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SPECTRAL VEGETATION INDEXES APPLIED TO NITROGEN SUFFICIENCY INDEX: A STRATEGY WITH POTENTIAL TO INCREASE NITROGEN USE EFFICIENCY ON TOMATO CROP

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KEYWORDS

fruit quality, precision agriculture, tomato nutrition, variable rate fertilization.

ABSTRACT

The tomato crop is one of the most demanding of nitrogen fertilizers. This element on soil has an elevated mobility that can represent danger to the environment and reduces its efficiency. Therefore, the purpose of this study was to evaluate the methodology for recommending nitrogen fertilizer for tutored tomatoes with a variable rate based on nitrogen sufficiency index. The treatments consisted of a reference plot and five treatments with the nitrogen sufficiency index calculated on spectral indexes NDVI, GNDVI, MCARI, PSSRa and the SPAD value. The productivity was evaluated considering the fruits size and viability. The descriptors of quality, color, soluble solids, total acidity, titratable acidity and flavor were also evaluated. All the indexes evaluated decreased significantly with the applied nitrogen during the cycle, the only exception being MCARI, which resulted in a similar nitrogen quantity to the reference. The NDVI, GNDVI, PSSRa and SPAD value indexes presented a total applied nitrogen decrease varying from 25.2% to 43.8%, neither reducing significantly the productivity nor the fruits quality. The marketable fruits productivity varied from 2332.9 to 2773.8 $g.plant^{-1}$ among treatments. Only the NDVI and the SPAD value presented significant improvements on the partial factor of nitrogen productivity, among the applied treatments.

INTRODUCTION

The tomato culture is worldwide and year after year, its production breaks records. In 2016, the world production was 177 million tons, an increase of 132% compared to the year 1990. Worldwide, the cultivated area has grown 62% between 1990 and 2016 (FAO, 2017). The more significant increase in production than the increase of cultivated area is due to the better culture productivity, because of genetic improvement and more adequate cultivation techniques.

Among the vegetables crops, tomato is one of the most nitrogen demanding cultures, with recommended doses close to $400kg.ha^{-1}$ depending on soil type, as for tutored tomato (Ribeiro et al., 1999).

The majority of nitrogen utilized on agriculture has elevated reactivity, making it highly mobile on the biosphere. When there is an excess of nitrate (NO_3), the nitrogen leach out and/or runoff due to rains or excessive irrigation (Billen et al., 2013) representing a contamination risk for the groundwater reservoirs and streams (Al-Rawabdeh et al., 2014; Chaudhuri & Ale, 2014; Huang et al., 2015). Losses may occur in a gaseous form by ammonia (NH_3) volatilization, nitrogen dioxide (NO_2) release and reactive oxides (NO_X) coming from the nitrification and denitrification processes (Butterbach-Bahl et al., 2013).

Due to its high mobility and the great nutritional demand from cultures, the mineral nitrogen forms are incapable of remaining on soil for long periods of time, meaning that the applied nitrogen does not present a prolonged residual effect (Guilherme et al., 1995). Therefore, the efficient nitrogen use depends on the synchrony between the nutrient supply and the culture need (Tremblay et al., 2011).

For the synchrony between the nutrient supply and the culture need, Francis & Piekielek (1999) proposed the use of the nitrogen sufficiency index (NSI) to manage the specific fertilization site, comparing measures carried out with the chlorophyll meter – SPAD, between a properly fertilized reference plot and the rest of the crop to be fertilized.

The elevated need of nitrogen for the tomato culture, the low residual effect of this nutrient on soil and the variations on the soil and climate conditions of the crop, indicate that precision agriculture and the nitrogen application on a variable rate have the potential to improve the efficiency use of this fertilizer. Applying a variable rate

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helps the synchrony between the nutrient supply and the culture demand (Arregui & Quemada, 2008), optimizing the applied nitrogen amount and not decreasing the culture productivity or the fruits quality. In addition to reducing production costs, it reduces the groundwater contamination risk (Billen et al., 2013).

There are several studies aiming to identify the nutritional state of nitrogen in a non- destructive way (Aparicio et al., 2000; Gabriel et al., 2017; Thorp et al., 2017; Hunt et al., 2018), but there is a lack in researches aiming the nitrogen application on a variable rate, especially for tutored tomatoes. Thus, this study has the goal to evaluate the methodology for nitrogen application on a variable rate recommendation for tutored tomatoes based on NSI and its impact on productivity, the fruits quality and the nitrogen partial factor productivity. Beyond the measures carried out with the SPAD, the Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Modified Chlorophyll Absorption in Reflectance Index (MCARI) and Pigment Specific Simple Ratio (PSSRa) were used for the NSI calculation.

