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USE OF ACTIVE OPTICAL SENSOR IN THE CHARACTERISTICS ANALYSIS OF THE FERTIGATED BRACHIARIA WITH TREATED SEWAGE

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ABSTRACT: Through the use of remote sensing, the productivity and the nutritional state of the plants can be estimated in relation to the nitrogen doses due to the modification of the canopy reflectance. In this study, values of the normalized difference vegetation index (NDVI) obtained by a terrestrial optical sensor were correlated with productivity and contents of nitrogen (N) and of foliar crude protein (CP) of *Brachiaria brizantha* cv. Marandu, fertigated with doses of sewage treatment effluent (STE) The NDVI average rates of the forage were obtained by the active terrestrial sensor (*GreenSeeker*) before the harvests that were realized every 28 days in 2014. Five fertigated treatments with the following fractions of STE in water were evaluated: E5 = 1.0; E4 = 0.87; E3 = 0.60; E2 = 0.31; and E1 = 0.11. During the 12 months of experiment, the treatment E5 received 1,132 kg ha^{-1} of N and the others received quantities proportional according to the application fractions defined in each treatment. The increasing application doses of STE resulted in higher yields of dry biomass and better leaf qualities in N and crude protein (CP). The productivity, the foliar N content and the NDVI index were increasing due to the gradual application of applied STE. There was a high linear correlation among the NDVI indexes and the productivity (r>0.9256) and with the N content (r>0.9570) and also for CP (r>0.8421) and leaf N (r>0.8339), demonstrating that the method can be used to estimate forage productivity and quality.

KEYWORDS: forage production estimation, *GreenSeeker*, terrestrial remote sensing.

INTRODUCTION

One of the applications of the geotechnologies use is the estimation of agricultural productivity and the nutritional status of the crops in a fast and precise way, due to the close relation between these variables and vegetation indices (Zerbato et al., 2016). The high correlation between biomass accumulation and vegetation indices occurs due to the high levels of chlorophyll in the plant, which varies according to the environmental conditions and crop management, such as nitrogen application, resulting in increments of leaf area and photosynthetic activity (Grohs et al., 2011).

The normalized difference vegetation index (NDVI) is an indicative of vegetation activity that enables to estimate the leaf area, the percentage of green cover and grain yield (Bredemeier et al., 2013). It is also possible to characterize soil chemical attributes (Zanzarini et al., 2013), to determine the chlorophyll content and green biomass of plants (Merotto Júnior et al., 2012), to characterize temporal series of phytoplankton in ponds (Lissner & Guasselli, 2013) and vegetation phytophysiology (Galvanin et al., 2014), and subsidize weed control (Merotto Júnior et al., 2012).

The determination of leaf quality, defined in terms of leaf nitrogen content, is an example of the potential of the application of the vegetation indices, since this variable can be readily correlated with NDVI (Bredemeier et al., 2013), while most methods based on chlorophyll meters and leaf analysis require a large number of leaf samples to identify the nutritional status of the crop in the field (Povh et al., 2008). Therefore, the obtaining of the NDVI data through terrestrial sensors allows fast assessment of productivity and foliage quality in relation to NDVI, without causing impacts by beddings on agricultural crops (Bredemeier et al., 2013).

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The *GreenSeeker* is one of these ground sensors that has been widely used to evaluate the performance of crops under variables doses of nitrogen, since the NDVI can indicate the nutritional status of the plant in relation to nitrogen (Grohs et al., 2011; Merotto Júnior et al., 2012; Bredemeier et al., 2013). These determinations can be performed local scale, as performed by Zanzarini et al. (2013) in an area of 32 hectares. The estimate of the crop quality in foliar nitrogen or crude protein, from a certain phenological stage of the plants, allows the nutritional management of the crop (Grohs et al., 2011).

In plants subjected to nitrogen stress, there is an increase in carotenoid concentrations and a reduction in chlorophyll production, which causes less energy absorption by leaves, reducing NDVI values (Motomiya et al., 2009). Nitrogen deficiency causes predictable changes in the development and composition of plant leaves and, indirectly, changes in spectral distribution of reflected radiation, which makes it difficult to estimate productivity (Motomiya et al., 2009).

