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Late additional application of nitrogen in common bean genotypes affecting grain yield and quality

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Abstract: Despite numerous studies conducted in Brazil on nitrogen fertilization in common bean, there are still many questions about the doses and timing of nitrogen (N) application in the crop, mainly regarding late nutrient application and its effect on grain yield and quality. This study aimed to quantify the effect of late additional N application on grain yield and their components, and on grain quality of common bean, irrigated by a central pivot in a no-tillage system. The experimental design was a split-plot, with five replications. The treatments consisted of the combination of four N managements, involving doses and application stages (Management 1: 70 kg ha^{-1} of N (V3) + 50 N (V4), Management 2: 70 N (V3) + 50 N (V4) + 50 N (R6), Management 3: 70 N (V3) + 50 N (R6), and Management 4: 70 N (V3) + 50 N (V4) + 50 N (R7)), with seven common bean cultivars/lines (1. BRS ELO FC423, 2. BRS FC104, 3. BRS FC409, 4. BRS FC416, 5. CNFC 16484, 6. CNFC487, and 7. CNFC 16729. The CNFC 16484 and CNFC 16497 lines and the BRS FC 416 cultivar were the most productive ones. The late additional N application contributed to increasing pods per plant and also improved grain quality, evidenced by the higher percentage of grains retained in Sieve 12 and the higher N content in the grains, which means higher protein content.

Key words: Late fertilization; Nitrogen fertilization; *Phaseolus vulgaris* L; Phenological stages.

Aplicação adicional tardia de nitrogênio em genótipos de feijão-comum afetando produtividade e qualidade de grãos

Resumo: Apesar de inúmeros estudos conduzidos no Brasil sobre a adubação nitrogenada no feijoeiro, ainda existem muitos questionamentos sobre doses e épocas de aplicação do nitrogênio (N) na cultura, principalmente relacionado à aplicação tardia do nutriente e seu efeito na produtividade e qualidade de grãos. Objetivou-se quantificar o efeito da aplicação adicional tardia de N na produtividade de grãos e componentes da produtividade, e na qualidade dos grãos do feijão-comum, irrigado via pivô-central, em sistema plantio direto. O delineamento experimental foi em parcelas subdivididas, com cinco repetições. Os tratamentos consistiram da combinação de quatro manejos de N, envolvendo doses e estádios de aplicação (Manejo 1: 70 kg ha^{-1} de N (V3) + 50 N (V4), Manejo 2: 70 N (V3) + 50 N (V4) + 50 N (R6), Manejo 3: 70 N (V3) + 50 N (R6) e Manejo 4: 70 N (V3) + 50 N (V4) + 50 N (R7)) com sete cultivares/linhagens de feijoeiro (1. BRS ELO FC423, 2. BRS FC104, 3. BRS FC409, 4. BRS FC416, 5. CNFC 16484, 6. CNFC487 e 7. CNFC 16729. As linhagens CNFC 16484, CNFC 16497 e a cultivar BRS FC 416 foram as mais produtivas. A aplicação adicional tardia de nitrogênio contribuiu para o incremento de vagens por planta do feijão-comum, como também aumentou a qualidade dos grãos evidenciada pela maior percentagem de grãos retidos na Peneira 12 e pelo maior teor de nitrogênio no grão, o que significa maior teor de proteína.

Palavras-chave: adubação nitrogenada; estádios fenológicos; fertilização tardia; *Phaseolus vulgaris* L.

1. INTRODUCTION

Adopting techniques that enable the maximization of the nitrogen (N) use efficiency by the common bean plants is extremely important to increase grain yield, reduce production costs, and avoid environmental contamination (SORATTO et al., 2005; BARBOSA et al., 2020). Common bean is highly demanding in N and, unlike other macronutrients, which have seen greater advances in their recommendations due to the contributions of soil chemical analysis, there has been little progress in its recommendation, and the topic remains challenging and a subject for research. An advance was the guidance on the use of a portable chlorophyllometer to quantify crop nitrogen fertilization (SILVEIRA & GONZAGA, 2016; SILVA et al., 2023; SILVEIRA et al., 2023a).

