58
T_0	0	-	0	391 b	1.52	5.90 b	9.52	-
				MC_3				
T_{REF}	150	-	150	970 a	2.80	27.25 a	17.52	3.47
T_{95}	75	3	93.75	1260 a	2.55	32.15 a	15.94	8.64
T_{90}	75	0	75	1111 a	2.48	27.71 a	15.52	8.81
T_{85}	75	0	75	1175 a	2.43	28.61 a	15.17	9.68
T_0	0	-	0	450 b	1.59	7.19 b	9.92	-
				MC_4				
T_{REF}	150	-	150	2293 a	2.11	48.13 a	13.21	8.96
T_{95}	75	4	100	2529 a	1.88	47.02 a	11.73	15.81
T_{90}	75	3	93.75	2474 a	1.73	41.29 a	10.82	16.28
T_{85}	75	0	75	2576 a	1.52	39.06 a	9.53	21.71
T_0	0	-	0	948 b	1.14	10.63 b	7.10	-

T_{REF} - reference; T_{95} - NSI thresholding of 0.95; T_{90} - NSI thresholding of 0.90; T_{85} - NSI thresholding of 0.85; T_0 - control; Z - number of nitrogen complementary applications; * - averages followed by same letter do not differ by 5% probability by Tukey's test.

Carloto et al. (2011) evaluated the nutritional value, canopy structure, forage intake and animal production in Xaraés pastures, managed at three different heights during the rainy period in Campo Grande, Mato Grosso do Sul state, Brazil. Applying a fixed dose of 100 kg ha^{-1} of N in the form of urea, the yield dry mass average was 6319 kg ha^{-1} for plants managed at 30 cm. The DM average obtained was approximately 2.5-fold higher than the DM in MC_4 of the present study. These differences may be due to differences in the harvesting method adopted in each study. The plants were cut close to the ground in the work of Carloto et al. (2011), while in the present work, the plants were managed with cuts at 15-cm high, simulating the height of the animals exiting the field. Thus, a great portion of dry mass produced by the forage remained in the area, composed of roots and plant parts up to 15 cm high. The management method adopted in the present study increases the speed of regrowth, since it conserves the apical meristem of the plants.

Pereira et al. (2011) applied 40.0 kg.ha^{-1} N and evaluated the yield dry mass of the cultivars Marandu and Xaraés during all seasons in the arid region of Vale do Jequitinhonha, Minas Gerais State, reaching 972.5 kg ha^{-1} for the Xaraés variety during the summer, during which the highest yield occurred, with values near to those obtained in the fourth cycle (MC_4) of the present study for the treatment without nitrogen fertilizer (T_0).

The dry mass foliar N (N_{DM}) in the plant fraction above 15 cm, corresponding to the plant portion consumed by the animals, followed the same trend as dry mass yield (DM) for most management cycles, with no significant difference among the treatments, except for the control plot. Therefore, the NSI threshold used in the variable rate treatments detecting the N losses may have occurred in the fixed rate treatment, since the variable rate treatments imposed the same amount of N_{DM} as the fixed rate treatment but also used less fertilizer.

The percentage of estimated crude protein (CP) ranged from 7.1 to 17.5% depending on the management cycle and treatment. Carloto et al. (2011) found a CP of approximately 11.2% for Xaraés forage pastures at 30 cm. Flores et al. (2008) found values from 9.6 to 11.1% depending on the canopy height. Pereira et al. (2011), working with Xaraés in all seasons, reached up to 12.6% of PB in the summer.

The N use efficiency (NUE) of the variable rate treatments were higher than the fixed rate treatment, except in MC_1, due to the field history and drastic uniformity cut performed at the beginning of the experiment. MC_1 required higher N for recovery and development of the plants. During MC_1, N losses by natural processes, such as volatilization and immobilization by microorganisms, must have occurred more intensely due to the nutritional deficiency of the field.

Lower NSI thresholding to apply N led to lower amounts of fertilizer during a management cycle, since it would require a greater difference between the SPAD readings of the reference plot and the field. Thus, NSI thresholding of 0.85 showed the best option for N management, with variable rate for Xaraés forage. The use of the methodology proposed by Francis and Piekielek (1999) adapted to pastures of Xaraés, using the SPAD chlorophyll meter, in addition to showing satisfactory results in terms of yield, can mitigate environmental impacts via the application of N excess, ultimately saving money in input application costs. Therefore, the use of the plant as a biosensor, allowing the effect of the local climate to influence the N dose, as proposed in the methodology used in the present work, leads to greater efficiency in the recommendation of N fertilization.

Use of conventional camera in the recommendation of nitrogen fertilization

The portable chlorophyll meter, although presenting itself as a practical apparatus for monitoring the foliar N status, has limitations in terms of the sampling area and required number of measurements. Its sampling area is only approximately 6 mm², and an average of 30 measurements are recommended by the NSI methodology, which, in addition to making the sampling process exhaustive, may compromise the representativeness in a large field with significant spatial variability of attributes. In this context, the use of remote sensing images plays an important role to enable the NSI methodology in large fields, since this would speed information acquisition and increase information representativeness.