The use of sewage treatment effluent (STE) can provide better leaf quality due to nutrient supply to crops (Matos et al., 2013). The nitrogen, a common element in STE, is one of the inputs that most influences the increase in productivity and the quality of the product harvested. This evidence was verified by Povh et al. (2008), in which the nitrogen supply increased yield of wheat, triticale, barley and maize and increased the green pigmentation of the plants, resulting in a higher concentration of leaf chlorophyll and, consequently, higher NDVI values.

In this study, the linear regression models were obtained between normalized difference vegetation index (NDVI), obtained by terrestrial optical sensor, with the productivity, foliar nitrogen (N) and crude protein (CP) content of biomass in the *Brachiaria brizantha* cv. Marandu fertilized with doses of sewage treatment effluent (STE).

MATERIAL AND METHODS

Characterization of the study area

The experiment was conducted during the year 2014 at the Faculty of Agrarian and Veterinary Sciences (FCAV - UNESP), in Jaboticabal, SP, located around the geographic coordinates of 21°14’41.9” S and 48°16’25.2” W (Figure 1).

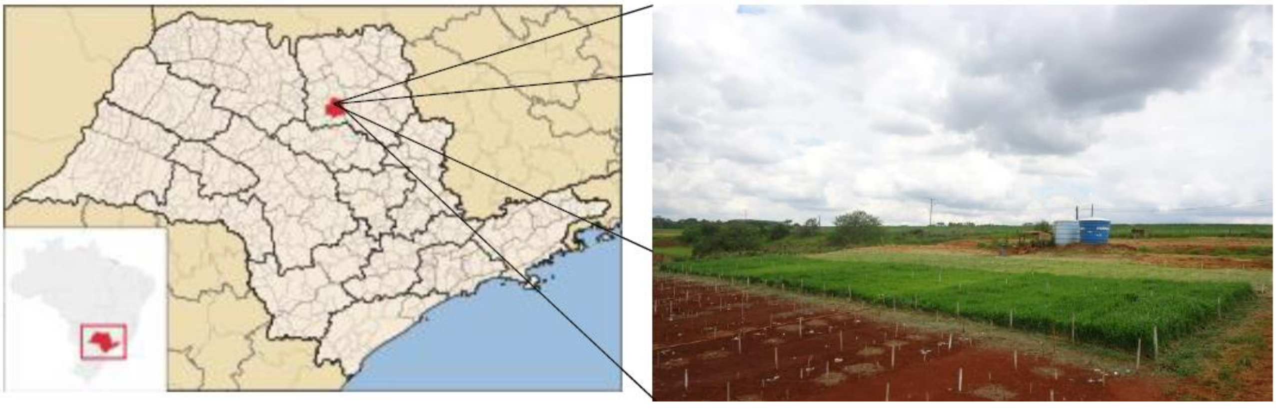


FIGURE 1. Location of the study area.

Effluent from the Dr. Adelson Taroco Sewage Treatment Station, located near the experimental area was used and the treatment system consists initially of mechanical railing (preliminary phase), followed by a mixed system (anaerobic and aerobic) composed of an upflow anaerobic digester (UFAD) (primary phase) and finalized with post treatment by three parallel facultative ponds (secondary phase). This station collects sewage from the city of Jaboticabal, whose municipality has 71,662 inhabitants, territorial area of 707 km^2 and population density of 101.4 inhabitants per km^2 (IBGE, 2010) and has an average flow of 202 L per inhabitant per day.

The climate of the region is subtropical humid, Aw, according to the classification of Köppen (Alvares et al. 2013), with dry and mild winter and hot and rainy summer (Table 1). The rainfall is concentrated in the hottest months of the year, with an occurrence of about 80% in the period from October to March.

TABLE 1. Mean climate conditions of Jaboticabal, SP, during the experimental period, in 2014.

Seasons	Temperature (°C)			Humidity (%)	Precipitation (mm)	ETo* (mm)
	Minimum	Maximum	Average			
Summer	15.8	35.9	24.8	68.8	348	584
Autumn-Winter	8.4	33.7	20.8	62.8	102	460
Spring	11.5	39.8	24.2	55.9	271	572

* ETo = Reference evapotranspiration. Source: Meteorological Station - UNESP (2015)

The soil is classified as Eutrophic Red Latosol (Santos et al., 2013), very clayey texture (> 50%), high iron content and good fertility. Sampling of soil between the treatments (E1-E5) from 0 to 100 cm was carried out at the implantation of the experiment (Table 2).