Pias et al. (2022) carried out a meta-analysis on common bean response to nitrogen fertilization in Brazil. The results of 160 experiments were analyzed under the most diverse edaphoclimatic conditions, involving N doses and sources, application time and splitting, biological N fixation, among other factors. Regarding the timing of top-dressing N application, almost all of the 160 studies reviewed considered applications in the early stages of the crop, up to the V4 stage (third open trifoliate leaf), and only four studies addressed nitrogen fertilization in later stages. Thus, it is evident that there is a scarcity of data on the late N application in common beans and its effects on grain yield and quality.

According to Leal et al. (2019), N uptake occurs throughout the crop cycle, but the time of greatest demand, when the uptake rate is maximum, occurs from 35 to 50 DAE (days after emergence), in the initial phase of the crop. On the other hand, Costa et al. (2022) found that N uptake lasts up to approximately 80 DAE. Nascente & Carvalho (2018) showed that N uptake occurs throughout the crop cycle. However, from the flowering stage onwards there is an increase in N uptake by pods and grains until harvest.

Considering the results presented by Nascente & Carvalho (2018) and Costa et al. (2022) it can be inferred that the N applied at the early stages of common bean development may no longer be available to the plant at 80 days after emergence, considering all factors of N losses that occur in the soil , such as leaching, immobilization, volatilization, among others. On the other hand, in recent years, tecnified producers, with cultivation under irrigation in autumn-winter, have been obtaining high grain yields, exceeding 3,000 kg ha^{-1}. Thus, if we consider the amounts of nitrogen extracted from the soil by roots, branches, leaves, pod shell and grains, these combined amounts are well above the N usually added to the soil at planting and top-dressing of the crop. Therefore, late additional fertilization is justified if this difference is not met by N from the mineralization of soil organic matter or by biological nitrogen fixation by the plant.

Soratto et al. (2005) reported an increase in grain protein content in common bean with late application of N in top dressing, at the beginning of the R7 stage (pod formation). Flôres et al. (2017) and Guimarães et al. (2017) reported, respectively, an increase in the number of pods and grain yield with the application of N at the R5 stage (pre-flowering). Soratto et al. (2011), in turn, showed that, in the absence of N topdressing, foliar N application in the reproductive stage increased grain weight and size, grain yield and grain protein content in common bean.

Regarding the positive effect of late split application of N, the hypothesis is that this additional late N, applied during the flowering stage of common bean, will be used directly by the plant's reproductive structures, since the plant's vegetative stage has already been surpassed (SILVEIRA et al., 2023).

This study aimed to quantify the effect of late additional N application on grain yield and their components, and on grain quality of common bean, irrigated by central pivot in a no-tillage system.

2. MATERIAL AND METHODS

The field experiment was conducted in the winter of 2023 at the Capivara Farm of Embrapa Rice & Beans, located in the municipality of Santo Antônio de Goiás, GO, Brazil. The geographical coordinates of the site are 16°28'00" S, 49º17'00" W, and the altitude is 823 m (SILVA et al., 2002). The climate is tropical savanna, considered Aw according to the Köppen's classification. There are two well-defined seasons: normally, the dry season extends from May to September (autumn/winter) and the rainy season from October to April (spring/summer) (ALVARES et al., 2013). The historical average annual rainfall ranges from 1,500 to 1,700 mm. The historical average annual temperature is 22.7°C, varying annually from 14.2°C to 34.8°C (SILVA et al., 2002).

Soil analysis at the beginning of the study showed pH (H_2O) = 5.9; Ca and Mg contents, respectively, 2.03 and 1.22 cmolc dm^{-3}, and P, K, Cu, Zn, and Mn, respectively, 8.89; 109.8; 1.1; 5.14 and 11.26 g dm^{-3}. According to Souza, Lobato (2004), these levels are classified as adequate to high, characterizing a soil with built-up fertility. The sand, silt and clay contents were, respectively, 496, 95, and 409 g kg^{-1} (clay soil) and the organic matter was 30.7 g kg^{-1}.