MATERIAL AND METHODS

Location and growing conditions

The experiment was installed on a protected environment, covered with plastic film Suncover AV Blue, 120 µm thick, located in Viçosa (latitude 20°45'S, longitude 42°50'W and altitude of 648m), Minas Gerais, Brazil. The tomato plants of the 'Santa Cruz' group, 'Santyno' F1 hybrid were cultivated in 10 liter vases, with a diameter of 30 centimeters, filled with a low fertility soil and textural classification sandy clay loam. The chosen spacing was 30 cm between plants and one meter between lines.

Fertilization

Previous to the seedlings transplantation, the soil pH was corrected, elevating the base saturation to 80% using dolomitic limestone. The fertilization with NPK carried out in accordance with Ribeiro et al. (1999) for tutored tomatoes based on physicochemical soil analysis.

The fertilizations were carried out weekly using water-soluble fertilizers previously diluted so that the volume of one liter corresponded with the weekly dose of fertilizer for a plant. If the electrical conductivity (EC) surpassed 2.5 $dS.m^{-1}$, it was diluted until the EC dropped below this value and the weekly fertilization was plotted so that a maximum of liter per day of the solution was applied, avoiding losses by leaching.

The reference plot received an equivalent dose from 300 kg ha^{-1} to N, 900 kg ha^{-1} of P_2O_5 and 600 kg ha^{-1} of K_2O. Such dose was plotted weekly over 18 weeks, based on what Alvarenga (2004) proposed. The plants also received equivalent doses from 4 kg ha^{-1} of B and 2 kg ha^{-1} of Zn over 7 weeks, from the 7th to the 14th week after the transplants and 20 kg ha^{-1} of Mg over 14 weeks, from the 2nd to the 16th week after the transplants.

TABLE 1. Nutrients distribution over the tomato cycle utilized for the reference plot.

<table>
<tr><th rowspan="2">Days after transplanting</th><th>N</th><th>P_2O_5</th><th>K_2O</th><th>Mg</th><th>B</th><th>Zn</th></tr>
<tr><th colspan="6">kg ha^{-1}</th></tr>
<tr><td>0</td><td>0</td><td>78.3</td><td>0</td><td></td><td></td><td></td></tr>
<tr><td>7</td><td>0.9</td><td>2.7</td><td>1,8</td><td rowspan="15">20.0</td><td></td><td></td></tr>
<tr><td>14</td><td>0.9</td><td>2.7</td><td>1,8</td><td></td><td></td></tr>
<tr><td>21</td><td>0.9</td><td>2.7</td><td>1,8</td><td></td><td></td></tr>
<tr><td>28</td><td>1.5</td><td>4.5</td><td>3</td><td></td><td></td></tr>
<tr><td>35</td><td>2.4</td><td>10.8</td><td>4.8</td><td></td><td></td></tr>
<tr><td>42</td><td>3.9</td><td>11.7</td><td>7.8</td><td rowspan="8">4.0</td><td rowspan="8">2.0</td></tr>
<tr><td>49</td><td>37.2</td><td>103.5</td><td>74.4</td></tr>
<tr><td>56</td><td>37.2</td><td>103.5</td><td>74.4</td></tr>
<tr><td>63</td><td>37.2</td><td>103.5</td><td>74.4</td></tr>
<tr><td>70</td><td>37.2</td><td>82.8</td><td>74.4</td></tr>
<tr><td>77</td><td>37.2</td><td>62.1</td><td>74.4</td></tr>
<tr><td>84</td><td>29.7</td><td>62.1</td><td>59.4</td></tr>
<tr><td>91</td><td>22.2</td><td>62.1</td><td>44.4</td></tr>
<tr><td>98</td><td>18.6</td><td>62.1</td><td>37.2</td><td></td><td></td></tr>
<tr><td>105</td><td>18.6</td><td>62.1</td><td>37.2</td><td></td><td></td></tr>
<tr><td>112</td><td>14.7</td><td>62.1</td><td>29.4</td><td></td><td></td><td></td></tr>
<tr><td>119</td><td>0</td><td>20.7</td><td>0</td><td></td><td></td><td></td></tr>
<tr><td>126</td><td>0</td><td>0</td><td>0</td><td></td><td></td><td></td></tr>
</table>

N – nitrogen; P_2O_5 – phosphorus pentoxide; K_2O – potassium oxide; Mg – magnesium; B – boron; Zn – zinc.

