**Division – Soil Use and Management** | Commission – Lime and Fertilizer

# Common bean yield responses to nitrogen fertilization in Brazilian no-till soils: A meta-analysis

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**ABSTRACT:** Although numerous studies have been conducted with common bean regarding nitrogen (N) dose, time of application, and source in no-till (NT) soils in Brazil, the heterogeneity of the results makes it difficult to establish technical recommendations based on individualized studies. This meta-analysis aimed to rank the main factors influencing common bean response to N management in NT areas. The database consisted of 99 scientific papers that encompassed 160 trials and 2394 observations. In general, the probability of obtaining a positive response to N application in common bean productivity was 77 %, with an average 18 % increment (358 kg ha$^{-1}$). The main factors that affect the response of common bean grain yield to N fertilization and the choice of the applied N dose are soil organic matter (OM) content and the preceding crop. In soils with OM content >20 g kg$^{-1}$, the N dose that determines the highest economic return is 50 kg ha$^{-1}$. For soils with OM content <20 g kg$^{-1}$, the N dose to be applied is 70 and 100 kg ha$^{-1}$ for crops preceded by legumes and grasses, respectively. The timing of the N application did not result in a significant difference in common bean yield in 62 % of the trials. However, the results showed that the average yield increase in the common bean went from 15 % (293 kg ha$^{-1}$) with a single application to 32 % (622 kg ha$^{-1}$) with split N applications. All N sources tested showed similar gains to those obtained with N application through urea. Excluding situations with high doses of N application (>100 kg ha$^{-1}$), inoculating common bean seeds increased grain yields by 6 % on average (118 kg ha$^{-1}$). The combined analysis of the available results demonstrated that the crop recommendations used in Brazilian soils under NT could be refined considering the soil OM concentration and preceding crop. Additionally, seed inoculation and N dose splitting in the form of common urea should be recommended.

**Keywords:** *Phaseolus vulgaris* L., N source, seed inoculation, N application time, N dose.

# INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a legume native to the Americas with high climatic adaptation and cultivated throughout Brazil (Salgado et al., 2012a). It is a staple food in developing countries and an important protein, mineral, and vitamin source (Lião et al., 2010; Hungria et al., 2013). In Brazil, small producers generally grow the common bean for subsistence via family labor and low technological level, obtaining low yields (Lobo et al., 2012). In recent years, the possibility of mechanizing the harvest of common bean and improved productive potential has led this crop to be produced at a large scale and part of crop rotation systems to diversify and intensify (off-season) the production (Dal Molin and Ernani, 2017).

Common bean is traditionally grown in central and southern Brazil, while the cowpea (*Vigna unguiculata* L.) is predominant in the north and northeast. Roughly 1.34 million ha of land is planted with the common bean in central and southern Brazil, with average productivity of 1.72 Mg ha$^{-1}$ (2019/2020 season; Conab, 2020). Moreover, the average productivity of common bean crops has gradually increased in recent decades in Brazil, although it is far below the potential of the crop, which is above 4.0 Mg ha$^{-1}$ (Barbosa Filho et al., 2004; Venturini et al., 2005; Arf et al., 2011a). Various factors contribute to the low average productivity in the country, including low technology employed (Lobo et al., 2012), inadequate phytosanitary control, adverse weather conditions (Damian et al., 2018), and inadequate fertilization management (Santi et al., 2006). Regarding fertilization, the common bean requires significant quantities of the nutrient nitrogen (N) (Crusciol et al., 2007), which influences vital plant functions such as photosynthesis and protein synthesis, being a primary constituent of chlorophyll, amino acids, nucleic acids, hormones (e.g., auxin and cytokinin), and alkaloids (Rabelo et al., 2017). Moreover, nitrogen deficiency directly influences biomass production and causes premature leaf senescence, reducing grain yield (Santos and Fageria, 2007).

