Research Article

Use of nitrogen sufficiency index to estimate topdressing doses for common bean[1]

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ABSTRACT

Portable chlorophyll meters can be used to improve the prediction of nitrogen (N) doses for common bean. This study aimed to evaluate two chlorophyll meters (Minolta SPAD-502 and ClorofiLOG CFL 1030) to predict topdressing N doses for the Pérola, TAA Gol and BRSMG Uai cultivars and for the VR 20 line. Eight field experiments (four genotypes and two devices) were carried out in a randomized blocks design, with four replicates, being the treatments topdressing N applications corresponding to four nitrogen sufficiency indices. There were discrepancies between the indices obtained by the different devices for the same genotype, as well as among those obtained with the same device for the different genotypes studied. Thus, when the index is used to define the N doses, the genotype and the chlorophyll meter used must be considered. In addition, the recommended index of 95 % should not be generalized to all the cultivars and should be reduced.

KEYWORDS: *Phaseolus vulgaris* L., chlorophyll meter, nitrogen fertilization.

RESUMO

Índice de suficiência de nitrogênio na estimativa de doses em cobertura para feijoeiro

Clorofilômetros portáteis podem ser utilizados para melhorar a previsão de doses de nitrogênio (N) em feijoeiro. Objetivou-se avaliar dois clorofilômetros (Minolta SPAD-502 e ClorofiLOG CFL 1030) para predizer doses de N em cobertura para as cultivares Pérola, TAA Gol, BRSMG Uai e para a linhagem VR 20. Oito experimentos de campo (quatro genótipos e dois dispositivos) foram conduzidos em delineamento de blocos casualizados, com quatro repetições, cujos tratamentos consistiram na aplicação de N em cobertura correspondendo a quatro índices de suficiência de nitrogênio. Houve discrepâncias entre os índices obtidos pelos diferentes dispositivos para o mesmo genótipo, bem como entre os obtidos com o mesmo dispositivo para os diferentes genótipos estudados. Assim, quando o índice é utilizado para definir as doses de N, deve-se considerar o genótipo e o clorofilômetro utilizado. Além disso, o índice recomendado de 95 % não deve ser generalizado para todas as cultivares e deve ser reduzido.

PALAVRAS-CHAVES: *Phaseolus vulgaris* L., clorofilômetro, adubação nitrogenada.

INTRODUCTION

Common bean has an extreme socioeconomic importance in Brazil, where it is grown in an area of 2,946,000 ha, with an estimated production of 2,973,000 t for 2021, resulting in a national average yield of 1,009 kg ha^{-1} (Conab 2021).

Among the factors that negatively affect the common bean yield in Brazil is the lack of adequate information for the management of nitrogen (N) fertilization for the main cultivars planted by farmers (Santi et al. 2006). For common bean, N is the most required nutrient and, although the crop has a high capacity to establish symbiotic associations with bacteria of the *Rhizobium* genus, when targeting grain yields higher than 2,500 kg ha^{-1} the biological N fixation alone does not supply the entire N demand of the crop (Pelegrin et al. 2009); thus, it is necessary to supply the nutrient using nitrogen fertilizers.

Accurate N fertilization recommendations are hampered by the complex N dynamics in the soil, which may result in a dose lower than the crop demand, thus limiting grain yield, or an excessive dose, which may not only increase the risk of environmental contamination but also compromise the profit of producers (Silveira et al. 2003). The

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combination of these factors, together with the high cost of N fertilizers, has triggered interest in developing management techniques to maximize the N use efficiency by common bean plants (Amado et al. 2000). Thus, chlorophyll meters began to be studied as tools to aid in decision making about when and how much N to supply as topdressing in common bean cultivation (Barbosa Filho et al. 2008, Barbosa Filho et al. 2009, Maia et al. 2013, Silveira & Gonzaga 2017).