Trial design and data analysis

The experiment used randomized blocks, with six treatments and six repetitions. Each plot was composed of six vases, with those at the extremities considered as boards, unevaluated during the experiment.

The normality was tested using Lilliefors' test and the variances equality checked by the Bartlett's test. The statistics analysis carried out through the ANOVA and Tukey's test at 5% of probability for average comparisons.

Treatments

For the treatments, the fertilization was carried out utilizing the same amount and temporal distribution of fertilizers as the reference plot, except for the nitrogen, which was applied only when the calculated NSI average for that treatment was equal or less than 0.95.

Obtainment of spectral readings and SPAD value

The readings were carried out during the period between 7:00 a.m. to 12:00, on the 29th, 36th, 44th, 50th, 69th, 77th, 97th, 105th days after transplanting (DAT), utilizing the 4th leaf, from the apex, completely expanded.

For the spectral readings, the ASD FieldSpec® HandHeld 2™ spectral radiometer was utilized. It is capable of carrying out reflectance readings from 325 to 1075nm. The equipment calibration was carried out before the beginning of readings and in each 30-minute period of use. For the calibration a Spectralon® SRS-99 disc was utilized. Two readings of each leaf in each of 24 plants, in a total of 48 readings by treatment were realized.

The SPAD values were obtained with the Minolta SPAD-502 chlorophyll meter. On each leaf in each of 24 plants, six readings were carried out, with a total of 144 readings by treatment.

Spectral indexes and NSI calculation

The indexes equations utilized for the NSI calculation are on Table 2.

TABLE 2. Spectral indexes utilized and their equations.

Index	Equation		
NDVI	$\frac{\rho_{800}-\rho_{670}}{\rho_{800}+\rho_{670}}$	(Daughtry, 2000)	(1)
GNDVI	$\frac{\rho_{801}-\rho_{550}}{\rho_{801}+\rho_{550}}$	(Daughtry, 2000)	(2)
MCARI	$[(\rho_{700}-\rho_{670})-0.2\times(\rho_{700}-\rho_{550})]\times\left(\frac{\rho_{700}}{\rho_{670}}\right)$	(Daughtry, 2000)	(3)
$PSSR_a$	$\frac{\rho_{800}}{\rho_{680}}$	(Blackburn, 1998)	(4)

$\rho 550$ – reflectance on the 550nm wavelength; $\rho 670$ – reflectance on the 670nm wavelength; $\rho 700$ – reflectance on the 700nm wavelength; $\rho 800$ – reflectance on the 800nm wavelength; $\rho 801$ – reflectance on the 801nm wavelength.

The NSI calculation was realized according to the [eq. (5)] for all the indexes except for the MCARI, which possessed the inverse relation to the foliar nitrogen concentration (Daughtry, 2000). For that index the inverse [eq. (5)] was used.

$$NSI = \frac{Index\ value\ on\ treatment}{Index\ value\ on\ reference\ plot} \quad (5)$$

Productivity

To evaluate the productivity, it was utilized the fruits weight per plant. The production of large, medium, small, total, marketable and defective fruits were evaluated (Table 3). It was considered as defective fruits those ones that showed apex rot, deformation, open or cracked fruits and fruits with less than a 40 mm diameter.

TABLE 3. Size classification of oblong tomato fruits.

Class	(MTD) (mm)
Defective	Less than 40
Small	More than 40 until 50
Medium	More than 50 until 60
Large	More than 60

MTD – Most transversal diameter.
SOURCE: MAPA, 2002 modified.

Fruits Quality

Three totally mature fruits from each plot were collected and taken to the laboratory for color analysis, soluble solids (SS), total acidity (pH), titratable acidity (TA) and flavor. The color obtained in two opposite spots on the equatorial region of each fruit, utilizing a CR-10 Minolta portable colorimeter, with the CIELab color coordinates system.

After the color obtainment, the fruits were crushed, and their pulp homogenized. The soluble solids were quantified with the undiluted pulp on the digital Hanna HI96801 refractometer and the result was expressed in °Brix.