The main source of N for common beans is from soil organic matter (OM). In no-till (NT) systems, the crop residues are kept on the soil surface, creating a concentration gradient of OM and nutrients in the soil profile that changes the dynamics of N compared to conventional tillage (Veloso et al., 2018). Furthermore, NT system creates a less oxidative environment in the soil that reduces the rates of N mineralization of OM, although OM accumulation compensates for this reduction over time, and the soil begins to provide more N to crops (Lovato et al., 2004). In turn, the increased cation exchange capacity (CEC) in the soil due to higher OM content (pH-dependent loads) favors N-NO$_3^-$ losses by leaching (Rojas et al., 2012). The NT areas have increased activity of the denitrifying community and, when not managed properly, they may lead to anaerobiosis due to soil compaction, thereby favoring N$_2$ losses by denitrification (Wang and Zou, 2020). Due to the dynamics of N in the soil, the various types of losses, and its high mobility in the profile, it is difficult to predict its availability for crops and an even greater challenge to make recommendations for N fertilization.

Through symbiosis with nitrogen-fixing bacteria (*rhizobia*), common bean converts atmospheric N into ammonium via nitrogenase activity (Pelegrin et al., 2009; Hungria et al., 2013); however, symbiotic N fixation in the common bean is not as efficient as other legumes (*e.g.,* lupine) due to several factors. One of the more notable factors is that common bean perform symbiosis with a high diversity of native bacteria in the soil, some of which are highly competitive and not as efficient as the selected strains (Pasqualini, 2008). Nitrogen fertilization also interferes in the crop nodulation. Soils with a high N concentration make the common bean more prone to absorbing the N available in the soil solution than performing symbiosis, which has a higher energy cost for the plant (Hungria et al., 2013). Thus, biological N fixation is usually not enough to meet the nutritional demands of the common bean, making it is necessary to use mineral fertilization to complement the crops' needs to achieve high yields (Cunha et al., 2011; Mingotte et al., 2014; Soratto et al.,

2017). Another component that favors common bean responses to N fertilization is its intrinsic feature of poorly developed and shallow root systems (less than 0.20 m deep), reducing its capacity to absorb N and water in soil subsurface layers (Caires et al., 2016). In addition, the current cultivar cycles are short and commonly vary between 90-100 days (Menegol et al., 2015; Silveira and Gonzaga et al., 2017; Damian et al., 2018), making the crop highly demanding in terms of soil N availability.

Nitrogen recommendations in Brazil are mainly based on estimates of N availability in the soil due to OM mineralization and common bean N requirements (expected yield) (CQFS-RS/SC, 2016) because there is no laboratory analysis capable of accurately identifying N availability in the soil for crops during their cycle (Barbosa Filho et al., 2008). For the southernmost Brazilian states (Rio Grande do Sul and Santa Catarina), the official recommendation for the common bean considers that doses should range from 30 to 70 kg ha$^{-1}$ according to the soil OM content. In addition, the expected yield should be considered, and when above 2.0 Mg ha$^{-1}$, the dose should be increased by 20 kg ha$^{-1}$ for each ton of grain to be produced (CQFS-RS/SC, 2016). For Minas Gerais State (southeastern Brazil), the recommendation is 40-100 kg ha$^{-1}$ depending on the technological level employed (Ribeiro et al., 1999). The recommended doses vary from 20 to 90 kg ha$^{-1}$ in São Paulo State (southeastern Brazil) depending on expected yield, preceding crop, and soil texture (Ambrosano et al., 1997).

Given the significant influence of N fertilization on common bean grain yield, a series of NT studies have been conducted in Brazil to determine the best N fertilization management. Nevertheless, the results varied widely and ranged from research with yield reduction by N application (Silva et al., 2006, 2009a; Arf et al., 2014; Guimarães et al., 2017), lack of response (Alves Junior et al., 2009; Lopes et al., 2011; Pacheco et al., 2012, 2016; Dal Molin and Ernani, 2017; Flôres et al., 2017), and significant increases in yield (Barbosa Filho et al., 2008; Franco et al., 2008; Teixeira et al., 2008; Sant'ana et al., 2010; Cunha et al., 2011). Local variables related to soil properties, climate (Damian et al., 2018), field management history (Arf et al., 2011b; Maia et al., 2012), N management, cultivar genetics (Salgado et al., 2012a), and biological N$_2$ fixation efficiency (Maia et al., 2012) have also been identified as factors contributing to the high variation in the response of the common bean to N fertilization.

