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THE NITROGEN SUFFICIENCY INDEX UNDERLYING ESTIMATES OF NITROGEN FERTILIZATION REQUIREMENTS OF COMMON BEAN[1]

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SUMMARY

Chlorophyll determination with a portable chlorophyll meter can indicate the period of highest N demand of plants and whether sidedressing is required or not. In this sense, defining the optimal timing of N application to common bean is fundamental to increase N use efficiency, increase yields and reduce the cost of fertilization. The objectives of this study were to evaluate the efficiency of N sufficiency index (NSI) calculated based on the relative chlorophyll index (RCI) in leaves, measured with a portable chlorophyll meter, as an indicator of time of N sidedressing fertilization and to verify which NSI (90 and 95 %) value is the most appropriate to indicate the moment of N fertilization of common bean cultivar Perola. The experiment was carried out in the rainy and dry growing seasons of the agricultural year 2009/10 on a dystroferric Red Nitosol, in Botucatu, São Paulo State, Brazil. The experiment was arranged in a randomized complete block design with five treatments, consisting of N managements (M1: 200 kg ha^{-1} N (40 kg at sowing + 80 kg 15 days after emergence (DAE) + 80 kg 30 DAE); M2: 100 kg ha^{-1} N (20 kg at sowing + 40 kg 15 DAE + 40 kg 30 DAE); M3: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} when chlorophyll meter readings indicated NSI < 95 %; M4: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} N when chlorophyll meter readings indicated NSI < 90 % and, M5: control (without N application)) and four replications. The variables RCI, aboveground dry matter, total leaf N concentration, production components, grain yield, relative yield, and N use efficiency were evaluated. The RCI correlated with leaf N concentrations. By monitoring the RCI with the chlorophyll meter, the period of N sidedressing of common bean could be defined,

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improving N use efficiency and avoiding unnecessary N supply to common bean. The NSI 90 % of the reference area was more efficient to define the moment of N sidedressing of common bean, to increase N use efficiency.

Index terms: *Phaseolus vulgaris*, chlorophyll, relative chlorophyll index, chlorophyll meter.

RESUMO: *USO DO ÍNDICE DE SUFICIÊNCIA DE NITROGÊNIO NA ESTIMATIVA DA NECESSIDADE DE ADUBAÇÃO NITROGENADA EM FEIJOEIRO*

As leituras indiretas de clorofila, obtidas com clorofilômetro portátil, podem indicar a época de maior demanda de N pelas plantas e se há ou não necessidade de sua aplicação em cobertura. Nesse sentido, a definição da melhor época para aplicação de N na cultura do feijão é fundamental para aumentar a eficiência de uso do N e a produtividade de grãos e reduzir custos com fertilizantes. Objetivou-se avaliar a eficiência do índice de suficiência de nitrogênio (ISN) de 90 e 95 %, calculado com base no índice relativo de clorofila (IRC) nas folhas, das plantas da área de referência, como indicador do momento de aplicação da adubação nitrogenada de cobertura no feijoeiro cultivar Pérola. O experimento foi conduzido durante as safras "das águas" e "da seca" no ano agrícola de 2009/10, em um Nitossolo Vermelho distroférrico, em Botucatu (SP). O delineamento experimental foi em blocos casualizados com cinco tratamentos, constituídos por manejos de N – M1: 200 kg ha^{-1} (40 kg na semeadura + 80 kg 15 dias após a emergência (DAE) + 80 kg 30 DAE); M2: 100 kg ha^{-1} (20 kg na semeadura + 40 kg 15 DAE + 40 kg 30 DAE); M3: 20 kg ha^{-1} na semeadura e 30 kg ha^{-1} quando o ISN < 95 %; M4: 20 kg ha^{-1} na semeadura e 30 kg ha^{-1} quando o ISN<90 %; e M5: testemunha sem N – e quatro repetições. Foram avaliados o IRC, a massa de matéria seca da parte aérea, o teor de N total nas folhas, os componentes de produção, a produtividade de grãos, a produtividade relativa e a eficiência de utilização do N aplicado. O IRC correlacionou-se com o teor de N na folha do feijoeiro. O monitoramento do IRC com o clorofilômetro permitiu definir quando se deve aplicar o N em cobertura no feijoeiro, melhorando a eficiência de utilização e evitando a aplicação desnecessária desse nutriente em cobertura na cultura do feijoeiro. O ISN de 90 % foi mais eficiente para definir quando aplicar N em cobertura no feijoeiro, por proporcionar maior eficiência de utilização.

Termos de indexação: Phaseolus vulgaris*, clorofila, índice relativo de clorofila, clorofilômetro.*

INTRODUCTION

Nitrogen is the nutrient taken up in highest amounts by common bean (*Phaseolus vulgaris* L.), since it is a constituent of amino acids, proteins, enzymes and the chlorophyll molecule, with a marked effect on photosynthesis and therefore on crop growth and yield (Malavolta et al., 1997; Soratto et al., 2004).