The total acidity was obtained with the undiluted pulp by inserting the probe of the Digimed DM-22 bench pH meter which was previously calibrated. The titratable acidity was obtained with a five-gram sample of diluted pulp in volumetric flask; to complete 100 mL of this solution, 10 mL was pipetted and titrated with NaOH 0.1 $mol.L^{-1}$. Two repetitions for each sample was carried out and expressed in citric acid percentage.

The flavor was obtained by the relation between soluble solids and titratable acidity, according to [eq. (6)] (Kader et al., 1978).

$$Flavor = \frac{SS}{TA} \quad (6)$$

Where,

SS – soluble solids, in °Brix,

TA – titratable acidity, in citric acid percentage.

Partial factor productivity of nitrogen (PFP_N)

The Partial factor productivity of nitrogen was calculated, according to the equation proposed by Fixen et al., (2015), dividing the total fruits production by the applied nitrogen dose on fertilizations [eq.(7)].

$$PFP_N = \frac{Y}{N} \quad (7)$$

Where,

PFPN – Partial factor productivity of nitrogen in $kg_{fruits}\ kg_{nitrogen}^{-1}$;

Y – Total fruits production in kg,

N – Applied nitrogen dose in kg.

RESULTS AND DISCUSSION

During the experiment period, climatic variables were monitored by an observation station of automatic surface from the National Institute of Meteorology INMET (Station of Viçosa – A510).

The higher daylight (day period with solar radiation) and nocturnal average temperatures observed were respectively 28 and 21.7 °C, and the lower from 15.5 and 9.9 °C. The daily solar radiation varied from 2.1 to 24.5 $MJ.m^2.day^{-1}$ with an average of 14.0 $MJ.m^2.day^{-1}$ (figure 1).

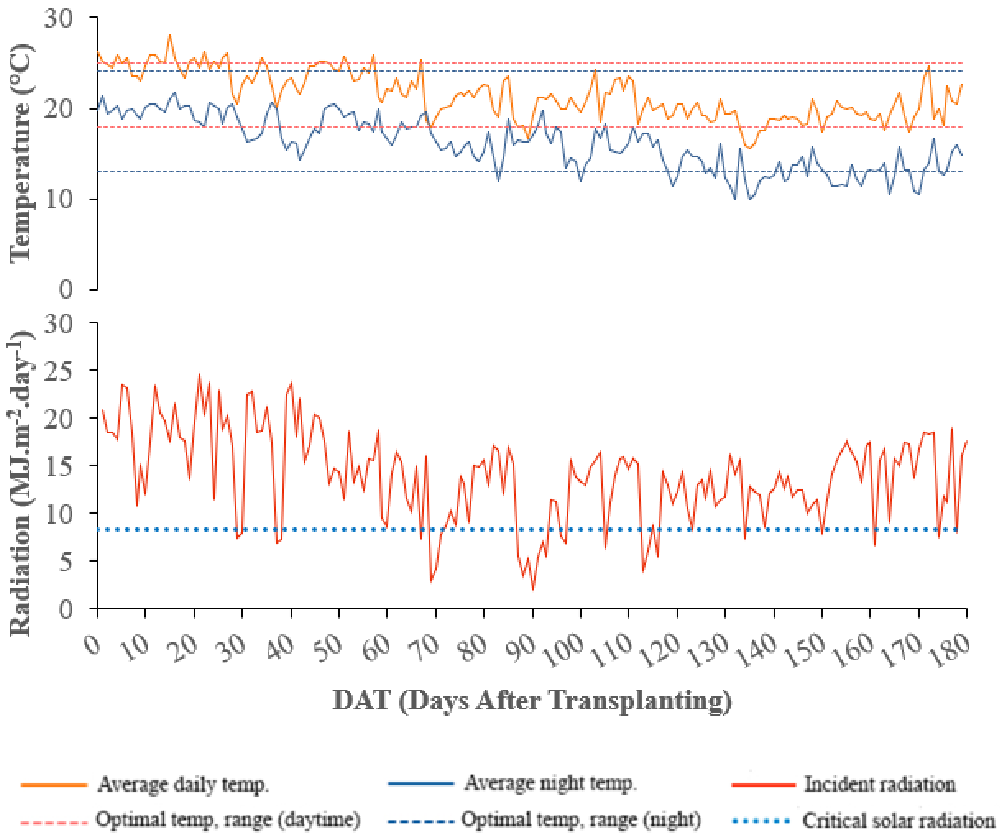

FIGURE 1. Daylight, nocturnal and ideal gap average temperatures for tomatoes (Dusi et al., 1993); daily solar radiation and critic level for tomatoes (Schmidt et al., 2017).