In the experimental area, under a no-tillage system, common bean was grown in the fall-winter season on soybean straw. The experimental design was in split plots, with five replications. The treatments consisted of the combination of seven common bean cultivars/lines (1. BRS ELO FC423, 2. BRS FC104, 3. BRS FC409, 4. BRS FC416, 5. CNFC 16484, 6. CNFC487, and 7. CNFC 16729) with four N management, applied at different plant stages (Management 1: 70 kg ha^{-1} of N (V3) + 50 N (V4); Management 2: 70 N (V3) + 50 N (V4) + 50 N (R6); Management 3: 70 N (V3) + 50 N (R6); and Management 4: 70 N (V3) + 50 N (V4) + 50 N (R7)), where V3 is the first open trifoliate leaf, V4 is the third trifoliate leaf, R6 is flowering, and R7 is pod formation. Managements 1 and 3 received a total of 120 kg ha^{-1} of N (70+50) as topdressing and Managements 2 and 4 received 170 kg ha^{-1} (70+50+50), with urea as the source.

The common bean sowing, with a spacing of 0.45 m between rows and 11 seeds per meter, was carried out on 04/26/2023 and the harvest on July 26, 2023 of the cultivar with a later cycle (91 days). The sowing fertilization was 200 kg ha^{-1} of MAP (11% N and 52% P_2O_5) plus 120 kg ha^{-1} of KCl and N topdressing was carried out according to the treatments.

Irrigations were carried out using the center pivot system, and irrigation management followed the irrigaFeijao software (https://www.cnpaf.embrapa.br/irrigaFeijao), with 326 mm of irrigation water applied during the crop cycle.

To determine grain yield (kg ha^{-1}) and 100-grain weight (g), two four-meter rows were collected in each plot, making up a usable area of 3.6 m^2. This material was threshed and weighed, and the moisture content was adjusted to 13% (wet basis). To assess the number of pods per plant and grains per pod, five plants were randomly collected within the useful area of the plot. The grain weight from the five plants was added to the grain weight of the corresponding treatment to obtain the final grain yield. The N content in the grains, percentage (%) of grains retained in Sieve 12, and N use efficiency were also determined. The last variable was obtained by dividing the grain yield by the amount of N applied. The variable % of grains retained in Sieve 12 is a technological quality characteristic that has become part of common bean improvement programs in recent years (HERRERA-HERNÁNDEZ et al., 2018), as it promotes better market acceptance (RIBEIRO et al., 2023). Sieve 12 is the largest sieve for classifying common bean grains due to its hole dimensions, which are oblong, 19.05 mm long and 4.76 mm wide.

The determined variables were subjected to analysis of variance, using the F test, and the means were compared using the Scott-Knott's test ($p<0.05$) for cultivars/lines and the Tukey's test ($p<0.05$) for N managements, using the Sisvar program (FERREIRA, 2011)..

3. RESULTS AND DISCUSSION

There was a significant effect of cultivars/lines on all the variables analyzed (Table 1), namely grain yield (GY), number of pods per plant (NPP), number of grains per pod (NGP), 100-grain weight (100GW), % of grains retained in Sieve 12 (S12), nitrogen use efficiency (NUE), and N content in the grains (NG). Nitrogen management influenced NPP, P12, NUE and NG. There was a significant interaction of treatments on NPP, S12, and NG.

The highest grain yields were obtained by the cultivar BRS FC416 cultivar and the lines CNFC 16484 and CNFC 16497 (Table 2), which can be considered the most responsive to applied N. The lowest grain yield was obtained by the cultivar BRS FC104, which can be justified because it is a super-early cultivar (MELO et al., 2017). On the other hand, the superiority of the lines is justified by the constant advances in plant breeding programs. Differences in the responses of common bean cultivars to late N fertilization were also reported by Guimarães et al. (2017).