Correlations between SPAD readings and color vegetation indices were significant ($P < 0.05$) for evaluated indices, for all dates and management cycles (Table 4), except ExB, BRAVI and ExGR. The correlation coefficients tended to be lower during MC_4 than the other management cycles, possibly due to the variation of illumination, with a greater presence of clouds during MC_4. This may influence the vegetation index values since no calibration was used to transform the pixel value into reflectance.

Table 4. Pearson correlation coefficients between vegetation indices derived from color camera and SPAD readings on each date of intercepted photosynthetically active radiation by vegetative canopy.

IPAR	75%	85%	95%	75%	85%	95%	75%	85%	95%	75%	85%	95%
Vegetation Indices	1st management cycle			2st management cycle			3st management cycle			4st management cycle		
ExG	0.5896**	0.6012**	0.5864**	0.7636**	0.7282**	0.5848**	0.7696**	0.8055**	0.7986**	0.1532	0.4308**	0.6951**
ExR	-0.7582**	-0.7760**	-0.7377**	-0.8561**	-0.8977**	-0.8252**	-0.8341**	-0.8031**	-0.8308**	-0.4986**	-0.7349**	-0.8186**
ExB	-0.2418	-0.1395	-0.3235	-0.4605	-0.0152	0.0880	-0.4315	-0.6836*	-0.6670*	0.0870	0.0971	-0.3526
ExGR	0.6699**	0.6899**	0.6551**	0.8148**	0.8251**	0.7268**	0.8061**	0.8096**	0.8151**	0.2812	0.5735**	0.7558**
NDI	0.7509**	0.7741**	0.7275**	0.8608**	0.9010**	0.8323**	0.8404**	0.8060**	0.8361**	0.4938**	0.7425**	0.8220**
$SAVI_{green}$	0.7456**	0.7680**	0.7331**	0.8565**	0.8951**	0.8243**	0.8362**	0.8055**	0.8317**	0.4741**	0.7263**	0.8156**
$NDVI_{rgb}$	0.8261**	0.8355**	0.8056**	0.8592**	0.9319**	0.8379**	0.8452**	0.7767**	0.8442**	0.6160**	0.8688**	0.8706**
$NDVI_{green}$	0.7509**	0.7741**	0.7275**	0.8608**	0.9010**	0.7051**	0.8404**	0.8027**	0.7626**	0.4938**	0.7425**	0.8220**
GMR	0.7378**	0.7570**	0.7178**	0.8485**	0.8837**	0.6077**	0.8287**	0.8060**	0.7024**	0.4419**	0.6971**	0.8042**
BRAVI	0.7612**	0.7816**	0.7548**	0.8722**	0.9202**	0.0571	0.8498**	0.8064**	0.2674	0.5491**	0.7887**	0.8426**
$EVI2_{green}$	0.7447**	0.7693**	0.7348**	0.8547**	0.8914**	0.6685**	0.8352**	0.8038**	0.7354**	0.4679**	0.7233**	0.8141**
$OSAVI_{green}$	0.7483**	0.7717**	0.7380**	0.8590**	0.8986**	0.7754**	0.8387**	0.8052**	0.8217**	0.4853**	0.7357**	0.8193**

**P < 0,05; IPAR - percentage of intercepted photosynthetically active radiation; ExG - Green Excess Index; ExR - Red Excess Index; ExB - Blue Excess Index; ExGR- Green minus Red Excess Index; NDI - Normalized Different Index; $SAVI_{green}$ - Green Soil Adjusted Vegetation Index; $NDVI_{rgb}$ - RGB Normalized Difference Vegetation Index; $NDVI_{green}$ - Green Normalized Difference Vegetation Index; GMR - Green Minus Red Index; BRAVI - Blue-Red Adjusted Vegetation Index; $EVI2_{green}$ - Green Enhanced Vegetation Index 2; $OSAVI_{green}$ - Green Optimized Soil Adjusted Vegetation Index.

The significant correlation between VIs and SPAD indicates the possibility of the use of conventional color cameras to target N status in Xaraés grass canopies. Based on this assumption, NSI was calculated using each significant VI instead of SPAD for all studied periods. This analysis was performed for the 18 plots that composed the three treatments that received variable rate doses of nitrogen (T_{85}, T_{90} and T_{95}). Figures 2 and 3 show the number of times decision-making based on SPAD reading coincided with VI value, when IPAR was 75% and 85%, respectively.

Figure 2. Number of times VI-based decision-making coincided with SPAD-based decisions when IPAR was 75%.