The use of chlorophyll meters is based on the positive correlation between the concentrations of chlorophyll and N in leaves (Barbosa Filho et al. 2008). However, different factors may affect the relative chlorophyll indices measured by these devices (Silveira & Gonzaga 2017). Thus, the N sufficiency index (NSI) has been used, whose purpose is to isolate the effect of the N concentration in leaves from other factors that may influence the readings, and thus assist in estimating the N dose to be applied as topdressing (Hussain et al. 2000).

The NSI is determined from chlorophyll meter readings of a reference plot, which consists of an area that received a high N dose to avoid the onset of N deficiency. According to Carvalho et al. (2012), the time interval between the fertilization of the reference area and the performance of readings to obtain the NSI must be of at least 10 days, a period necessary for the plants to absorb the supplied N and transport it to the leaves. After this period, readings are performed in all plots, i.e., in previously fertilized areas (reference plot) and in areas to be fertilized. The NSI is calculated from the values obtained by the measurement device.

According to Barbosa Filho et al. (2009), if an NSI of 90 % is obtained for common bean, the index can be considered adequate and fertilization is not necessary. Maia et al. (2012) consider that common bean plants still require fertilization when the obtained NSI is 90 %. Silveira & Gonzaga (2017) argue that, in addition to defining the most appropriate NSI for common bean plants, the amount of N to be supplied as topdressing should be established, and that the NSI for common bean plants is equal to 95 % and the amount of N to be applied as topdressing should be of 11-15 kg ha^{-1} for each 1 % below an NSI of 95 %. However, the variations among the results found in the literature show the need for further clarification of which NSI is most suitable for common bean plants.

Thus, this study aimed to evaluate the potential use of two portable chlorophyll meters as an auxiliary tool in the definition of topdressing N doses for common bean cultivars of the Carioca group (Pérola, TAA Gol and BRSMG Uai) and for the VR 20 line of the red group.

MATERIAL AND METHODS

The experiments were performed in the 2017/2018 crop season (spring/summer), at the Universidade Federal de Lavras, in Lavras, southern Minas Gerais state, Brazil (-21.185727S; -44.998992W).

A total of eight experiments were carried out, corresponding to the combination of three Carioca-type grains (Pérola, BRSMG Uai and TAA Gol) and one red common bean line (VR 20) with two portable chlorophyll meters (Minolta SPAD-502 and ClorofiLOG CFL 1030).

The experiments were set up under no-tillage conditions, in an area covered with corn straw, where the soil is classified as "Latossolo Vermelho-Amarelo Distrófico típico" (Santos et al. 2018) or Typic Hapludox (USDA 2014). A composite soil sample was collected from the 0-20 cm layer before sowing, showing the following attributes: pH (H_2O) = 5.2; P ($Mehlich^{-1}$) = 12.5 mg dm^{-3}; K = 120.5 mg dm^{-3}; organic matter = 2.0 dag kg^{-1}; Ca = 2.3 $cmol_c$ dm^{-3}; Mg = 0.6 $cmol_c$ dm^{-3}; Al = 0.04 $cmol_c$ dm^{-3}; H + Al = 4.8 $cmol_c$ dm^{-3}; cation exchange capacity = 8.01 $cmol_c$ dm^{-3}; base saturation = 40.5 %; Zn = 4.88 mg dm^{-3}; Fe = 71.1 mg dm^{-3}; Mn = 10.0 mg dm^{-3}; Cu = 1.0 mg dm^{-3}; B = 0.29 mg dm^{-3}; S = 0.74 mg dm^{-3}.