TABLE 2. Average chemical characteristics (treatments E1 – E5) of the soil in the experimental area at the depths of 0-100 cm, in November of 2012.

pH	OM	K	Ca	Mg	H+Al	SB	T	Al	P	B	Cu	Fe	Mn	Zn	S	V
	g dm^{-3}	---------------- mmoldm^{-3} ----------------							------------------ mg dm^{-3} -------------------							%
5.5	20	4	25	12	27	40	68	0	53	0.3	3.4	12	18	2	24	57

Experimental design and management used

A conventional sprinkler system was used with three parallel lines of sprinklers spaced 12 m apart in order to apply a uniform irrigation level, but gradual of STE (Figure 2). The treatments consisted of five doses of STE, distributed in four replications, with the following average fractions of water effluent: E5 = 1.0; E4 = 0.87; E3 = 0.60; E2 = 0.31 and E1 = 0.11.

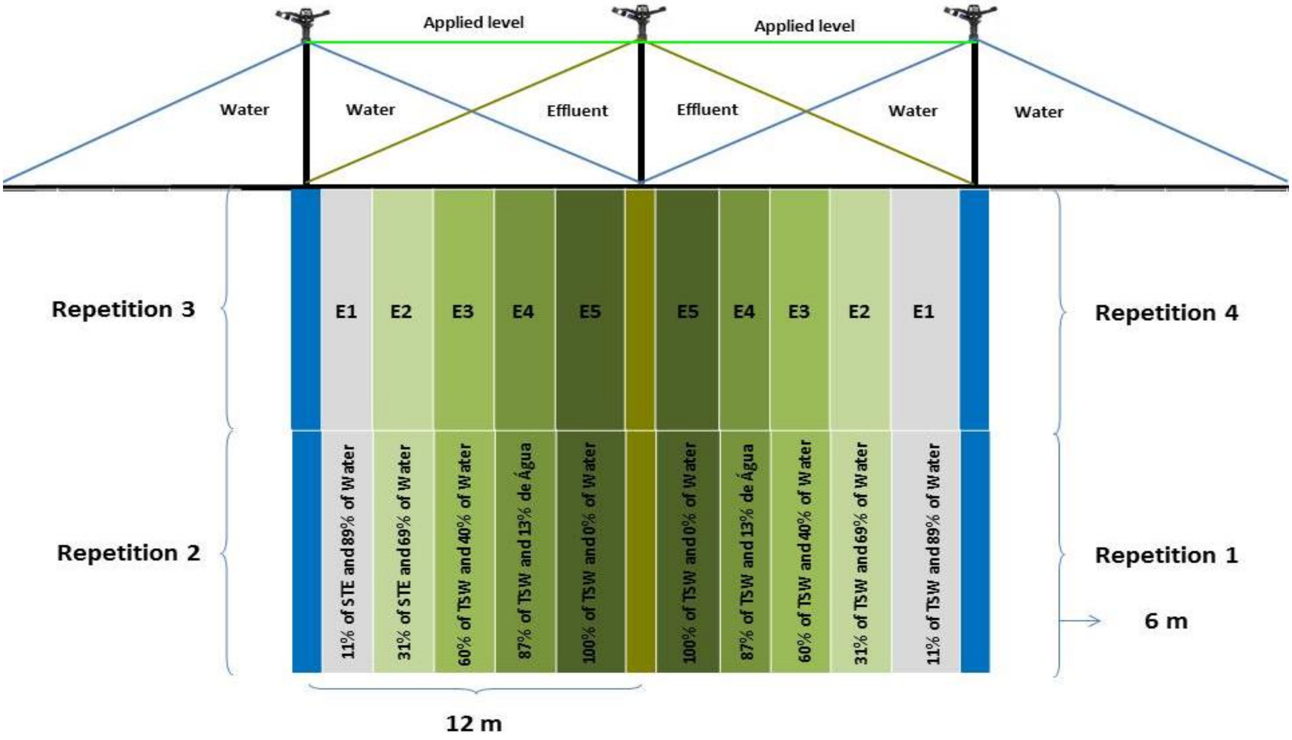


FIGURE 2. Experimental schemes with treatments (E5 = 1.0; E4 = 0.87; E3 = 0.60; E2 = 0.31 and E1 = 0.l1) distributed in strips with a gradual distribution of STE in water.