Given the heterogeneity of the responses of the common bean to N fertilization obtained by individual studies conducted in different Brazilian regions, it is difficult to extract information to support the refinement of N recommendations for the crop. In this context, a meta-analysis of the data available in the literature was conducted to answer the following questions: (i) What is the average increment in grain yield by N fertilization and what is the probability of obtaining a positive response? (ii) Which factors influence the magnitude of common bean grain yield response to N fertilization? (iii) Which dose, the timing of application and source of N show the best results? (iv) What is the viability of inoculating common bean seeds?

## MATERIALS AND METHODS

### Data collection

The data covered by the meta-analysis were obtained from scientific papers that evaluated the effects of N fertilization on common bean productivity in NT systems in Brazil. The following search terms in Portuguese and English (separately and together) were used in the databases Web of Science, SciELO, and Google Scholar: "nitrogen", "common bean", "Brazil," and "no-till system". The papers that met one or more of the following criteria were excluded: i) production under conventional tillage soil, ii) studies in greenhouses, iii) lack of control treatment (without N), and iv) lack of grain yield data. After applying the exclusion criteria, the database consisted of 99 scientific papers published from 2000 to 2018, totaling 160 trials (site × year) and 2394 observations (Table 1).

**Table 1.** Description of the papers that evaluated common bean response to mineral nitrogen fertilization in Brazil, with details of the number of observations, number of the trials, N dose, N source, N application time and the use of seed inoculant

| Reference | Obs.[1] | Trials[2] | N dose | N source[3] | N application time[4] | Inocul.[5] |
|---|---|---|---|---|---|---|
| | | | kg ha$^{-1}$ | | | |
| Afonso et al. (2011) | 24 | 2 | 0 and 80 | UR and AS | 15 + 19 DAE | Not |
| Alvarez et al. (2005) | 24 | 2 | 0, 25, 50, 75 100 and 125 | UR and CN | 21 DAE | Not |
| Alves Junior et al. (2009) | 16 | 1 | 0, 40, 80 and 120 | UR | 20 DAE | Not |
| Amaral et al. (2016) | 15 | 1 | 0, 40, 80, 120 and 160 | UR | 36 DAE | Not |