NSI, spectral indexes and SPAD values

The spectral indexes, SPAD values and NSI obtained within the crop cycle are on figure 2, as well as fertilizations realized during the observations period.

The spectral indexes NDVI, GNDVI, PSSRa and the SPAD values presented a similar behavior during the observations period, with lower values observed between the 29th and the 50th DAT, period that a smaller fertilizer quantity was applied weekly compared to the rest of the cycle. The comprehended period between the 50th and the 71st DAT characterized by a gradual decline on incident solar radiation, attained values below the trophic limit for tomatoes, considering 8.4 $MJ.m^2.day^{-1}$. In this radiation threshold the energy expended with respiration equals the energy produced through photosynthesis (Andriolo, 2000) concomitant with the period when it was not possible to obtain the spectral indexes due to operational problems with the equipment, this way all the treatments received nitrogen in fertilizations, resulting in an elevation in NDVI, GNDVI, PSSRa indexes and SPAD values but a drop in MCARI. With the incident solar radiation directly related to the nitrogen absorption capacity (Peng & Cassman, 1998), the supplied nitrogen in this period was not a bounding factor that approached the SPAD values and spectral indexes of the treatments with those of the reference plot, elevating the

NSI to values close to one in all treatments, exception made by T_{MCARI}. These results indicate the sensibility of the variable rate nitrogen fertilization based on NSI method to local soil and climatic conditions.

The NSI values observed on T_{GNDVI} and T_{PSSRa} treatments were similar in behavior over the time, with gradual decline between the 29th and the 50th DAT, going below the 0.95 threshold on the 50th DAT, increasing above it on the 69th and the 78th DAT, below the threshold again from the 97th and the105th DAT.

The NSI for the T_{SPAD} treatment showed similar behavior on T_{GNDVI} and T_{PSSRa} treatments, but presented a value below the limit on the 44th, the 97th and the 105th DAT.

The calculated NSI for the T_{NDVI} treatment remained above 0.95 during the entire observed period, reflex of the low difference between the index's values observed on the reference parcel and the T_{NDVI} treatment.

The T_{MCARI} treatment only presented an NSI value above the limit on the 29th DAT, with gradual elevation between the 50th and the 105th DAT.