The control of the fertirrigation followed the hydric or nutritional necessity of the culture, adopting the criterion of greater value in the interval of 28 days. The nutritional demand was performed according to Vilela et al. (1998), applying 15; 3.5 and 18 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, per ton of forage dry matter of *Brachiaria* produced in cycles of 28 days. The water demand supplied by irrigations twice a week, with equal levels to the reference evapotranspiration calculated by the FAO 56 method, taking the E3 treatment as reference.

The irrigation levels were 750, 661 and 842 mm in summer, autumn-winter and spring, respectively, allowing the application of 1,132 kg ha^{-1} of nitrogen in the E5 treatment (Table 3). The water excess, especially in the rainy season, was a consequence of the nutritional criterion. The others nutrients were applied by STE in the following amounts (kg ha^{-1}) in treatment E5: P = 21, K = 463, Ca = 358, Mg = 108, Na = 1,428, SO_4^- = 421, Fe = 17, Mn = 2 and Zn = 3. The others treatments received amounts proportional to the application fractions defined in each treatment.

Due to the low concentration of phosphorus and potassium in the effluent, mineral supplementation was necessary, applying in the summer, autumn-winter and spring 136 and 696 kg ha^{-1} of P_2O_5 and K_2O, respectively. The fertilizations were staggered according to the needs of the crop in each cutting cycle (28 days), with 13 fertilizations being realized in the year 2014.

TABLE 3. The nitrogen fertilization via sewage treated effluent (kg ha^{-1}) applied according to treatment during Summer, Autumn-Winter and Spring, in 2014*.

Season	Treated				
	E5	E4	E3	E2	E1
Summer	346	304	210	107	38
Autumn-Winter	366	321	222	113	40
Spring	420	369	255	130	46
Total	1.132	994	687	350	124

* E5 = 1.0; E4 = 0.87; E3 = 0.60; E2 = 0.31 and E1 = 0.11 are sewage effluent doses in water.

The production of dry biomass was determined with the help of a metal frame (0.25 m^2) by taking samples randomly in three replicates in the plot and four per treatment. The cutting height was 15 cm. The forage harvested was homogenized and then, a sample was then taken to be weighed and taken to the greenhouse with forced air circulation, determining the dried biomass at 65°C until constant weight (Lacerda et al., 2009).

The qualitative evaluations of the forage were based on the crude protein (CP) and the nitrogen (N) content of the leaf, being obtained in the respective seasons of the year.

Data collection and analysis

The active ground sensor used was the *GreenSeeker HandHeld*^{TM}, portable. The data collection with the *GreenSeeker* was done manually, with passage over the canopy of the forage, always evaluating the center of each plot. The monitoring was always done one day before the beginning of the harvest. The *GreenSeeker* calibration was always performed on soil without vegetation.

The readings in all treatments (Figure 1) were obtained from an average height of 0.8 to 1.0 m between the sensor and the target (Grohs et al., 2011) and performed at 7.2 m^2 (12 m of linear displacement on the experimental unit, multiplied by the useful width of 0.6 m captured by the sensor), generating an average value of 20 to 30 measurements of NDVI performed per treatment.

Rouse et al. (1973) proposed the NDVI (Equation 1) to quantify the growth of vegetation and accumulated biomass, with values ranging from -1 and +1, and the higher the NDVI value, the greater the development vigor of the crop and the more distant form zero will be the value of NDVI.

$$NDVI = \frac{(\rho nir - \rho r)}{(\rho nir + \rho r)} \tag{1}$$

in which,

NDVI: normalized difference vegetation index,

ρnir: near infrared reflectance (770 nm), and

ρr: red reflectance (650 nm).

An electronic spreadsheet for data editing and graphing was used and the BioEstat v.5.3 software was also used to determine the linear correlation model between the variables, as well as the calculation of the coefficient of determination (R^2), the Pearson linear correlation coefficient (r) and analysis of the regression residuals, as well as the F value for the regression. In the analysis of residues, the value of 1σ for the detection interval of the *outliers*.

For the interpretation of the linear correlation between variables, the classification proposed by Callegari-Jacques (2003) was adopted. In order to represent the spatial distribution of the NDVI values, the *software* SPRING v.5.3 was used.