| Araújo et al. (2009) | 32 | 2 | 0 and 50 | AS | 15 + 25 DAE | Not |
| Arf et al. (2004) | 30 | 2 | 0, 30, 60, 90 and 120 | UR | 15 DAE | Not |
| Arf et al. (2008) | 24 | 2 | 0, 25, 50, 75 100 and 125 | UR | 15 DAE | Not |
| Arf et al. (2011a) | 16 | 2 | 0, 60, 120 and 180 | UR | V$_{4-5}$ | Yes |
| Arf et al. (2011b) | 36 | 2 | 0, 60, 120 and 180 | UR, AS and ASN | 21 + 30 DAE | Not |
| Arf et al. (2014) | 84 | 2 | 0, 25, 50, 75, 100 and 125 | UR | 15 DAE | Not |
| Barbosa et al. (2010) | 20 | 2 | 0, 30, 60, 90 and 120 | UR | V$_{4-3}$ | Not |
| Barbosa Filho et al. (2004) | 45 | 3 | 0 and 80 | UR and AS | 15 + 30 DAE | Not |
| Barbosa Filho et al. (2005) | 90 | 3 | 0, 60, 90, 120 and 150 | UR and AS | 30, 15 + 30, and 15 + 30 + 45 DAE | Not |
| Barbosa Filho et al. (2008) | 4 | 1 | 0, 60, 120 and 240 | UR | Sowing, 15 and 30 DAE | Not |
| Barbosa Filho et al. (2009) | 6 | 1 | 0, 60, 120 and 240 | UR | 15 DBS + sowing + 15 + 30 DAE, 15 DBS + sowing, 15 DBS + sowing + 15 DAE | Not |
| Bernardes et al. (2015) | 6 | 1 | 0 and 100 | UR, AS, AN, URUI and URSR | Sowing + 26 DAE | Not |
| Binotti et al. (2007) | 24 | 3 | 0 and 75 | UR | Sowing, V$_{3-1}$ and V$_{4-3}$ | Not |
| Binotti et al. (2009) | 30 | 1 | 0, 50, 100, 150 and 200 | UR and AS | Sowing and sowing + 23 DAE | Not |
| Binotti et al. (2010) | 9 | 1 | 0, 40 and 80 | UR and AS | 20 DAE | Not |
| Binotti et al. (2014) | 12 | 1 | 0 and 80 | UR and AS | 20, 30 and 20 + 30 DAE | Not |
| Bordin et al. (2003) | 24 | 1 | 0, 25, 50 and 75 | UR | 30 DAE | Not |
| Brito et al. (2015) | 35 | 4 | 0, 20, 40, 60, 80 and 120 | UR | 25 DAE | Yes |
| Carmeis Filho et al. (2014) | 15 | 1 | 0, 40, 80, 120 and 160 | UR | V$_{4-4}$ | Not |
| Carvalho et al. (2003) | 15 | 1 | 0, 35, 70, 105 and 140 | UR | 15, 30 and 15 + 30 DAE | Not |
| Costa et al. (2009) | 60 | 2 | 0, 25, 50, 75 and 100 | UR | 16 DAE | Not |
| Crusciol et al. (2007) | 8 | 1 | 0, 30, 60 and 120 | UR and NC | 22 DAE | Not |
| Cunha et al. (2011) | 16 | 1 | 0, 60, 120 and 180 | UR and URUI | V$_{4-3}$ + V$_{4-6}$ | Not |
| Cunha et al. (2015) | 15 | 1 | 0, 40, 80, 120 and 160 | UR | V$_{4-3}$ | Not |
| Dal Molin and Ernani (2017) | 9 | 1 | 0 and 60 | UR, NA and URSR | 23 DAE | Not |
| Damian et al. (2018) | 50 | 1 | 0, 60, 90, 120 and 180 | UR | 7, 14, 21, 28 and 35 DAE | Not |