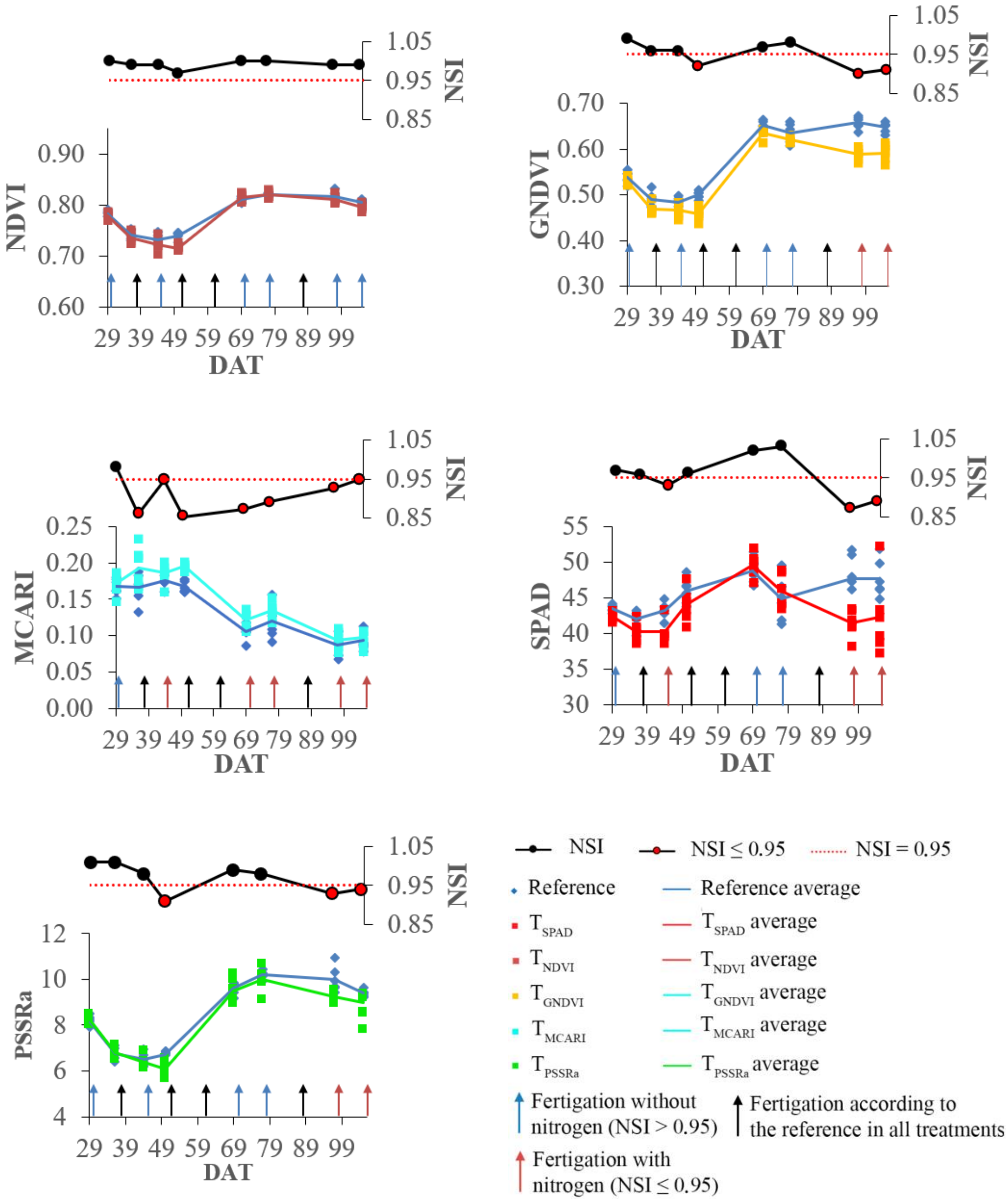

FIGURE 2. SPAD Values and spectral indexes on the reference plot compared with the other treatments, calculated NSI during the periods and form as the fertilizations were realized during the observation period.

On the 37th, 52nd, 61st and the 88th DAT it was not possible to obtain the spectral readings, thus there was no difference on the nitrogen fertilization among the treatments (black arrows on figure 2). Every treatment was fertilized according to the reference on these periods.

Nitrogenous fertilization

The applied nitrogen total dose for treatments and the reference plot are on figure 3.

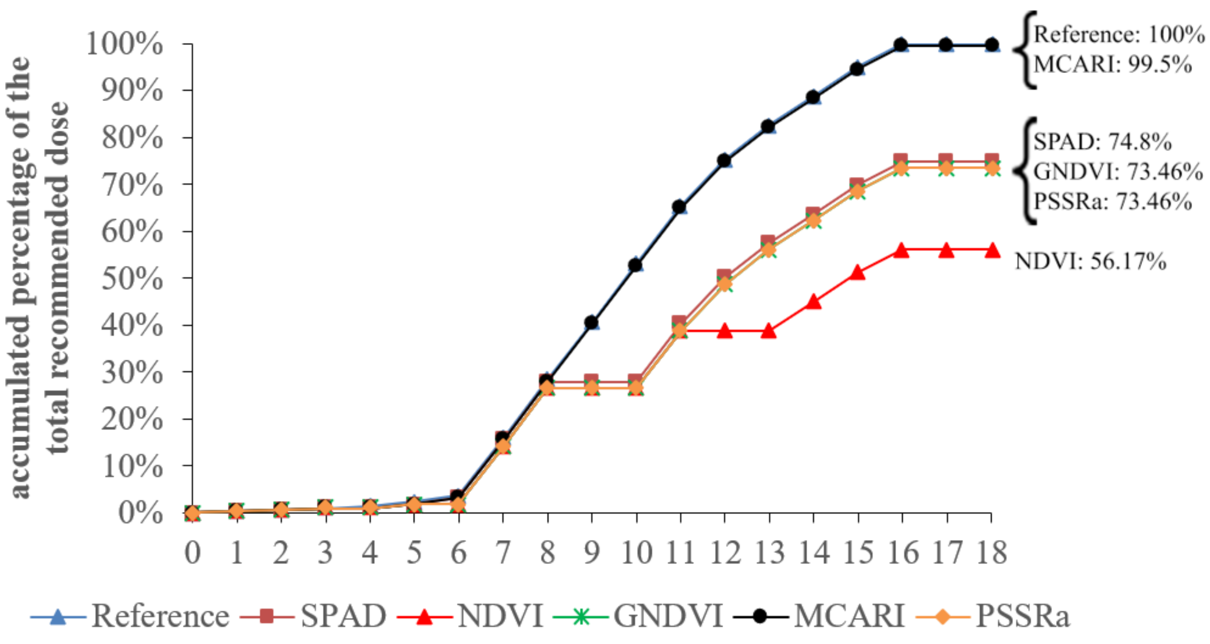

FIGURE 3. Total accumulated nitrogen applied over the culture cycle for each treatment and for the reference plot.