Although the common bean satisfies part of its requirements for N by symbiosis with bacteria of the genus *Rhizobium* (Pelegrin et al., 2009), N fertilizer must be supplied to achieve high yields (Santos et al., 2003; Silveira et al., 2003; Soratto et al., 2004, 2005, 2006; Farinelli et al., 2006; Barbosa Filho 2008, 2009; Pelegrin et al., 2009). The demand for N sidedressing is usually determined by one of four methods: a) visual crop inspection, b) traditional recommendations based on the plant response curve to N, developed in field experiments (Silveira et al., 2003), c) observation of the soil organic matter content and, more recently, d) data of previous crops, especially in the Brazilian States of Rio Grande do Sul and Santa Catarina (Amado et al., 2002). There is no efficient laboratory method to assess the soil capacity to supply N to plants (Barbosa Filho et al., 2008). However, due to the complex dynamics of N applied to soil, it is very difficult to know whether the dose recommended for a given crop is sufficient to enable the plants to achieve their yield potential, or if it is excessive, increasing costs and causing environmental risks (Santos et al., 2003; Silveira et al., 2003). Additionally, if simple recommendations are followed, the moment of N fertilization may fail to coincide with the period of highest crop demand for this nutrient (Barbosa Filho et al., 2009).

Between 50 and 70 % of all N in the leaf consists of chlorophyll (Pan et al., 2004). Therefore, the development of the chlorophyll meter to provide a non-destructive, instant reading of the relative chlorophyll concentration in the leaves, positively correlated with N concentration (Silveira et al., 2003; Soratto et al., 2004; Barbosa Filho et al., 2008, 2009), is an alternative for determining plant N levels. Estimating the relative chlorophyll concentration also provides an indicator of common bean N levels closely correlated with bean yield (Soratto et al., 2004; Barbosa Filho et al., 2008).

The portable chlorophyll meter is easy to use and can be an important tool in deciding whether and when N supply is needed (Hussain et al., 2000; Barbosa Filho et al., 2008, 2009). The meter operation is simple and based on diodes that emit light (bands 650–940 nm) through the leaf (transmittance), to provide an indirect measurement of the relative chlorophyll concentration, expressed as the relative chlorophyll index (RCI) (Nunes, 2003).

To test the RCI, Barbosa Filho et al. (2008, 2009) proposed setting up a reference area in the plantation, fertilized based on chlorophyll meter readings. The dose to be applied to the reference area should be high, from1.8 to 2 times the recommended dose for the crop, so as to produce the maximum chlorophyll concentration in the leaves and ensure that no N-deficiency can occur (Hussain et al., 2000). To facilitate this type of management, the N sufficiency index (NSI) is calculated using the ratio of the RCI in the crop leaves by the leaves in the reference area (no N-deficiency), so that N can be applied whenever the crop plant NSI drops below 90 % of the NSI in the reference area. The authors managed to reduce the N supply, but the yield of the crop managed indirectly based on the chlorophyll meter readings in the reference area was significantly lower indicating that the NSI determined as 90 % of the reference area may induce to N-deficiency in the bean crop, i.e. the value of 90 % of the NSI of the reference area could have been too low so that the existing N-deficiency in the bean crop was not detected.

According to Varvel et al. (1997), if the NSI is below 90 % at the 8-leaf stage of maize, N-deficiency cannot be corrected by sidedressing application to maximize yield. Jemison & Lytle (1996) concluded that an NSI below 93 % indicated N-deficiency. Blackmer & Schepers (1994) and Varvel et al. (1997) set the N-deficiency threshold at 95 % for this crop. However, a suitable NSI to indicate when N sidedressing is required in common bean still needs to be defined.

The purpose of this study was to evaluate the efficacy of NSI levels of 90 and 95 %, calculated based on the RCI of leaves in a reference area, measured with a portable chlorophyll meter, as an indicator of when the common bean cultivar Perola needs N sidedressing.

MATERIAL AND METHODS

The study was conducted in the rainy and dry growing seasons in the 2009/2010 agricultural year, in Botucatu, São Paulo State, Brazil (48º 23’ W, 22º 51’ S, 765 m asl). According to the Köppen classification, the climate is Cwa, characterized as highland tropical, with a dry winter and hot, rainy summer.

The experiment was carried out in areas that had been under no-till for around 10 years. For the rainy growing season, common bean was sown on 8/12/2009 in an area previously planted with maize/white oat/maize. For the dry growing season, the seeds were sown on 2/09/2010 in an area previously used for maize/black oat/pearl millet. The row spacing was 0.45 m and seed density 16 seeds per meter.