A soil correction was performed three months before sowing, to increase the base saturation to 70 %, by applying 3 t ha^{-1} of limestone. The sowing fertilization was carried out with 270 kg ha^{-1} of an NPK (09-38-00) mixture (24.3 kg ha^{-1} of N; 102.6 kg ha^{-1} of P_2O_5) associated with 18 % of sulfur (48.6 kg ha^{-1}), 0.15 % of boron (405 g ha^{-1}), 0.15 % of copper (405 g ha^{-1}), 0.45 % of manganese (1,215 g ha^{-1}) and 0.45 % of zinc (1,215 g ha^{-1}). The potassium fertilization was performed in the total area after sowing with 50 kg ha^{-1} of K_2O. It should be noted that the fertilization was performed according to the soil analysis results, following recommendations by Souza & Lobato (2004).

The sowing took place on November 08 (2017), using a randomized blocks design with four replicates, and the treatments were determined as a function of the N sufficiency index (NSI), being four NSIs proposed for each of the common bean genotypes and each chlorophyll meter. A spacing of 0.6 m between the planting rows was used, and the spacing between plants was defined according to the size characteristics presented by each genotype. Thus, 11 seeds m^{-1} were planted for the Pérola cultivar, 17 seeds m^{-1} for the TAA Gol cultivar and 14 seeds m^{-1} for the BRSMG Uai cultivar and the VR 20 line. Each experimental plot consisted of four 5-m-long rows, and the two central rows were considered the useful area.

The reference areas were established on November 23 (2017), eight days after the plants emergence (November 15, 2017). At this moment, in a plot consisting of four 5-m-long rows, 150 kg ha^{-1} of N were applied as topdressing using urea (45 % of N) (Silveira & Gonzaga 2017), with manual application between the planting rows.

Readings with the chlorophyll meters were performed after the opening of the third trifoliate leaf (stage V4), on December 06 (2017), thirteen days after the implementation of the reference areas. The readings (one per leaflet) were carried out in five plants per plot, at the first mature trifoliate leaf from the apex of each sampled plant, and in the reference areas which had been previously fertilized, totaling 15 readings per plot.

After obtaining the relative chlorophyll indices for all the plots to be fertilized and for the reference area of each genotype, the NSI was calculated using the formula NSI (%) = (mean of the readings of the plot to be fertilized/mean of the readings of the reference plot) x 100.

This procedure was performed for each of the chlorophyll meters tested, and a common reference plot was used for both the devices when analyzing the same genotype. According to the genotype-specific NSI obtained with each of the devices used, four desired NSIs were stipulated as it follows: the difference between the index obtained from the readings and the NSI of 95 % (defined as the maximum NSI to be achieved) was calculated (Silveira & Gonzaga 2017), the value of the difference was divided into four equal intervals, and these intervals were sequentially added to the NSI obtained from the readings. The following is an example of how the four NSIs were defined: if an NSI of 87 % was obtained from the readings and an NSI of 95 % was defined as the maximum value to be achieved, the difference between them (8 %) was divided into four equal intervals. Thus, the sequential sum of this interval (2 %) to the NSI of 87 % would result in indices of NSI_1 = 89 %, NSI_2 = 91 %, NSI_3 = 93 % and NSI_4 = 95 %, which were then evaluated. Calculation example: NSI_1 = obtained NSI + [(obtained NSI - defined NSI)/4] and NSI_2 = NSI_1 + [(obtained NSI - defined NSI)]/4.

After defining the NSI to be achieved, N topdressing was performed on December 08 (2017) in the eight experimental plots, using urea as the N source. As discussed by Silveira & Gonzaga (2017), for each 1 % lower than the NSI, 15 kg ha^{-1} of N were applied. Table 1 shows the relationship among the genotypes, the devices used, the NSIs evaluated and the corresponding N doses applied as topdressing, at the V3 phenological stage.

Harvesting was performed according to the maturity presented by the genotype under evaluation.

Table 1. Genotypes, chlorophyll meters (Minolta SPAD-502 and ClorofiLOG CFL 1030), nitrogen sufficiency indices (NSI) and N doses applied as topdressing for the experiments conducted during the 2017/2018 season.