Table 1. Summary of the analysis of variance of the variables grain yield (GY), number of pods per plant (NPP), number of grains per pod (NGP), 100-grain weight (100GW), % of grains retained in Sieve 12 (S12), nitrogen use efficiency (NUE), and N content in the grains (NG).

Source of variation	DF	Mean Square						
		GY	NPP	NGP	100GW	S12	NUE	NG
Block	4	175224ns	6.5ns	0.1ns	0.3ns	80.4ns	8.9ns	2.3ns
Cultivars C	6	1164349**	240.2**	1.9**	56.2**	2650.4**	53.6**	246.8**
Nitrogen N	3	306892ns	119.5**	0.1ns	2.3ns	93.3**	765.3**	70.1**
C x N	18	211655ns	44.8**	0.1ns	2.2ns	115.5**	8.1ns	14.9**
CV (%)		10.62	14.65	5.98	5.16	5.45	10.64	5.94

DF = degrees of freedom; CV = coefficient of variation; ns = F not significant; ** = F significant, $p \leq 0.01$.

In general, these same cultivars/lines performed well in the variables number of grains per pod, 100-grain weight, and nitrogen use efficiency (Table 2).

Comparing Management 1 with 2 and Management 3 with 4 (Table 3), it is observed that managements with higher N doses (2 and 4), applied at later stages (R6 and R7), tend to present higher grain yield, number of pods per plant, and nitrogen in the grain, especially management 4. This management exhibited grain yield, number of pods per plant, and nitrogen in the grain, respectively, 5.0%, 18.8%, and 8.6% more than Management 3. The hypothesis is that this late N, applied at the pod formation stage (R7) of the common bean, will be used directly by the reproductive structures of the plant, since the vegetative stage of the plant has already been surpassed. According to Carvalho & Nakagawa (2000), the nutritional requirements of crops, in general, become more intense with the onset of the reproductive phase, being most critical at the time of seed formation, when considerable amounts of nutrients are translocated to them. This greater requirement is due to the fact that nutrients are essential for the formation and development of new reserve organs. Marrou et al. (2018) demonstrated that N accumulation in common bean plants was found to persist in seed growth. This challenges a common hypothesis that seed growth causes a decrease in N accumulation because of a shift of the photosynthate supply to support the seed growth. Corroborating this study, Silva & Moreira (2022) observed N accumulation in common beans up to the grain filling stage (R8).

Table 2. Grain yield (GY), number of pods per plant (NPP), number of grains per pod (NGP), 100-grain weight (100GW), % of grains retained in Sieve 12 (S12), nitrogen use efficiency (NUE), and N content in the grains (NG) as affected by cultivars/lines.

Cultivar/Line	GY	NPP	NGP	100GW	S12	NUE	NG
	kg ha^{-1}	un	un	g	%	kg kg^{-1}	g kg^{-1}
BRS ELO FC423	3,757b[1]	23.2	5.6c	24.3c	96.2	26.67b	31.77
BRS FC104	3,261c	29.8	5.6c	22.8d	71.7	23.24c	27.74
BRS FC409	3,672b	20.4	5.4d	27.7a	76.4	25.96 b	36.07
BRS FC416	3,933a	22.7	5.9b	26.2b	71.7	27.78b	27.39
CNFC 16484	3,870a	25.6	6.0b	27.2a	95.0	27.32b	28.76
CNFC 16497	3,979a	26.2	5.9b	26.1b	91.8	28.15a	35.32
CNFC 16729	3,682b	20.0	6.4a	25.0c	94.8	26.14b	30.39

[1]Means followed by the same letter in the column do not differ from each other using the Scott-Knott's test, at 5% probability.

Conversely, Managements 1 and 3 (120 kg ha^{-1} of N) providing higher NUE values than Managements 2 and 4 (170 kg ha^{-1} of N). This is because the higher N doses in the last two managements influenced the calculation of the variable.