The soil was classified as a dystroferric Red Nitosol. Before setting up the experiment for each growing season, soil samples were taken in the 0–20 cm layer to determine the chemical properties. For the rainy growing season, the results were: pH ($CaCl_2$) = 4.7; OM = 27.0 g dm^{-3}; P(resin) = 61 mg dm^{-3}; H + Al = 53 $mmol_c$ dm^{-3}, K^+ = 3.3 $mmol_c$ dm^{-3}, Ca^{2+} = 24 $mmol_c$ dm^{-3}, Mg^{2+} = 10 $mmol_c$ dm^{-3}, CEC = 90 $mmol_c$ dm^{-3}, and base saturation = 41 %. For the dry growing season: pH ($CaCl_2$) = 5.0; OM = 30.0 g dm^{-3}; P(resin) = 32 mg dm^{-3}; H + Al = 73 $mmol_c$ dm^{-3}, K^+ = 2.2 $mmol_c$ dm^{-3}, Ca^{2+} = 30 $mmol_c$ dm^{-3}, Mg^{2+} = 17 $mmol_c$ dm^{-3}, CEC = 98 $mmol_c$ dm^{-3} and base saturation = 50 %.

The experiment was arranged in a randomized complete block design with five treatments consisting of N sidedressing management in the form of ammonium nitrate and four replications. The N doses were M1: 40 kg ha^{-1} N at sowing + 80 kg ha^{-1} 15 days after emergence (DAE) + 80 kg ha^{-1} 30 DAE, and this was the designated reference treatment (twice the maximum dose of N recommended for the crop (Ambrosano et al., 1997), to ensure there is no N-deficiency); M2: 20 kg ha^{-1} N at sowing + 40 kg ha^{-1} 15 DAE + 40 kg ha^{-1} 30 DAE, a dose based on the local recommendation given by Ambrosano et al., 1997; M3: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} when chlorophyll meter readings indicated NSI < 95 %; M4: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} when chlorophyll meter readings indicated NSI < 90 % and, M5: control (without N application). Each experimental unit consisted of eight 6m-long rows, of which the six central rows of the plot were evaluated, without the borders of 0.5 m at either end of each row.

The basic P and K fertilization applied at sowing in the rainy and dry growing seasons consisted of 40 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} K_2O, in the form of simple superphosphate and potassium chloride.

Both crops were irrigated by a conventional sprinkler system, with an irrigation level of 7.0 mm, according to the crop requirements, in the early morning hours.

Chlorophyll meter readings (Minolta SPAD-502) were first taken 15 DAE (stage V_3) and then weekly until 64 DAE (stage R_8) on five randomly selected plants per experimental unit. Two readings were taken per trifoliate on the last fully expanded trifoliate leaf. A total of 30 readings per plot were taken, from the middle of the leaf blade, avoiding the ribs.

The NSI was calculated based on the ratio of the RCI values (measured using a Minolta SPAD-502 chlorophyll meter) in each treatment plot (TP) and in the reference plot (RP) using equation 1.

$$NSI\ (\%) = (TP / RP) \times 100 \quad (1)$$

In the rainy growing season, N had to be supplied (NSI < 95 %) in treatment M3 15, 22 and 43 DAE, totaling 110 kg ha^{-1} N, but for treatment M4, monitoring indicated that N sidedressing was only required 22 DAE, totaling 50 kg ha^{-1} N sidedressing. In the dry growing season, treatment M3 required 80 kg ha^{-1} N, i.e. sidedressing 15 and 37 DAE, whereas treatment M4 required no N sidedressing.

Full flowering (R_6) of the Perola cultivar in the rainy and dry growing seasons occurred on 10/05/2009 (44 DAE) and 03/22/2010 (36 DAE), respectively. At this stage, the following evaluations were conducted: (a) aboveground dry matter: eight plants were collected per plot, dried to constant weight in a forced convection oven at 60–70 °C; (b) total N concentration in the leaves: after determining the RCI, these leaves were collected immediately, washed in distilled water, placed in paper bags and oven-dried, then ground for analyzing total N concentration (Malavolta et al., 1997); (c) yield components (number of pods per plant, number of grain per pod and 100–grain weight) at harvest, collecting 10 plants per treatment; (d) bean yield: plants collected from two 3-m-long rows per treatment and then mechanically threshed. Thereafter, the grains were weighed, the yield calculated in kg ha^{-1}, and moisture content adjusted to 0.13 kg kg^{-1}; (e) relative yield: calculated by defining the average grain yield increase (%) for each N management treatment compared to the average for the control (without N application) (Relative Yield (%) = (bean yield for each treatment x 100)/bean yield for the control), and (f) efficiency of use of the N applied (UE): determined by the ratio of kg ha^{-1} yield increase / kg ha^{-1} N applied per treatment, relative to the control (UE (%) = (grain yield per treatment – grain yield of control)/quantity of N applied to each treatment).

The data of each crop were subjected to analysis of variance. The averages for the treatments were compared by the Tukey test at 5 %. Linear correlations were calculated based on the mean relation between RCI and leaf N concentration for each period of evaluation, with the leaf N concentration, aboveground dry weight and aboveground N concentration determined at stage R_6, and with grain yield. The t-test was used to verify the significance of the correlation coefficient.

RESULTS AND DISCUSSION

The RCI values of the bean leaves in all treatments and for both crops (rainy and dry growing seasons) increased until 36 DAE (full flowering), and then became practically stable (Figure 1a,b). This could mean that chlorophyll concentration in the leaves stabilized after flowering, and that after this growth phase, the crop response to N is low, probably due to the higher contribution of biological N_2 fixation and redistribution of N in the plant to other tissues, in line with the results obtained by Silveira et al. (2003) and Barbosa Filho et al. (2008, 2009).