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| | | | | | | |
|---|---|---|---|---|---|---|
| Farinelli et al. (2006) | 10 | 2 | 0, 40, 80, 120 and 160 | UR | $V_{4-3}$ | Not |
| Fernandes et al. (2005) | 32 | 2 | 0, 20 and 70 | UR | 16 + 21 DAE | Not |
| Ferreira et al. (2009) | 7 | 1 | 0 and 80 | UR | $V_{4-3}$ | Yes |
| Ferreira et al. (2013) | 32 | 2 | 0, 40, 80 and 120 | UR | $V_{4-3}$ | Not |
| Fiorentin et al. (2011) | 15 | 1 | 0, 40, 80, 120 and 160 | UR | $V_{4-4}$ | Not |
| Flôres et al. (2017) | 30 | 1 | 0 and 90 | UR | $V_{3-1}$, $V_{4-3}$ and $R_5$ | Not |
| Fonseca et al. (2013) | 24 | 1 | - | - | - | Yes |
| Fornasieri Filho et al. (2007) | 16 | 2 | 0, 50, 100 and 150 | UR | $V_{4-3}$ | Not |
| Franco et al. (2008) | 6 | 1 | 0, 50, 100, 150 and 200 | UR | Sowing + $V_{4-3}$ | Not |
| Gerlach et al. (2013) | 48 | 2 | 0, 30, 60 and 90 | UR | $V_{4-4}$ | Not |
| Gitti et al. (2012) | 12 | 1 | 0, 15, 30, 45, 60 and 90 | UR | 30 DAE | Not |
| Gomes Junior et al. (2005) | 48 | 2 | 0, 40 and 80 | UR | 24, 28, 31, 34, 36, 38, 41, 43 and 45 DAE | Not |
| Gomes Junior et al. (2008b) | 60 | 1 | 0, 30, 60, 90 and 120 | UR | $V_{4-3}$ + $V_{4-6}$ | Not |
| Gomes Junior et al. (2008a) | 34 | 2 | 0, 40 and 80 | UR | $V_{4-3}$, $V_{4-4}$, $V_{4-5}$, $V_{4-6}$, $V_{4-7}$, $V_{4-8}$, $V_{4-9}$ and $V_{4-10}$ | Not |
| Guimarães et al. 2017) | 32 | 1 | 0, 40, 80 and 120 | UR | $V_2$, $V_{3-1}$, $V_{4-3}$, $R_5$ and $R_6$ | Not |
| Hungria et al. (2013) | 15 | 5 | 0 and 80 | UR | 25 DAE | Yes |
| Kaneko et al. (2010) | 32 | 2 | 0, 60, 120 and 180 | UR | $V_{4-3}$ | Yes |
| Lobo et al. (2012) | 2 | 1 | 0 and 70 | UR | 29 DAE | Not |
| Lopes et al. (2011) | 12 | 1 | 0, 50, 100 and 150 | UR | 36 DAE | Not |
| Maia et al. (2012) | 10 | 2 | 0, 20, 50, 80, 100, 110 and 200 | AN | Sowing, 15 and 30 DAE | Not |
| Meira et al. (2005) | 21 | 1 | 0, 40, 80, 120, 160, 200 and 240 | UR | 21, 32 and 38 DAE | Not |
| Menegol et al. (2015) | 40 | 1 | 0, 40, 80, 120, 160, 200 and 240 | UR | 10, 15, 20 and 30 DAE | Not |
| Mingotte et al. (2014) | 15 | 1 | 0, 40, 80, 120 and 160 | UR | $V_{4-4}$ | Not |
| Monteiro et al. (2010) | 12 | 1 | 0, 80 and 160 | AS | Sowing + 7 + 24 DAE | Not |
| Muller and Zanão Junior (2015) | 10 | 1 | 0 and 60 | UR | 30 DBS, sowing, 10, 20 and 30 DAE | Not |
| Nascente et al. (2017) | 64 | 4 | 0 and 90 | UR | Sowing, $V_{4-3}$ and Sowing + $V_{4-3}$ | Not |
| Nascimento et al. (2004) | 16 | 1 | 0, 30, 60 and 90 | UR | $V_{3-1}$ | Not |
| Nascimento et al. (2009) | 60 | 2 | 0, 30, 60, 90 and 120 | UR | $V_{3-1}$ | Not |
| Pacheco et al. (2012) | 12 | 1 | 0, 50 100 and 150 | UR | 30 DAE | Not |
| Pacheco et al. (2016) | 12 | 1 | 0, 50 100 and 150 | UR | 30 DAE | Not |
| Perez et al. (2013) | 16 | 2 | 0, 60 and 120 | AN | 8 DBS, $V_{4-3}$ and 8 DBS + $V_{4-3}$ | Not |
| Piaskowski et al. (2001) | 12 | 2 | 0, 20, 40, 60, 80 and 100 | UR | $V_{3-1}$ | Not |
| Repassi et al. (2003) | 12 | 1 | 0, 20, 40, 60 80 and 100 | UR and AN | 27 DAE | Not |
| Romanini Junior et al. (2007) | 32 | 2 | 0, 25, 50 and 75 | UR | 15 + 21 DAE | Yes |
| Sabundjian et al. (2013) | 32 | 1 | 0, 30, 60 and 90 | UR | 25 DAE | Not |