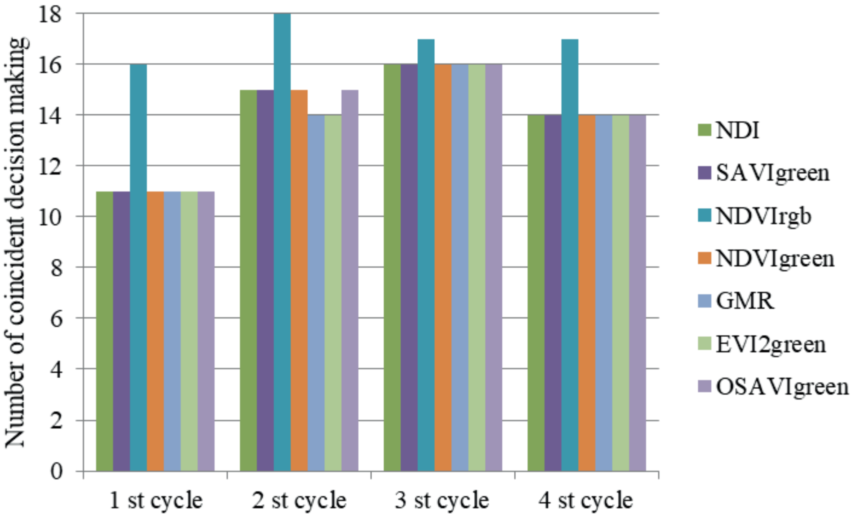
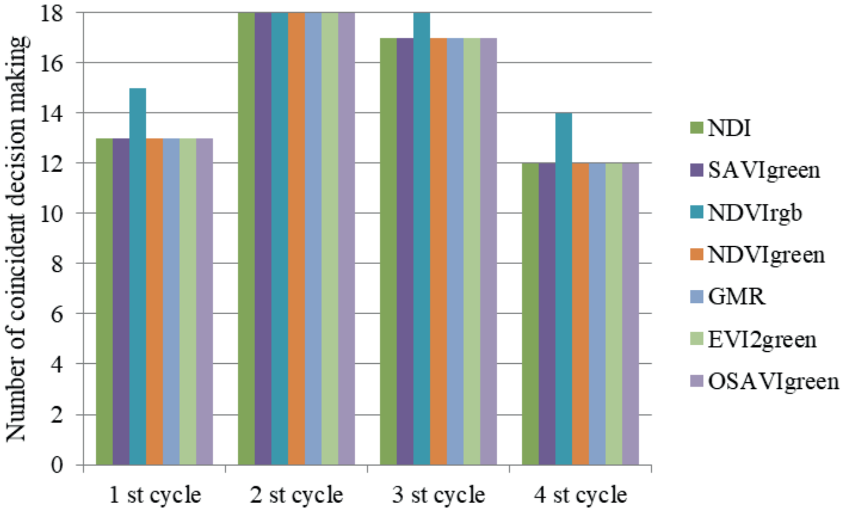


Figure 3. Number of times VI-based decision-making coincided with SPAD-based decisions when IPAR was 85%.



All indices were presented as potential alternatives in the use of conventional camera as a substitute for SPAD. However, the $NDVI_{rgb}$ index stands out. If this index was used as the input spectral variable in the NSI calculation, the decision based on this coincided more often than did the other VI evaluated.

This index is composed of three bands of the visible spectrum (R, G and B). Variation in the usual NDVI was based on the near infrared spectral band (NIR) and the R band (ROUSE et al., 1974). Leaf green intensity and N levels vary linearly with red band intensity (R) and the intensity of the green band (G). However, it can indicate the levels of N indirectly via observed reflection of the photosynthetic pigments. This intensity tends to vary within each level of foliar N. However, the linearity between G intensity and N levels can possibly be improved by including the intensity of the blue band (B) (WIDJAJA PUTRA et al., 2017).

Conclusion

This work evaluated the response of pastures of the Xaraés variety to nitrogen fertilization based on nitrogen sufficiency index methodology (NSI). In addition to using the SPAD-502 chlorophyll meter for indirect quantification of leaf N level, the use of a digital camera was evaluated as a low-cost alternative. At the end of the study, it was possible to draw the following conclusions:

The efficiency of N use was higher for the NSI of 0.85 since the dry matter and foliar N yields were statistically the same as for other treatments that received nitrogen fertilization.

The treatments with N application at varied rates showed greater efficiencies in dry matter production than the treatment that received a single dose, resulting in N use economy.

The application of vegetation indices using bands in the visible region can be used as a fast method to determine the nutritional requirements of N in pastures of *Brachiaria brizantha* cv. Xaraés through the NSI.

Most indices studied presented a strong correlation with SPAD readings, but the $NDVI_{rgb}$ index was best adapted to the conditions of the study.

Acknowledgments

The authors thank the National Research Council (CNPq) and the Agricultural Research Company of Minas Gerais state (EPAMIG), for the financial resources and support for the implementation of the project.

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