Table 3. Grain yield (GY), number of pods per plant (NPP), number of grains per pod (NGP), 100-grain weight (100GW), % of grains retained in Sieve 12 (S12), nitrogen use efficiency (NUE), and N content in the grains (NG) as affected by N managements.

N management	GY	NPP	NGP	100GW	S12	NUE	NG
	kg ha^{-1}	un	un	g	%	kg kg^{-1}	g kg^{-1}
Management 1	3,701	23.3	5.8	25.6	86.7	30.8a[1]	29.7
Management 2	3,823	23.6	5.9	25.9	85.8	22.5b	31.3
Management 3	3,620	22.4	5.9	25.3	83.0	30.2a	30.3
Management 4	3,800	26.6	5.8	25.6	86.0	22.4b	32.9

[1]Means followed by the same letter in the column do not differ from each other using the Tukey's test, at 5% probability. Management 1 = 70 N (V3) + 50 N (V4); Management 2 = 70 N (V3) + 50 N (V4) + 50 N (R6); Management 3 = 70 N (V3) + 50 N (R6); and Management 4 = 70 N (V3) + 50 N (V4) + 50 N (R7).

The interactions between cultivars/lines and N management on the variables number of pods per plant, % of grains retained in Sieve 12 and N content in the grains are presented in Tables 4, 5 and 6, respectively.

The number of pods per plant in the cultivar BRS FC104 and lines CNFC 16484 and CNFC 16497 was affected by N management (Table 4). Management 4, in which there was a late additional application of N, resulted in a higher number of pods per plant compared to Management 1 in cultivar BRS FC104, which did not receive this application. In Management 3, lines CNFC 16484 and CNFC 16497 also showed a lower number of pods per plant under the same condition, without late topdressing of N, compared to Management 4. Flôres et al. (2017) also observed an increase in the number of pods per plant with late N application. Similary, Rosa et al. (2020), working with different timings and split application of nitrogen topdressing in common bean, observed differences among cultivars in the number of pods per plant. The BRS FC 104 cultivar stood out for their higher number of pods per plant across all managements.

Among the seven cultivars/lines evaluated, only cultivars BRS FC409 and BRS FC416 had the % of grains retained in Sieve 12 affected by N management (Table 5). Management 4, which included a late additional application of N, resulted in an equal to or superior perfomance compared to the other managements.

The lines CNFC 16484, CNFC 16497, CNFC 16729, and cultivar BRS ELO FC 423 showed a higher percentage of grains retained in Sieve 12 than the other cultivars in all managements, except for cultivar BRS FC 409 in Management 4. These lines/cultivarexhibited a % of grains retained in Sieve 12 equal to or greater than 90%. According to Herrera-Hernández et al. (2018) and Ribeiro et al. (2023), this indicates good commercial acceptance of these materials.

Table 4. Analysis of the interaction between cultivars/lines and nitrogen management in the number of pods per plant.

Cultivar/Line	Management 1	Management 2	Management 3	Management 4
BRS ELO FC 423	24.6ABa[1]	20.1BCa	22.6Ba	25.5BCa
BRS FC104	25.4ABb	31.1Aab	29.4Aab	33.0Aa
BRS FC409	18.8BCa	22.2BCa	22.3Ba	18.3Da
BRS FC 416	24.4ABa	21.5BCa	20.6Ba	24.2BCDa
CNFC 16484	25.1ABab	25.6ABab	21.8Bb	29.9ABa
CNFC 16497	27.5Aab	25.9ABb	18.5Bc	32.9Aa
CNFC 16729	17.1Ca	18.8Ca	21.5Ba	22.5CDa

[1]Means followed by the same uppercase letter in the column and by the some lowercase letter in the row do not differ from each other using the Tukey's test, at 5% probability. Management 1 = 70 N (V3) + 50 N (V4); Management 2 = 70 N (V3) + 50 N (V4) + 50 N (R6); Management 3 = 70 N (V3) + 50 N (R6); and Management 4 = 70 N (V3) + 50 N (V4) + 50 N (R7).