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| | [1] | [2] | N rates | [3] | [4] | [5] |
|---|---|---|---|---|---|---|
| Sabundjian et al. (2016) | 64 | 2 | 0, 40, 80 and 120 | UR | 25 DAE | Not |
| Salgado et al. (2012) | 24 | 1 | 0 and 100 | UR | 15 + 30 DAE | Not |
| Sant'Ana et al. (2010) | 5 | 1 | 0, 30, 60, 120 and 240 | UR | 10 + 17 DAE | Not |
| Santi et al. (2013) | 72 | 1 | 70 | UR | Sowing, 7, 14, 21, 28 and 35 DAE | Not |
| Schoninger et al. (2015) | 12 | 1 | 0, 40 and 80 | UR | 30 DAE | Not |
| Silva et al. (2002) | 18 | 2 | 120 | UR | 20 DBS + sowing + 35, Sowing + 35,35 DAE | Not |
| Silva et al. (2003) | 42 | 1 | 0, 30, 60, 90, 120 and 150 | UR | 24 DAE | Not |
| Silva et al. (2004) | 15 | 3 | 0, 25, 50, 75 and 100 | UR | 21 DAE | Not |
| Silva et al. (2006) | 8 | 1 | 0, 30, 60 and 120 | UR | 22 DAE | Not |
| Silva et al. (2009a) | 6 | 1 | 0 and 70 | UR | 25 DAE | Not |
| Silva et al. (2009b) | 24 | 1 | 0, 40, 80 and 120 | UR | Sowing + $V_{4-6}$ | Yes |
| Silva et al. (2009c) | 6 | 1 | 0 and 70 | UR | 25 DAE | Not |
| Silva and Silveira (2000) | 12 | 2 | 0, 25, 50, 75, 100 and 125 | UR | 37 DAE | Not |
| Silveira and Gonzaga (2017) | 24 | 3 | 0, 10, 20, 30, 50,60, 80 and 160 | UR | $V_{4-3}$ | Not |
| Silveira et al. (2003) | 8 | 1 | 0, 30, 60 and 120 | UR | 15 + 25 DAE | Not |
| Silveira et al. (2005) | 28 | 1 | 0, 30, 60 and 120 | UR | 15 + 25 DAE | Not |
| Soares et al. (2016) | 14 | 2 | 0, 20, 40, 60 and 80 | UR | 15 + 25 + 35 DAE | Yes |
| Soratto et al. (2003) | 12 | 1 | 75 | AN | Sowing, $V_{4-3}$, sowing + $V_{4-3}$ | Not |
| Soratto et al. (2004) | 5 | 1 | 0, 35, 70, 150 and 210 | UR | 20 DAE | Not |
| Soratto et al. (2005) | 8 | 1 | 0, 30, 60, 90, 120, 150 and 210 | AN | $V_{4-3}$ and $R_7$ | Not |
| Soratto et al. (2006a) | 15 | 1 | 0, 35, 70, 105 and 140 | UR | 15, 30 and 15 + 30 DAE | Not |
| Soratto et al. (2006b) | 6 | 1 | 0 and 90 | UR | $V_4$ and $R_5$ | Not |
| Soratto et al. (2011) | 12 | 1 | 0, 45 and 90 | AN | 26 DAE | Not |
| Soratto et al. (2013) | 8 | 1 | 0 and 100 | AS | 33 DAS, Sowing, and 23 DAE | Not |
| Soratto et al. (2017) | 30 | 1 | 0, 30, 60, 120 and 180 | AN | 14 + 28 DAE | Not |
| Souza and Ferreira (2017) | 21 | 7 | 0 and 80 | UR | Sowing + 25 DAE | Yes |
| Souza et al. (2011) | 32 | 4 | 0, 35, 70 and 140 | AN | Sowing + 25 DAE | Yes |
| Stone and Moreira (2001) | 80 | 4 | 0, 20, 40,60, 80 and 120 | AS | 35 DAE | Not |
| Teixeira et al. (2008) | 20 | 1 | 0, 50, 100 and 150 | AS | Sowing + 20 + 30 DAE | Not |
| Teixeira et al. (2010) | 18 | 1 | 0, 40, 80 and 120 | UR | 20 + 30 DAE | Yes |
| Valadão et al. (2009) | 8 | 1 | 0 and 60 | UR | Sowing + $V_{4-5}$ | Yes |
| Valderrama et al. (2009) | 8 | 1 | 0, 40, 80 and 120 | UR and URSR | $V_{4-6}$ | Not |
| Venturini et al. (2005) | 32 | 2 | 0 and 160 | UR | 20 DAE | Yes |
| Yagi et al. (2015) | 60 | 2 | 0 and 80 | UR | Sowing + 25 DAE | Yes |
| Total | 2394 | 160 | 154 | 21 | 39 | 37 |