RESULTS AND DISCUSSION

A total of 13 harvestings were taken in 2014, with an increase in NDVI values in response to the increase of nitrogen doses via STE. To illustrate this effect, Figure 3 shows the spatial distribution of NDVI in the study area, obtained in the harvest performed on 04/29/2014. Note that in the central region of the study area, higher values of NDVI (dark green areas) were observed, which coincide approximately with the region of higher STE levels. Similar results were obtained in the other harvests in 2014, with decreasing mean values as a function of decreasing STE application (Figure 4).

In the residue analysis, the linear regressions presented only a value outside the range, denoting a low presence of *outliers*. The F values were all significant, indicating that the variables correlated with the NDVI values increased as the NDVI value increased.

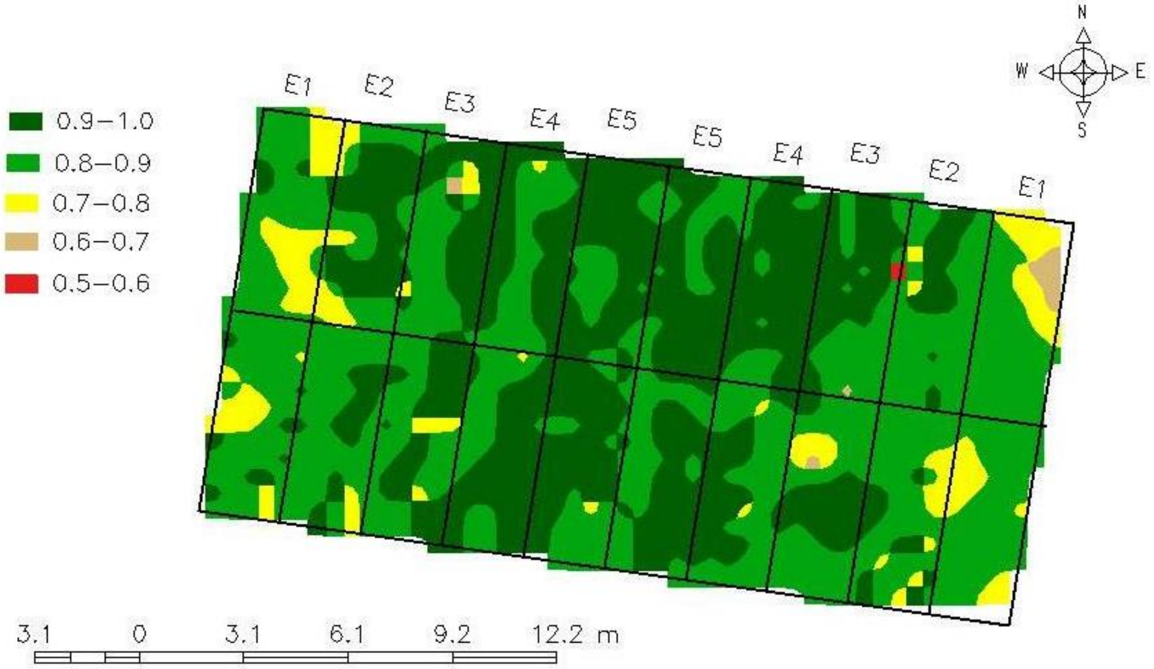


FIGURE 3. Spatial distribution of Normalized Difference Vegetation Index (NDVI) in a experimental area of *Brachiaria brizantha* fertigated with doses of sewage treated effluent (E5 = 1.0; E4 = 0.87; E3 = 0.60; E2 = 0.31 and E1 = 0.11) before the harvest on 04/29/2014.