In the rainy growing season, in the early growth phase of common bean, the RCI values of the control treatment (M5) were below the readings obtained on the fertilized plots, but after 50 DAE, the RCI values of the plants in M5 were very close to those of the fertilized plots (Figure 1a). Throughout the growth period of the dry season, the RCI values of the control treatment (M5) were very close to the readings obtained on the fertilized plots, and differed from reference treatment (M1) only in the evaluations 36 and 43 DAE (Figure 1b). These results can be explained by the process of N mineralization of the plant residues left on the soil surface or by the process of atmospheric N_2 symbiotic fixation, which under suitable environmental conditions can satisfy some of the bean crop requirements for N in combination with bacteria of the genus *Rhizobium* (Soares et al., 2006). Barbosa Filho et al. (2008) observed that, after flowering, the green of the bean plants in the control treatment was more intense, resulting from RCI values very close to those read on the fertilized plots, and reported that this is a result of N mineralization of the plant residues left on the soil surface.

In treatment M3 of the rainy growing season, treated with N according to the chlorophyll meter readings (NSI < 95 %), an NSI of 89 % was observed in the evaluation 15 DAE, indicating the need for a first N sidedressing, and in treatment M4 with an NSI limit of 90 %, no readings were below the threshold, requiring no N sidedressing (Figure 1c).

In treatment M3 of the dry growing season, the NSI value was 94 % of that observed in treatment M1, indicating the need for a first N sidedressing (Figure 1d). However, the NSI readings in M4 did not drop below the threshold at any stage fall, and no N sidedressing was necessary. Therefore, in treatment M4 the only N application in the dry growing season was 20 kg ha^{-1} N at sowing.

In the rainy growing season 22 DAE, NSI values were 89 % for M3 and 80 % for M4 (Figure 1c). These values were low, indicating the need for N sidedressing, and 30 kg ha^{-1} N were applied. The RCI values for treatments M2, M3 and M4 after application of N were similar to those observed in the reference treatment (M1) 29 and 36 DAE, and since the NSI values for treatments M3 and M4 were higher than the limits defined for each of these treatments, no further fertilizer was required.

In the dry growing season, 36 DAE the NSI values of the plants in treatment M3 were below 95 % of the value observed in the reference treatment (M1) (Figure 1d), requiring N sidedressing. The NSI values in M3 reached 93 % (NSI < 95 %) 43 DAE, indicating the need for further N fertilization. At the same time in the rainy growing season, 30 kg ha^{-1} N were applied (Figure 1c). In treatment M4 (NSI < 90 %), NSI values were above the limit defined. In the NSI values calculated after 50 DAE for M3 and M4, no values were below the limit indicating N insufficiency, which can be explained by the stabilization of RCI after 50 DAE, i.e. the difference between RCI values in the treatments was small (Figure 1a).

In the rainy growing season, leaf N concentrations in treatment M1 remained practically constant during the initial evaluations and decreased in all