TAA Gol		Pérola		BRSMG Uai		VR 20	
NSI (%)	N dose (kg ha^{-1})	NSI (%)	N dose (kg ha^{-1})	NSI (%)	N dose (kg ha^{-1})	NSI (%)	N dose (kg ha^{-1})
			SPAD-502				
81	75	81	62	92	23	89	29
86	150	86	137	93	38	92	59
90	210	90	197	94	53	93	89
95	285	95	272	95	68	95	119
			CFL 1030				
85	57	88	40	88	37	90	29
88	102	90	70	90	67	92	59
92	162	93	115	93	113	93	74
95	207	95	145	95	142	95	104

Thus, the TAA Gol and BRSMG Uai cultivars were harvested on January 25 (2018), whereas the Pérola cultivar and the VR 20 line were harvested on February 01 (2018). In all the experiments, the plants in the two central rows of each plot were manually uprooted and then mechanically threshed.

The grain yields were determined by harvesting the two central rows of each plot after standardizing the grain moisture to 13 %. The data were subjected to analysis of variance using the F test, in the Sisvar statistical analysis software (Ferreira 2011). The variables that showed significance at 5 % by the F test were subjected to regression analysis.

To justify the choice of the NSI, the confidence interval of the regression analysis estimate was determined using the equation by Draper & Smith (1966):

$$CIRAE = \left\{ \hat{\beta}_0 + \hat{\beta}_1 x0 \pm t_{\left(1-\frac{\alpha}{2};n-2\right)} \sqrt{MSE\left[\frac{1}{n} + \frac{(x0-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right]} \right\}$$

where: *CIRAE* is the confidence interval of the regression analysis estimate; $\hat{\beta}_0$ and $\hat{\beta}_1$ the regression coefficients; $x0$ the value of interest for the sample; t the tabulated value, Student's t distribution; α the significance level adopted; n the total number of plots; *MSE* the mean square error; x_i the observed values of the predictor variable; and $\bar{x}$ the mean value of the samples.

RESULTS AND DISCUSSION

The discrepancies between the NSIs observed at the time of the readings did not allow a joint analysis of the eight experiments, since they made the treatments personalized, as a function of the varied response of the sum of the cultivar and chlorophyll factors. This situation reveals, as a first result, the impossibility of adopting a generalized method for the indirect measurement of common bean leaf chlorophylls without considering the model of the device used and the genotype cultivated. Thus, the experiments were analyzed separately according to the genotype and device used. In both the experiments carried out with the TAA Gol cultivar, the grain yield responded linearly and positively to increases in the N dose applied as topdressing (Figures 1A and 1B), according to the experiments carried out with the SPAD-502 and CFL 1030 devices; however, the increase of 210 kg in the N dose, with the use of the SPAD 502, resulted in a variation of 380 %, while the variation for the CFL 1030 was 363 %, despite the increase in the dose being less than 150 kg, proving again the distinct behavior of the devices. The observed results are similar to those found by Crusciol et al. (2007) and Moreira et al. (2013), who reported an increase in the grain yield of Carioca bean as a function of the increase in the N dose applied as topdressing.

Due to the impossibility of defining the NSI considered ideal for a cultivar only by regression analysis, another criterion was used to obtain the NSI considered appropriate for each device for the TAA Gol cultivar. Regression analysis determines the response trend of a trait as a function of treatment. However, by using the CIRAE, it is possible to infer at which point or points the evaluated trait differs significantly from those under other treatments (Draper & Smith 1966). In a practical sense, for the present study, the common bean yields obtained with the various NSIs may be considered statistically equal, because they had overlapping CIRAEs.

Figures 1A and 1B show that, as the NSI increases, there is a positive response in grain yield, regardless of the chlorophyll meter used. However, according to the proposed methodology, considering the tested NSIs, it is recommended the smallest one, whose CIRAE overlapped the CIRAE obtained for the NSI of 95 %.