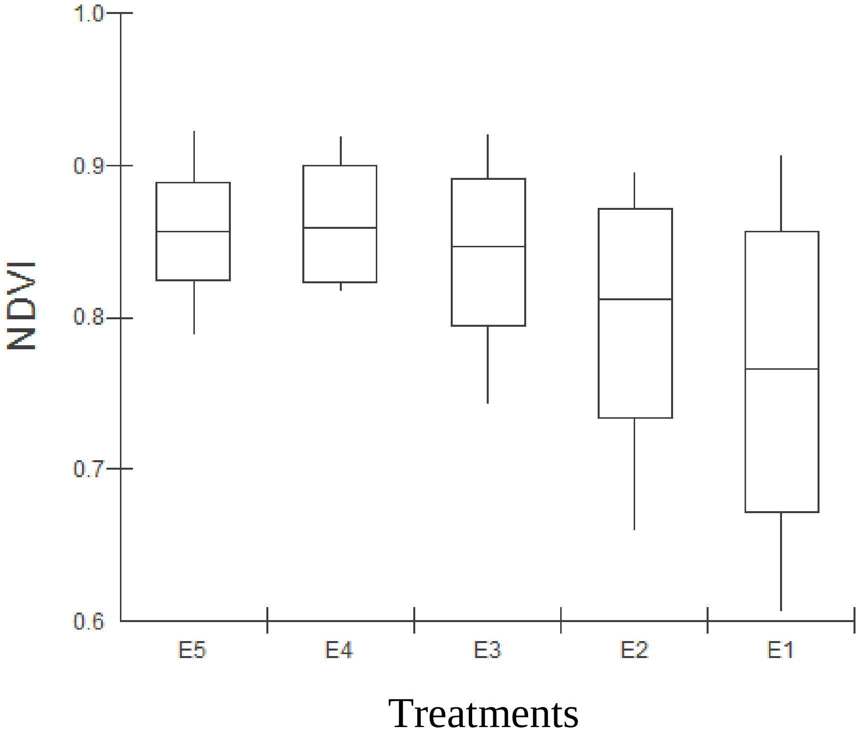
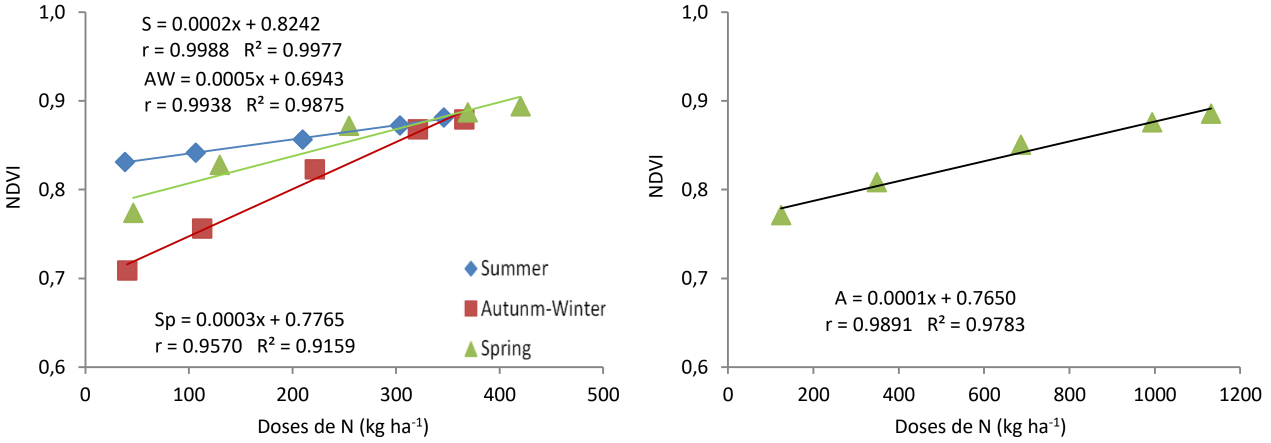


FIGURE 4. Box-plot for Normalized Difference Vegetation Index (NDVI) in *Brachiaria brizantha* fertigated with doses of sewage treated effluent (E5 = 1.0; E4 = 0.87; E3 = 0.60; E2 = 0.31 and E1 = 0.11) during 2014.

There was a high linear correlation (r>0.9570) between the nitrogen and NDVI doses (Figure 5). In addition, there was a greater effect on the reflectance indices in the autumn and winter. This fact occurs due to water deficit in the same period, resulting in gradual nitrogen uptake via STE by the forage.