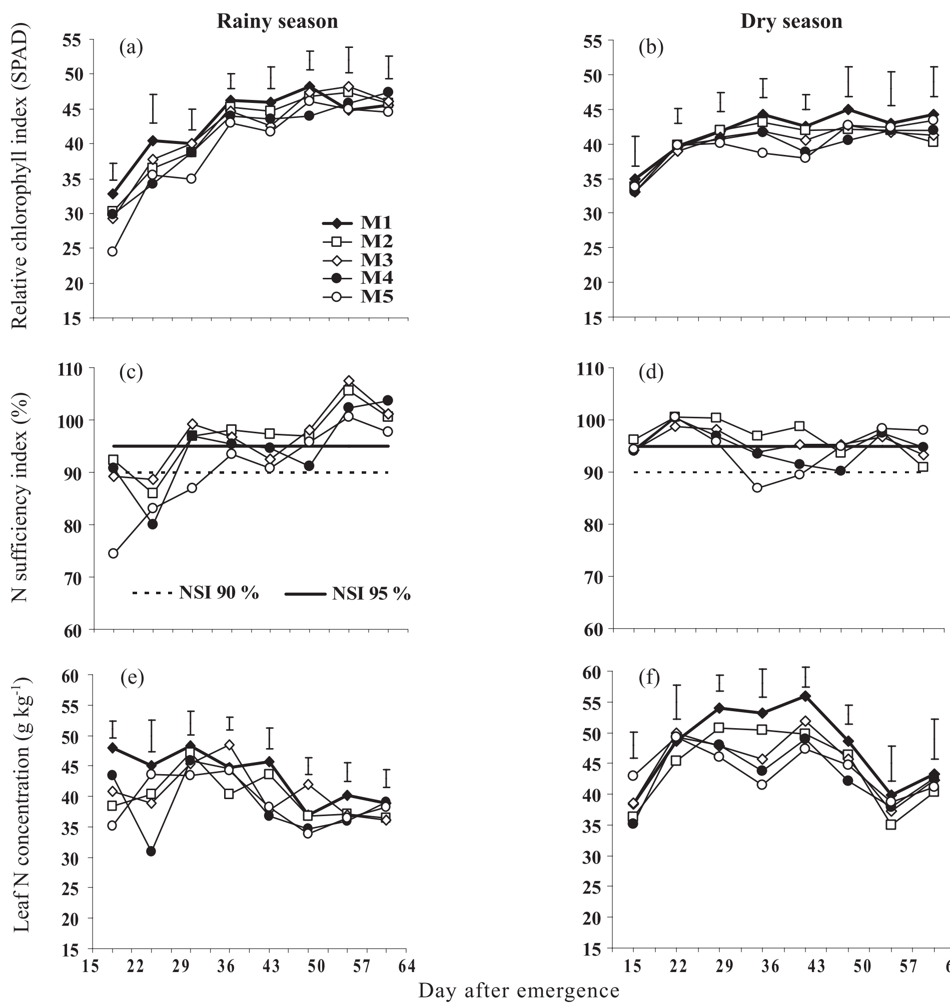

Figure 1. Relative chlorophyll index (a) and (b), N sufficiency index (c) and (d) and leaf N concentration (e) and (f) in common bean cv. Perola, at different stages of evaluation as affected by N sidedressing management in the rainy and dry growing seasons. M1: 40 + 80 + 80 kg ha^{-1}, M2: 20 + 40 + 40 kg ha^{-1}, M3: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} when chlorophyll readings indicated NSI<95 %; M4: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} when chlorophyll readings indicated NSI<90 and M5: control, without N application. Vertical bars represent LSD by the Tukey test as 5 %.

treatments after 43 DAE (Figure 1e). This could indicate that concentrates of mobile nutrients, such as N, drop with leaf age due to translocation to other tissues, mainly the reproductive structures, since the plant priorized seed production as a form of species survival, reducing the N concentration in the leaves. In the other treatments, N concentrations varied significantly over time, especially when N was applied to treatments M2, M3 and M4, but also dropped in the beginning of the reproductive phase. However, it is important to note that leaf N concentrations of the control plants (M5) at some stages during the evaluations were above those of some N sidedressed treatments, and practically equal to those observed in the reference treatment (M1). These results are probably related to a dilution effect, since in the N-fertilized treatments, the dry matter quantity accumulated in the aerial part was higher than in the control (Table 1). In the dry growing season, leaf N concentration increased up to the beginning of stage R_7 (43 DAE) and decreased in this stage (Figure 1f). Note that treatments fertilized with the highest quantities of N had higher leaf N concentrations, especially between 29 and 36 DAE (beginning of the reproductive phase). Despite the drop in leaf N concentration between 43 and 57 DAE, there was an increase in leaf N concentrations as of 57 DAE, showing that N may be absorbed in later stages by the bean cultivar Perola, as observed by Soratto et al. (2005).

Nitrogen treatments brought about differences in leaf N concentration at stage R6 (43 DAE) in both crops (Figure 1e,f). In the rainy growing season, the doses of N applied to treatments M1 and M2 raised the leaf N concentration above that of the other treatments. During dry growing season, the highest doses of N applied produced higher leaf N concentration. However, N concentrations in all treatments were within the range considered adequate (30–50 g kg^{-1}) for the bean crop (Ambrosano et al., 1997). Binotti et al. (2009) also pointed out that applying five doses of N increased N concentrations in the common bean leaves collected during flowering.

With the exception of the evaluations conducted 36 and 57 DAE in the rainy growing season and 22 DAE in the dry growing season, leaf N concentrations were positively correlated with RCI (Table 2). A number of studies also report a correlation between the chlorophyll meter RCI readings and bean leaf N concentration (Carvalho

Table 1. Quantity of N applied, aboveground dry matter, yield components, grain yield, relative yield, use efficiency of the N applied (UE) of common bean cv. Perola as affected by N applications in the rainy and dry growing seasons

N management treatment	N applied	Aboveground dry matter	Pod per plant	Grain per pod	100 grain weight	Grain yield	Relative yield	UE
	kg ha^{-1}	g/plant			g	kg ha^{-1}	%	kg of grain per kg of N
Rainy growing season								
M1	200	6.5a	13.9a	4.5a	25.6a	3002a	160	5.6
M2	100	4.9ab	12.9a	4.4a	24.7a	2532ab	135	6.6
M3	110	4.8b	13.5a	4.7a	23.8a	2512ab	134	5.8
M4	50	3.2b	11.8ab	4.4a	24.7a	2296ab	122	8.4
M5	0	2.8b	9.8b	4.4a	24.4a	1875b	100	-
CV (%)	-	18.0	8.9	9.1	8.7	18.7	-	-
Dry growing season								
M1	200	6.3ab	10.5a	3.8a	28.8a	2556a	106	0.7
M2	100	5.8b	11.0a	3.8a	29.8a	2558a	106	1.4
M3	80	7.3a	8.8ab	4.3a	28.5a	2530a	104	1.4
M4	20	6.8ab	6.8b	4.8a	29.3a	2643a	109	11.3
M5	0	4.5c	7.3b	5.3a	29.8a	2417a	100	-
CV (%)	-	8.2	12.6	22.0	3.8	7.6	-	-