In the experiment with the TAA Gol cultivar and SPAD-502 apparatus, the NSI of 90 % had values in common with the NSI of 95 %, considering their CIRAEs. For the grain yields evaluated with the CFL 1030 chlorophyll meter, the NSIs of 92 and 95 % had overlapping CIRAEs (Figure 1B). Thus, the adoption of NSIs of 90 (SPAD-502) and 92 % (CFL 1030) resulted in reductions of 75 and 45 kg ha^{-1} of N, respectively, when compared to the N application rate corresponding to the NSI of 95% recommended by Silveira & Gonzaga (2017).

The Pérola cultivar also showed a similar behavior in the experiments using the SPAD-502 and CFL 1030 chlorophyll meters (Figures 1C and 1D). In the experiment with the SPAD-502 chlorophyll meter, the NSIs of 90 and 95 % had grain yield values in common according to the CIRAE equation (Figure 1C), since the confidence intervals of the two indices overlapped. Thus, the NSI of 90 % was adopted as appropriate, and the N dose corresponding to this index was 197 kg ha^{-1}, which is quite high, when compared to the N doses used by producers.

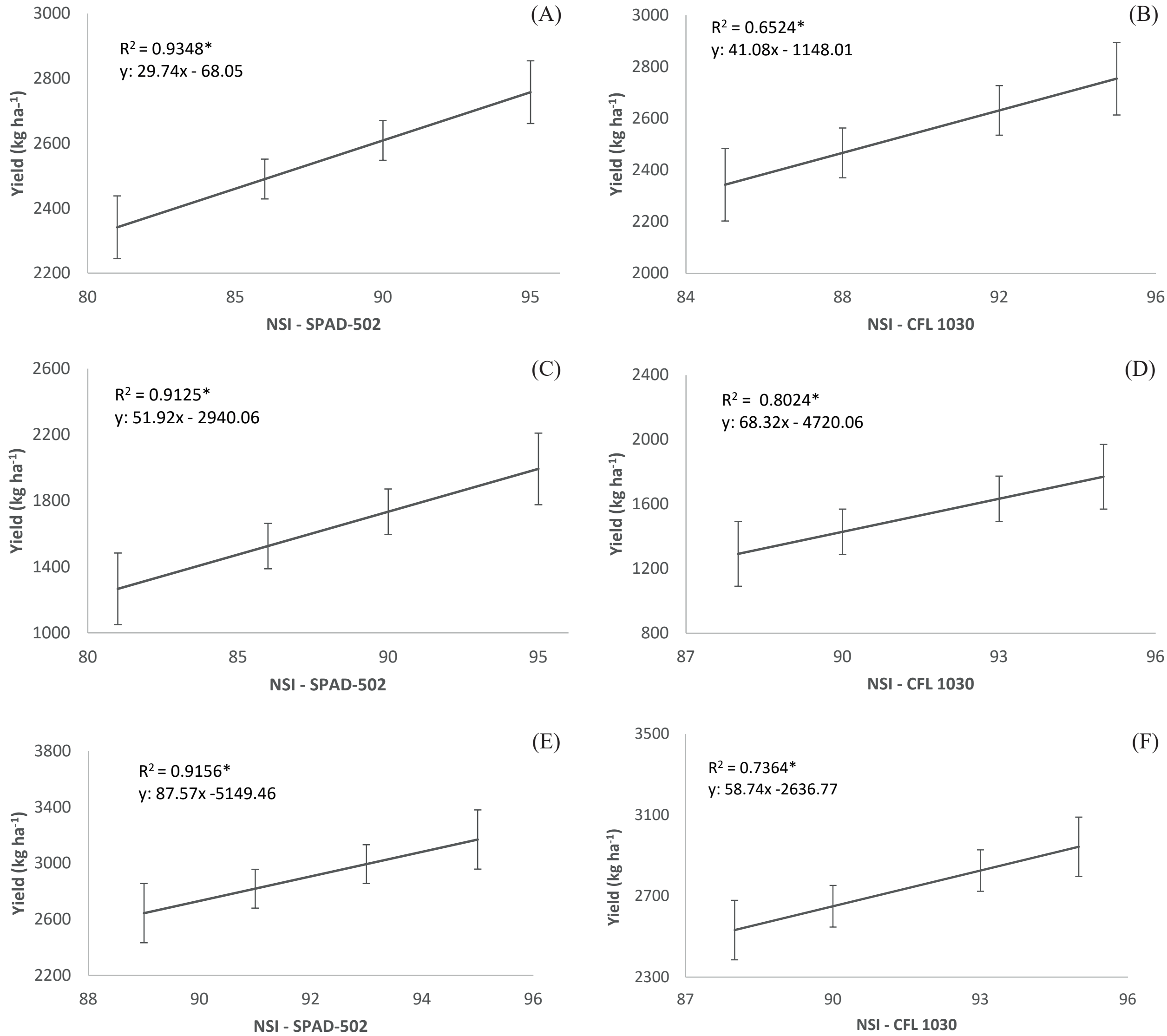

Figure 1. Grain yields of the common bean genotypes evaluated as a function of the nitrogen sufficiency index (NSI) defined with the aid of the SPAD-502 and CFL 1030 chlorophyll meters: (A) and (B): yields of the TAA Gol cultivar; (C) and (D): yields of the Pérola cultivar; (E): yield of the VR 20 line; (F): yield of the BRSMG Uai cultivar. * Significant at 5 % by the t-test. The vertical bars indicate the confidence interval of the regression analysis estimate.

Binotti et al. (2009) observed increases in the yield of the Pérola cultivar greater than 2,700 kg ha^{-1}, until the application of 198 kg ha^{-1} of N, evidencing that this cultivar can be responsive to high N doses as topdressing, especially when grown on grass residue. Fornasieri