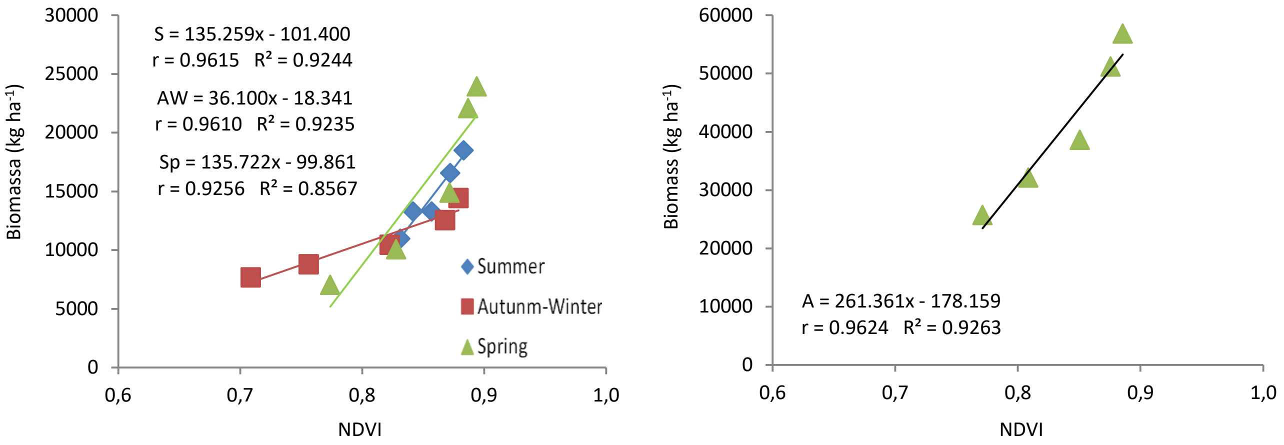
(a) (b)

FIGURE 5. Normalized Difference of Vegetation Index in function of N doses applied via sewage treated effluent, and respective coefficients of correlation, for: a) season of the year (S = Summer, AW = Autumn-Winter and Sp = Spring) and b) annual in 2014.

In autumn-winter and spring, nitrogen doses of less than 200 kg ha^{-1} by season of the year caused less development of the forage causing many flaws and, in this way, there was a direct influence on the area of exposed soil or dry biomass, resulting in lower NDVI values. In the summer, the climatic factors favored the rapid development of the crop, and it was possible to determine, with higher quality, and without the interference of areas with exposed soil, the canopy reflectance variability.

Similar linear correlation results (r>0.90) were obtained by Povh et al. (2008), evaluating the relations of the readings performed with an active sensor with N doses, nitrogen concentration in the leaves, dry biomass production and grain yield in the wheat, triticale, barley and corn crops. Zerbato et al. (2016), evaluating the linear correlation between NDVI and peanut yield in the production of green and dry peanut mass, obtained positive linear regression and determination coefficients of 0.3161 and 0.2761, respectively. The low NDVI values were attributed to naked soil exposure between rows of plants.

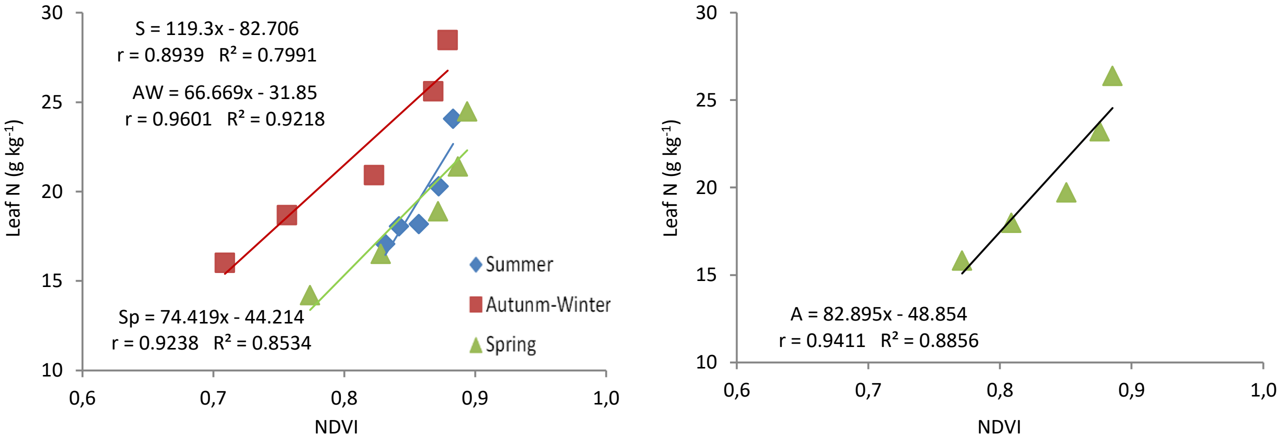
There was a high linear correlation (r>0.9256) between NDVI and dry biomass, demonstrating that the method can be used to estimate this variable (Figure 6). Povh et al. (2008) evaluated the determination coefficient between NDVI and nitrogen doses in wheat crop, they showed that the NDVI and dry biomass production at the end of the seasoning were satisfactory, with a determination coefficient varying from 83% to 99%.