The T_{SPAD}, T_{NDVI}, T_{GNDVI} and T_{PSSRa} treatments lead to a total applied nitrogen reduction between 25.2% and 43.8% of the total recommended dose. The T_{MCARI} treatment presenting NSI values below 0.95 during almost all the observed period resulted in a similar nitrogen reference dose.

Productivity

There was a significant statistical difference of a 5% probability level on productivity average for medium size fruits and defective fruits. On the other evaluated productivity indicators, statistical differences among averages have not been detected (Table 4).

TABLE 4. p-value and productivity average of treatments and reference plot in fruit size, presence of defects, marketable and total fruits productivity.

Treatment	LFP	MFP*	SFP	MFP	DFP*	TP
	p-value					
	0.813	0.006	0.282	0.091	0.012	0.184
	Productivity ----------------------------------g.pl^{-1}----------------------------------					
Reference	1452.08	1119.35a	131.71	2773.80	93.18ab	2866.98
T_{SPAD}	1505.53	1015.85ab	145.23	2738.90	50.22b	2789.12
T_{NDVI}	1508.95	866.89ab	113.99	2577.80	112.45a	2690.25
T_{GNDVI}	1303.80	788.38b	168.13	2332.90	127.49a	2460.39
T_{MCARI}	1545.31	1018.56ab	108.71	2752.62	98.18ab	2850.80
T_{PSSRa}	1354.15	907.00ab	139.10	2478.68	111.64a	2590.32

LFP large fruits productivity; MFP medium fruits productivity; SFP small fruits productivity; TFP marketable fruits productivity; DFP defective fruits productivity; TP total productivity; *averages with the same letter does not differ at 5% of probability on the Tukey test.

Fruit quality

There was no significant statistical difference in any of the fruits quality describers evaluated. The describers' averages per treatment and the p-values are on Table 5.

TABLE 5. p-value averages from fruit quality describers: luminosity (L), red/green coordinated (a), yellow/blue coordinated (b), total acidity (pH), soluble solids in °Brix (SS), titratable acidity in citric acid percentage (TA) and Flavor (SS/AT).

Treatment	L	a	b	pH	SS	TA	Flavor
	p-value						
	0.817	0.121	0.951	0.860	0.233	0.187	0.821
	Averages						
Reference	37.06	18.39	22.79	4.13	4.47	0.31	13.77
T_{SPAD}	37.61	15.60	22.18	4.15	4.13	0.30	13.92
T_{NDVI}	37.37	16.03	21.51	4.10	4.10	0.29	14.20
T_{GNDVI}	37.32	17.11	21.88	4.10	3.98	0.33	12.80
T_{MCARI}	37.64	15.37	21.94	4.11	4.32	0.34	12.99
T_{PSSRa}	37.51	17.50	22.28	4.12	3.93	0.30	13.24

Partial factor productivity of nitrogen averages (PFP_N)

The partial factor productivity of nitrogen averages presented significant statistical differences between treatments (Table 6).

TABLE 6. Partial factor of nitrogen productivity averages for the treatments and reference plot.

Treatment	PFP_N (kg.kg^{-1})	
T_{MCARI}	318.36	a
Reference	318.56	a
T_{GNDVI}	372.13	ab
T_{PSSRa}	391.78	ab
T_{SPAD}	414.33	b
T_{NDVI}	532.13	c

Averages with the same letter don’t differ at 5% of probability on Tukey’s test;

PFP_N – partial factor productivity of nitrogen.

The maximum observed SPAD values in this study are within the threshold observed to study different substrates for tomatoes in a protected environment as described by (Qian et al., 2014), also within values for industrial tomatoes in the fall/spring cycle as Ferreira et al. (2006) described and close to the values for tomatoes of indeterminate growth in ideal nitrogen supply conditions observed by Padilla et al. (2015). The maximum NDVI and GNDVI indexes values observed corroborated with values obtained by Padilla et al. (2015) for tomatoes in ideal nitrogen supply conditions.