Values in a column, within growing season, followed by the same letter were not significantly different by the Tukey test at 5 %. M1: 40 + 80 + 80 kg ha^{-1}, M2: 20 + 40 + 40 kg ha^{-1}, M3: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} when chlorophyll readings indicated NSI < 95 %; M4: 20 kg ha^{-1} N at sowing + 30 kg ha^{-1} when chlorophyll readings indicated NSI < 90 and M5: control, without N application.

et al., 2003; Soratto et al., 2004; Barbosa Filho et al., 2008). Estimating leaf N concentrations using the RCI has the advantage that any deficiency can be immediately corrected. However, this method is most efficient when used until the full flowering stage, since after flowering, the response of bean plant to N is low and the leaf RCI stabilizes (Barbosa Filho et al., 2008, 2009).

In the rainy growing season, treatment M1 (reference) produced a higher dry matter yield than the treatments that received lower doses of N (M3 and M4) and the control (M5) (Table 1). The aboveground dry matter produced by the reference treatment (M1) was 132 % higher than that of the control treatment (M5 – without N application). In the dry growing season, the treatment that produced the highest aboveground dry matter yield was M3 (7.3 g/plant), but did not differ significantly from treatments M1 and M4; the lowest value was observed in treatment M5 (4.3 g/plant). A number of studies confirmed increased aboveground dry weight in common bean with the application of N sidedressing (Soratto et al., 2005; Farinelli et al., 2006; Binotti et al., 2010).

In the rainy growing season, a higher number of pods per plant was observed in treatments M1, M2 and M3, differing only from treatment M5 (Table 1). In the dry season, the highest values were observed for treatments M1 and M2, differing only from M4 and M5. The results show that there is a direct relationship between the dose of N applied and the number of pods per plant. According to the recommendations, N fertilizer should be applied before flowering in order to increase the number of pods per plant, since this is the yield characteristic most influenced by fertilizing (Soratto et al., 2004, 2005, 2006; Farinelli et al., 2006).

The number of grains per pod was not significantly influenced by the N treatments applied to the two crops (rainy and dry growing season) (Table 2), probably because this trait is intrinsic to the cultivar (genotype) and little influenced by farming practices. Furthermore, this characteristic is generally not correlated with grain yield (Soratto et al, 2004). Soratto et al. (2004) and Binotti et al. (2009) did not detect any significant effect on the number of grains per pod using N sidedressing.

The weight of 100 grains also remained unchanged by N treatment in both rainy and dry growing seasons (Table 2). Gomes Júnior et al. (2008) found that there was no significant difference in the weight of 100 grains when no-till crops were

Table 2. Simple linear correlation coefficients for relative chlorophyll index (RCI), leaf N concentration at each evaluation, aboveground dry matter determined at stage R_6 and grain yield of common bean cv. Perola, in the rainy and dry growing seasons

Variable	Leaf N concentration		Aboveground dry matter		Grain yield	
	Rainy	Dry	Rainy	Dry	Rainy	Dry
1st reading (15 DAE) – Stage V_3						
RCI	0.859***	0.503*	0.567**	ns	0.651**	ns
N concentration	-	-	0.478*	ns	0.574**	ns
2nd reading (22 DAE) – Stage V_4						
RCI	0.663***	ns	0.666**	ns	0.615**	ns
N concentration	-	-	ns	ns	ns	ns
3rd reading (29 DAE) – Stage V_{4-5}						
RCI	0.698**	0.653**	0.611**	ns	0.528*	ns
N concentration	-	-	0.612**	ns	0.531*	ns
4th reading (36 DAE) – Stage R_5						
RCI	ns	0.876***	0.595**	ns	0.563*	ns
N concentration	-	-	ns	ns	ns	ns
5th reading (43 DAE) – Stage R_6						
RCI	0.613**	0.772***	0.452*	ns	0.540*	ns
N concentration	-	-	0.681**	ns	ns	ns
6th reading (50 DAE) – Stage R_7						
RCI	0.467*	0.846***	0.462*	ns	ns	ns
N concentration	-	-	ns	ns	ns	ns
7th reading (57 DAE) – Stage R_7						
RCI	ns	0.660**	ns	ns	ns	ns
N concentration	-	-	0.537*	ns	0.639*	ns
8th reading (64 DAE) – Stage R_8						
RCI	0.582**	0.787***	ns	ns	ns	ns
N concentration	-	-	ns	ns	ns	ns

*, **, *** and ns: t-test significance 5, 1, 0.1 and not significant.

treated with N doses at various stages. Soratto et al. (2004, 2005) also observed that N sidedressing did not significantly affect the weight of 100 grains. For Soratto et al. (2004), N doses induced no major variation in 100–grain weight, which is one of the characteristics that remains fairly constant, irrespective of changes in the crop environment. Arf et al. (2008) argued that grain weight is more closely related to the genetic characteristics of a cultivar, i.e. this genetic trait is highly heritable.