Filho et al. (2007) reported a linear response in common bean yield (2,400 kg ha^{-1}) as a function of the application of N as topdressing at doses of up to 150 kg ha^{-1}. Menegol et al. (2015) found no differences for common bean yield (2,061 kg ha^{-1} as an average yield) as a function of the N dose applied as topdressing up to 280 kg ha^{-1}.

The CIRAE of the NSI of 90 % defined by the CFL 1030 chlorophyll meter for the Pérola cultivar overlapped with that of the NSI of 95 % (Figure 1D). Thus, with the CFL 1030 chlorophyll meter, the NSI of 90 % corresponded to a dose of 70 kg ha^{-1} of N, which is much lower than the 197 kg ha^{-1} obtained with the SPAD-502 device. Moreover, the estimated yield obtained with the NSI of 90 % determined with the CFL 1030 was 1,428 kg ha^{-1}, lower than that obtained with the SPAD-502 chlorophyll meter (1,733 kg ha^{-1}). However, in both cases, the yield was higher than the national average (1,212 kg ha^{-1}) and the Minas Gerais state average (1,261 kg ha^{-1}) for the same crop season (Conab 2019).

For the experiment conducted with the VR 20 line using the SPAD-502 chlorophyll meter, the grain yield varied linearly with increasing N doses of 29-119 kg ha^{-1}, as defined according to the evaluated NSIs (Figure 1E). These results are consistent with those reported by Crusciol et al. (2007), Valderrama et al. (2009) and Moreira et al. (2013), who applied up to 120 kg ha^{-1} of N as topdressing and obtained a linear response for grain yield in common bean cultivars, always with yields above 2,400 kg ha^{-1}.

However, in addition to the regression analysis, the CIRAE was adopted, and overlapping CIRAEs were observed for the NSIs of 91, 93 and 95 %. Thus, the adoption of the NSI of 91 % resulted in reductions of 30 and 60 kg ha^{-1} of N, when compared to the NSIs of 93 and 95 %, respectively.