(a) (b)

FIGURE 6. Dry biomass in function of the normalized difference vegetation index by season (a) and annual in 2014 (b).

The successive applications and in graded doses of STE resulted in better leaf quality as compared to nitrogen, correlating with higher NDVI indexes (Figure 7). It was obtained high linear correlation (r> 0.8939) between NDVI and leaf nitrogen.

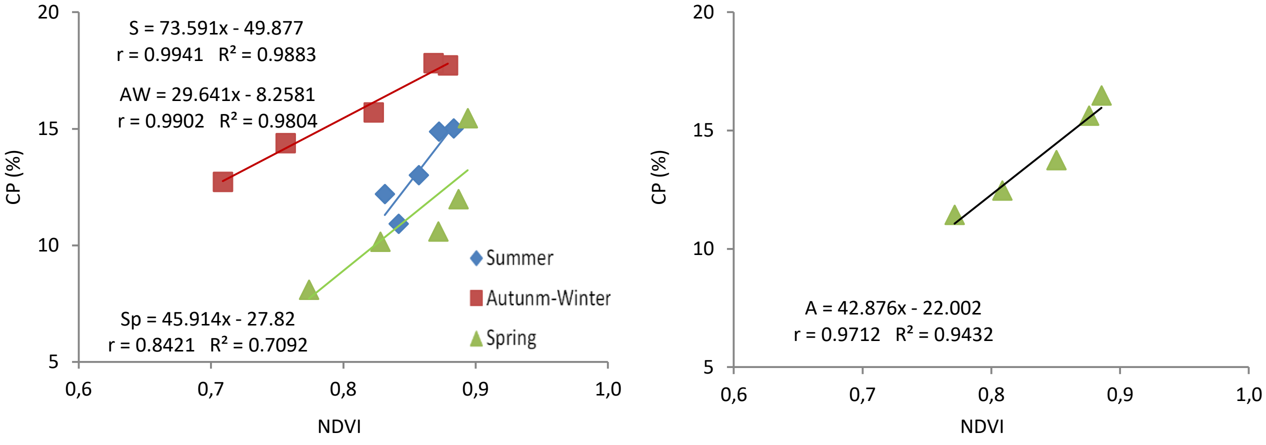


(a) (b)

FIGURE 7. Leaf nitrogen in function of the normalized difference vegetation index by season (a) and annual (b).

The lowest leaf nitrogen content in spring and summer and, consequently, NDVI indexes, is caused by the higher foliar expansion velocity in the period, providing dilution of foliar nutrients (Silva et al., 2012). Motomiya et al. (2009), evaluating foliar nitrogen deficiency in the cotton crop using active terrestrial sensor, obtained an increase in NDVI rates with the increase of the applied nitrogen rates, being an efficient tool for the detection of foliar nitrogen deficiency.

The availability of nitrogen to the forages favored the best nutritional quality of the forage, as a consequence of the increase of more digestible compounds, there being a gradual effect on the crude protein content and consequently higher values of NDVI with the application of nitrogen via STE. A high linear correlation coefficient (r>0.8421) was obtained between NDVI and the forage crude protein content (Figure 8).



(a) (b)

FIGURE 8. Crude protein in function of the normalized difference vegetation index by season (a) and annual in 2014(b).

CONCLUSIONS

The successive application of treated sewage effluent resulted in higher productivity in dry biomass and better leaf quality (higher levels of nitrogen and crude protein).

The productivity, the quality and the vegetation indices increased due to the application in gradual doses of applied sewage treatment effluent.

The levels of nitrogen and crude protein and the production of dry biomass showed a close correlation with the normalized vegetation index, demonstrating that the method can be used to estimate the yield and quality of the forage of *Brachiaria brizantha* cv. *Marandu*.

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