The T_{SPAD}, T_{NDVI}, T_{GNDVI} and T_{PSSRa} treatments did not receive nitrogenous fertilization on the 70th and the 78th DAT (period that the solar radiation incident increased), they presented spectral indexes and the SPAD values reduction on treatments compared to the reference plot, implicating a decline on NSI values below the 0.95 threshold on the 97th and the 105th DAT except T_{NDVI}.

The NSI on T_{MCARI} treatment presented a value above the 0.95 threshold only on the 29th DAT, followed by a decrease. This could be associated with the fertilization without nitrogen realized on the 30th DAT, however similar behavioral decrease on the 50th DAT was observed also when the treatment received an identical nitrogen dose to the reference plot on the 37th and the 45th DAT. The NSI on T_{MCARI} treatment presented a value above the 0.95 threshold on the 29th DAT, followed by a decrease on the 36th DAT.

Despite the T_{GNDVI} treatment presenting a significant statistical difference between the average fruits productivity comparing to the reference, such fact does not relate to the applied nitrogen doses, once the T_{PSSRa} treatment presented nitrogen quantity and temporal distribution identical to the T_{GNDVI} treatment, with a medium fruit’s productivity statistically as the reference plot.

Diverse effects related to the fruits size were reported for different nitrogen doses, as the non-altered fruits size for nitrogen doses between zero and 600 kg.ha^{-1} (Warner et al., 2004) and between zero and 300 kg.ha^{-1} (Farneselli et al., 2015) or even for nitrogen doses 25% and 50% above the recommendation (Mahajan & Singh, 2006). Yet Parisi et al. (2006), varying N doses from zero to 250 kg.ha^{-1} reported a variation in fruits size homogeneity, regardless of the applied nitrogen doses.

The difference between the defective fruits productivity among treatments also do not appear to be related with the fertilizer doses and temporal distribution, hence the T_{SPAD} treatment that presented the lowest defective fruits productivity received nitrogen in quantity and temporal distribution as the T_{GNDVI} and T_{PSSRa} treatments, which presented the most defective fruits productivity. In fact, the study with varying doses from zero to 250 kg.ha^{-1}, Parisi et al. (2006) observed a variation of biotic defects independently of the applied nitrogen doses, there was no significant alteration related to the fruits abiotic defects.

The observed values on the *a* color coordinate varied from 15.17 to 18.39 being higher than the observed (Radzevičius et al., 2014) in a study of the fruits quality during different ripening stages.

Despite soluble solids increased in a direct manner with increase nitrogen doses applied (Warner et al., 2004; Cayuela et al., 2014; Frias-Moreno et al., 2014; Ochoa-Velasco et al., 2016), none of the treatments presented a statistically significant difference in °Brix compared to the reference or among treatments, indicating that the use of NSI for management of the variable rate fertilization was capable of reducing the applied nitrogen quantity without compromising the fruits soluble solids percentage.

The SS/TA rate is directly related to the fruits flavor. The higher the sugar amount and lower the acidity, the more palatable the fruit will be (Jones, 2007). The observed values of the study are characteristic from high quality fruits, presenting SS/TA>10 for Kader et al. (1978) and SS/TA≅14.5 for Nascimento et al. (2013).

The T_{MCARI} treatment and the reference plot presented low PFP_N, result of the higher nitrogen quantity used without significant productivity gain.

The T_{SPAD} and T_{NDVI} treatments lead to higher values of PFP_N than the reference plot, indicating that those treatments had better efficiency on nitrogen utilized compared to the reference plot.

Therefore, this study reinforced the potential of the precision agriculture on the tomato culture. The synchrony between nitrogen supply and the culture demand for a determined soil and climatic condition provoked by the variable application rate, was capable of reducing the applied nitrogen amount, increasing its use efficiency that may also reflect on less water streams contamination risk, leading to the more adequate management of this fertilizer.

CONCLUSIONS

The utilized methodology lead to reduction of applied nitrogen on T_{SPAD}, T_{NDVI}, T_{GNDVI} and T_{PSSRa} treatments with no loss of total and marketable fruits productivity or alteration on the fruit's quality.

The utilized methodology was responsive to climatic and soil conditions of the crop, being capable of reducing the applied nitrogen amount between 25.2 and 43.8% if compared with the recommended dose, and the nitrogen did not become a limiting factor for the culture.

The treatments that used the spectral NDVI index and the SPAD value were capable of improving the nitrogen efficiency utilization by plants.

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