Grain yield was significantly influenced by N management in the rainy growing season (Table 1). In the reference treatment (M1), the yield differed from the control (M5) only, and was 60 % higher. Treatments based on the use of a chlorophyll meter (M3 and M4) did not differ from the reference treatment (M1), but allowed smaller quantities of N to be used in the fertilizer, and although there was no statistical difference in comparison with the control, treatments M3 and M4 produced 34 and 22 % higher yields than those of the control (without N application). Treatment M4 (based on NSI of 90 %) was more efficient in the use of the N applied (UE) compared with M3 (based on NSI of 95 %) (Table 1). Although grain yield for treatment M4 was 23.5 % lower (706 kg ha^{-1}), it consumed 150 kg ha^{-1} less N sidedressing than M1 (reference). Treatment M3 received 90 kg ha^{-1} less than M1.

The grain yield obtained in the dry growing season was not influenced by N management (Table 1). Treatment M1 resulted in grain yield that was only 6 % higher than that of the control (M5). N management based on monitoring chlorophyll with the meter produced increases only 4 % (M3) and 9 % (M4) higher than the control (M5). The fact that the control treatment resulted in high grain yield could be due to symbiotic N_2 fixation and/or mineralization of waste from previous crops. Treatment M4 also resulted in a higher UE value (Table 1). This treatment received only 20 kg ha^{-1} N at sowing since it did not exhibit any N deficiency during the cycle, consuming 180 kg ha^{-1} less N than treatment M1 (reference).

In both growing seasons, the lowest quantity of N was used in treatment M4, with no drop in grain yield in comparison with treatment M2 based on local recommendations (Ambrosano et al., 1997), i.e. there was a saving in N fertilizer, compared to the routinely used amount (Table 1). The results obtained for treatment M4 indicate that monitoring with the chlorophyll meter to detect the NSI < 90 % decision criterion in relation to the reference plot could be an important tool to prevent unnecessary N sidedressing of common bean crops.

Nitrogen is a nutrient closely correlated with the chlorophyll molecule (Carvalho et al., 2003). Therefore, providing adequate N supply increases plant growth and protein synthesis, which are both directly linked to grain yield. Positive correlations of RCI with aboveground dry matter and bean yield were verified for the rainy growing season (Table 2). However, in the dry growing season, there was no significant correlation between RCI values and grain yield (Table 2). Soratto et al. (2004) and Sant'Ana et al. (2010) observed a positive correlation between RCI values and common bean yield. Leaf N concentration evaluated during the initial crop stages correlated with aboveground dry matter and grain yield in the rainy growing season, although the correlation was weaker than RCI.

CONCLUSIONS

1. The relative chlorophyll index obtained with a portable chlorophyll meter correlated with leaf N concentrations of common bean.

2. Monitoring the RCI with the chlorophyll meter oriented decision making on N sidedressing of the bean crop, improving use efficiency and avoiding unnecessary N applications.

3. An N sufficiency index of 90 % is more efficient than of 95 % for defining the threshold below which common bean should be N sidedressed to optimize the use efficiency of applied N.

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LITERATURE CITED

AMADO, T.J.C.; MIELNICZUK, J. & AITA, C. Recomendação de adubação nitrogenada para o milho no RS e SC adaptada ao uso de culturas de cobertura do solo, sob sistema de plantio direto. R. Bras. C. Solo, 26:241-248, 2002.

AMBROSANO, E.J.; TANAKA, R.T.; MASCARENHAS, H.A.A.; RAIJ, B.van; QUAGGIO, J.A. & CANTARELA, H. Leguminosas e oleaginosas. In: RAIJ, B.van; CANTARELA, H.; QUAGGIO, J.A. & FURLANI, A.M.C., eds. Recomendações de adubação e calagem para o Estado de São Paulo. 2.ed. Campinas, Instituto Agronômico e Fundação IAC, 1997. p.187-203. (Boletim Técnico, 100)

ARF, O.; AFONSO, R.J.; ROMANINI JUNIOR, A.; SILVA, M.G. & BUZETTI, S. Mecanismos de abertura do sulco e adubação nitrogenada no cultivo do feijoeiro em sistema plantio direto. Bragantia, 67:499-506, 2008.

BARBOSA FILHO, M.P.; COBUCCI, T.; FAGERIA, N.K. & MENDES, P.N. Determinação da necessidade de adubação nitrogenada de cobertura no feijoeiro irrigado com auxílio do clorofilômetro portátil. Ci. Rural, 38:1843-1848, 2008.

BARBOSA FILHO, M.P.; COBUCCI, T.; FAGERIA, N.K. & MENDES, P.N. Época de aplicação de nitrogênio no feijoeiro irrigado monitorada com auxílio de sensor portátil. Ci. Agrotec., 33:425-431, 2009.