The N dose defined with the aid of the CFL 1030 chlorophyll meter, which varied between 29 and 104 kg ha^{-1}, had no effect on the grain yield of the VR 20 line, which showed an overall mean yield of 3,005 kg ha^{-1} (Table 2).

The obtained results are also in agreement with those reported by Arf et al. (2004) and Silva et al. (2006), since an increase in the N dose applied as topdressing in common bean did not increase the grain yield.

For the BRSMG Uai cultivar, when using the SPAD-502 chlorophyll meter, N doses ranging from 23 to 68 kg ha^{-1} (defined according to their NSIs) did not significantly influence the grain yield (Table 3). This result was similar to those in the studies by Nascimento et al. (2004) and Silva et al. (2006), in which the increase of N doses applied as topdressing, with maximum doses of 90 and 120 kg ha^{-1}, respectively, had no significant effect on grain yield for Carioca common bean cultivars, with yields slightly higher than 2,000 kg ha^{-1}.

Thus, the NSI adopted as appropriate for the BRSMG Uai cultivar with the SPAD-502 chlorophyll meter was 92 %. This was the lowest index, with a grain yield statistically equal to those of the other NSIs tested. The obtained results differed from those presented by Silveira & Gonzaga (2017), who reported that the ideal NSI for common bean plants is 95 %, when considering a fertilization factor between 11 and 15 kg ha^{-1} of N, for the Pérola cultivar and the CNPF 15874 line.

In the experiment with the CFL 1030 chlorophyll meter, the yield increased with increasing N doses, ranging from 37 to 142 kg ha^{-1}, according to the NSIs tested (Figure 1F). Leal et al. (2019) also obtained a positive response in grain yield for the BRSMG Uai cultivar with increasing N doses applied as topdressing. As discussed, in addition to the regression analysis, the CIRAE was used, and, because the CIRAEs of the NSIs of 93 and 95 % overlapped, the NSI of 93 % was considered appropriate for the BRSMG Uai cultivar.

The N dose corresponding to the NSI of 93 % was 112 kg ha^{-1}, with yield of approximately 2,800 kg ha^{-1}, while the mean obtained in the experiment with the SPAD-502 device was 2,700 kg ha^{-1}. In both experiments, the obtained yields were higher than the overall mean of 2,361 kg ha^{-1} determined from 27 experiments performed from 2007 to 2009 with this cultivar, according to Abreu et al. (2018).

The discrepancies among the NSIs found with the different devices and cultivars evaluated prevent a generalized recommendation for the use of chlorophyll meters without compromising the achievement of a higher efficiency for N fertilization. However, it is believed that the present study may contribute significantly to future studies on the use of chlorophyll meters to improve the efficiency of N fertilizers for common bean. The results show

Table 2. Grain yield of the VR 20 common bean line as a function of the N dose corresponding to the nitrogen sufficiency index (NSI) determined from the CFL 1030 chlorophyll meter.

NSI (%)	N dose (kg ha^{-1})	Yield (kg ha^{-1})
90	29	2,910
92	59	3,105
93	74	2,996
95	104	3,011

Table 3. Grain yield of the BRSMG Uai common bean cultivar as a function of the N dose corresponding to the nitrogen sufficiency index (NSI) determined from the SPAD-502 chlorophyll meter.

NSI (%)	N dose (kg ha^{-1})	Yield (kg ha^{-1})
92	23	2,659
93	38	2,668
94	53	2,687
95	68	2,821

the need of further data on the use of chlorophyll meters for genotypes with different traits, in different cultivation systems, to evaluate the performance of the devices in environments that strongly influence the plant N availability.

CONCLUSIONS

1. By using a fertilization factor of approximately 15 kg ha^{-1} of N, the appropriate nitrogen sufficiency index for common bean plants can be reduced to less than 95 %;
2. The choice of the appropriate nitrogen sufficiency index varies depending on the chosen common bean cultivar.

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