As mentioned earlier, the superiority of the lines and cultivar BRS ELO FC 423 is justified by the constant advances in plant breeding programs, especially related to commercial acceptance.

Table 5. Analysis of the interaction between cultivars/lines and nitrogen management in the percentage of grains retained in Sieve 12.

Cultivar/Line	Management 1	Management 2	Management 3	Management 4
BRS ELO FC 423	97.0Aa[1]	97.8Aa	97.4Aa	92.8Aa
BRS FC 104	74.4BCa	72.7Ba	68.3BCa	71.6Ba
BRS FC 409	81.5Ba	72.1Bb	63.3Cc	88.6Aa
BRS FC 416	67.2Cb	76.0Ba	73.7Bab	69.8Bab
CNFC 16484	96.3Aa	95.8Aa	94.7Aa	93.3Aa
CNFC 16497	94.7Aa	92.3Aa	90.0Aa	90.5Aa
CNFC 16729	96.2Aa	94.0Aa	93.9Aa	95.2Aa

[1]Means followed by the same uppercase letter in the column and by the same lowercase letter in the row do not differ from each other using the Tukey's test, at 5% probability. Management 1 = 70 N (V3) + 50 N (V4); Management 2 = 70 N (V3) + 50 N (V4) + 50 N (R6); Management 3 = 70 N (V3) + 50 N (R6); and Management 4 = 70 N (V3) + 50 N (V4) + 50 N (R7).

The analysis of the interaction between cultivars/lines and N management showed that only for the cultivar BRS ELO FC423 it was not significant (Table 6). Also, only in the CNFC 16729 line the late additional application of N (Management 4) was not equal to or superior to the other managements, showing that this management was efficient in increasing the N content in the grains, which means higher protein content, corroborating the results of Soratto et al. (2005). The BRS FC 409 cultivar and the line CNFC 16497 line stood out for their higher N content in the grains across all managements.

Table 6. Analysis of the interaction between cultivars/lines and nitrogen management in the N content in the grains.

Cultivar/Line	Management 1	Management 2	Management 3	Management 4
BRS ELO FC 423	32.5Aa[1]	32.0BCa	31.8ABa	30.9Ba
BRS FC 104	26.6Bb	26.2DEb	27.2CDb	30.9Ba
BRS FC 409	33.3Ac	36.8Aab	34.5Abc	39.8Aa
BRS FC 416	27.5Bab	25.5Eb	26.9CDab	29.6Ba
CNFC 16484	28.1Bb	29.3CDab	26.6Db	31.1Ba
CNFC 16497	33.3Ab	35.4ABab	34.7Ab	37.9Aa
CNFC 16729	26.9Bc	33.9ABa	30.4BCb	30.4Bb

[1]Means followed by the same uppercase letter in the column and by the same lowercase letter in the row do not differ from each other using the Tukey's test, at 5% probability. Management 1 = 70 N (V3) + 50 N (V4); Management 2 = 70 N (V3) + 50 N (V4) + 50 N (R6); Management 3 = 70 N (V3) + 50 N (R6); and Management 4 = 70 N (V3) + 50 N (V4) + 50 N (R7).

In the past, late N application was challenging in commercial common bean crops due to the fact that bean plants already fully covered the soil by that time (SILVEIRA et al., 2023b). Nowadays, agricultural equipment is available for fertilizer distribution, allowing for application at longer distances and working in the same line with self-propelled sprayers used for pesticide application. This avoids the need for additional "roads" in the field, thus facilitating nitrogen application at later stages of the crop cycle.

4. CONCLUSIONS

The lines CNFC 16484, CNFC 16497 and the cultivar BRS FC 416 were the most productive ones. The late additional N application contributed to increasing pods per plant and also improved grain quality, evidenced by the higher percentage of grains retained in Sieve 12 and the higher N content in the grains, which means higher protein content.

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