BINOTTI, F.F.S.; ARF, O.; SÁ, M.E.; BUZETTI, S.; ALVAREZ, A.C.C. & KAMIMURA, K.M. Fontes, doses e modo de aplicação de nitrogênio em feijoeiro no sistema plantio direto. Bragantia, 68:473-481, 2009.

BINOTTI, F.F.S.; ARF, O.; CARDOSO, E.D.; SÁ, M.E.; BUZETTI, S. & NASCIMENTO, V. Fontes e doses de nitrogênio em cobertura no feijoeiro de inverno irrigado no sistema plantio direto. Biosc. J., 26:770–778, 2010.

BLACKMER, T.M. & SCHEPERS, J.S. Light reflectance compared with other nitrogen stress measurements in corn leaves. Agron. J., 86:934-938, 1994.

CARVALHO, M.A.C.; FURLANI JÚNIOR, E.; ARF, O.; SÁ, M.E.; PAULINO, H.B. & BUZETTI, S. Doses e épocas de aplicação de nitrogênio e teores foliares deste nutriente e de clorofila em feijoeiro. R. Bras. C. Solo, 27:445-450, 2003.

FARINELLI, R.F.; LEMOS, L.B.; PENARIOL, F.G.; EGÉA, M.M. & GASPAROTO, M.G. Adubação nitrogenada de cobertura no feijoeiro, em plantio direto e convencional. Pesq. Agropec. Bras., 41:307-312, 2006.

GOMES JÚNIOR, F.G.; SÁ, M.E. & VALÉRIO FILHO, W.V. Nitrogênio no feijoeiro em sistema de plantio direto sobre gramíneas. Acta. Sci. Agron., 30:387-395, 2008.

HUSSAIN, F.; BRONSON, K.F.; YADVINDER-SINGH; BIJAY-SINGH & PENG, S. Use of chlorophyll meter sufficiency indices for nitrogen management of irrigated rice in Asia. Agron. J., 92:875-879. 2000.

JEMISON, J.M. & LYTLE, D.E. Field evaluation of two nitrogen testing methods in maize. J. Prod. Agric., 9:108-13, 1996.

MALAVOLTA, E.; VITTI, G.C. & OLIVEIRA, S.A. Avaliação do estado nutricional de plantas: princípios e aplicações. Piracicaba, Potafos, 1997. 308p.

NUNES, J. C. S. Efeito da palhada de sorgo localizada na superfície do solo em característica de plantas de soja e milho. R. Ceres, 50:115-126, 2003.

PAN, Y.; HOM, J.; JENKINS, J. & BIRDESEY, R. Importance of foliar nitrogen concentration to predict forest productivity in the mid-Atlantic region. For. Sci., 3:279-289, 2004.

PELEGRIN, R.; MERCANTE, F.M.; OTSUBO, I.M.N. & OTSUBO, A.A. Resposta da cultura do feijoeiro à adubação nitrogenada e à inoculação com rizóbio. R. Bras. C. Solo, 3:219-226, 2009.

SANT'ANA, E.V.P.; SANTOS, A.B. & SILVEIRA, P.M. Adubação nitrogenada na produtividade, leitura SPAD e teor de nitrogênio em folhas de feijoeiro. Pesq. Agropec. Trop., 40:491-496, 2010.

SANTOS, A.B.; FAGERIA, N.K.; SILVA, O.F. & MELO, M.L.B. Resposta do feijoeiro ao manejo de nitrogênio em várzeas tropicais. Pesq. Agropec. Bras., 38:1265-1271, 2003.

SILVEIRA, P.M.; BRAZ, A.J.B.P. & DIDONET, A.D. Uso do clorofilômetro como indicador da necessidade de adubação nitrogenada em cobertura no feijoeiro. Pesq. Agropec. Bras., 38:1083-1087, 2003.

SOARES, A.L.L.; FERREIRA, P.A.A. & PEREIRA, J.P. Eficiência agronômica de rizóbios selecionados e diversidade de populações nativas nodulíferas em Perdões (MG): II - feijoeiro. R. Bras. C. Solo, 30:750–758, 2006.

SORATTO, R.P.; CARVALHO, M.A.C. & ARF, O. Nitrogênio em cobertura no feijoeiro cultivado em plantio direto. R. Bras. C. Solo, 30:259-266, 2006.

SORATTO, R.P.; CARVALHO, M.A.C. & ARF, O. Teor de clorofila e produtividade do feijoeiro em razão da adubação nitrogenada. Pesq. Agropec. Bras., 39:895-901, 2004.

SORATTO, R.P.; CRUSCIOL, C.A.C.; SILVA, L.M. & LEMOS, L.B. Aplicação tardia de nitrogênio no feijoeiro em sistema de plantio direto. Bragantia, 64:211-218, 2005.

VARVEL, G.E.; SCHEPERS, J.S. & FRANCIS, D.D. Ability for in-season correction of nitrogen deficiency in corn using chlorophyll meters. Soil Sci. Soc. Am. J., 61:1233-1239, 1997.