[1] Number of observations; [2] Number of the trials evaluated in each primary study (year x location); [3] UR: Urea; AS: Ammonium sulfate; AN: Ammonium nitrate; ASN: Ammonium sulfonitrate; NC: nitrocalcium; CN: calcium nitrate; URUI: urea with urease inhibitor; and URSR: urea of slow-release; [4] DBS: days before sowing; and DAE: days after emergence ; [5] Use of seed inoculation.

The information extracted from the papers was the average grain yield of treatments with N and the control treatment, which did not receive N application, the N dose applied (0-280 kg ha$^{-1}$), N application time (anticipated, at sowing, and topdressing in different phonological stages), number of N application (the total N dose applied at once, or split in two or three times) sowing season [sowing season of the common bean in the primary studies: crop (September to November), off-season (January to March), and winter (May to July)], N source used (urea, ammonium sulfate, ammonium nitrate, urea with urease inhibitors and others), whether or not N was incorporated into the soil (through irrigation soon after N application), soil OM content, soil clay concentration and pH, soil type (Oxisol, Ultisol, Alfisol and Entisol), climate type (tropical or subtropical), use or not of irrigation and seed inoculants, time of adopting (years) the NT system, commercial grain group of the common bean (carioca, buttery, and black), and preceding crop (grass or legume).

**Regression tree analysis**

Conditioning factors of the effects of N fertilization on common bean yield were determined by regression tree analysis using Jmp® 13 software (SAS Inc, Cary, USA). Categorical (preceding crop, climate zone, soil type, commercial group of grains, N source, inoculant use, N incorporation, irrigation use) and continuous (N dose, clay concentration, OM content, soil pH, NT system adoption year) variables were used in the analysis as variation factors and the effects of N fertilization on common bean grain yield (relationship between treatment yield and control yield) as the response variable.

The regression tree analysis was based on the test of zero variance, that is, the independence between the variation factors and response variable (effect on productivity). When the first hypothesis is rejected, the software selects the variation factor closer to the response variable, repeating the process in each node of the regression tree. Data analysis reliability was maintained and data particularization was avoided by setting the initial and intermediate nodes of the regression tree to contain at least 20 % (479 observations) of the total data.

**Data meta-analysis**

Meta-analysis was performed by only comparing paired treatments (with and without N fertilization in the same trial), and from the entire database, the effects of N dose, N source, seed inoculation, and timing of N application were evaluated separately. For N dose, the grain yield of the treatments (with N) and the controls were used to determine their differences (treatment - control), which was considered the effect of N fertilization on grain yield. Different N sources were compared with urea, which was considered a control since it is the most used N source in Brazil. For the effects of inoculation, the difference in yield was calculated for treatments with and without inoculant (control). The effects of the timing of N application were not evaluated using meta-analysis because the treatments applied in the primary studies were highly variable. In addition, some studies presented the timing of N application chronologically in days after emergence and/or sowing instead of the phenological stage. Thus, we counted the trials in which there was or was not a significant effect of the application timing treatments. The most promising treatments were manually identified in the studies with a significant difference between the timing applications.

From the values of the effects of treatments on grain yield, the natural logarithm of the values was obtained for the analyses. Since most of the primary studies used in this meta-analysis did not present dispersion measures of their means, the different studies were weighted according to the number of repetitions (*n*) using equation 1, as suggested by Pittelkow et al. (2015) and Kihara et al. (2017). To privilege results obtained in different trials (year × location), when the trial presented more than one observation for the same subgroup of data, the weight of the trial was divided among the number of observations (Pias et al., 2020).

Weight = {($n$ control × $n$ treatment) ÷ ($n$ control + $n$ treatment)}          Eq. 1

The regression tree selected factors of interest for the meta-analysis, including soil OM content and preceding crops. For each factor in the database, the 95 % confidence intervals for the obtained means of effect of N fertilization on grain yield were calculated by the Bootstrapping procedure using 4999 repetitions. The Bootstrapping procedure is an efficient way to estimate confidence intervals by simulating different datasets from the initial dataset. In addition, the data to be processed need not exhibit a normal distribution, and the results are scarcely influenced by the presence of outliers. A significant effect of the treatments was considered when the confidence intervals did not exceed the value zero and when the factors did not cross their confidence intervals. The meta-analysis data was analyzed using the Statkey 2.0.1 software (Lock et al., 2017). At the end of the analysis, the mean values of the response rate were transformed to the normal scale and presented as the effect on common bean grain yield (kg ha$^{-1}$). To evaluate the profitability of the different N managements, the average price of the common bean sack (R$ 106.99; US$ 27.65) and urea ton (R$ 1,168.00; US$ 301.91) for 2018 in Mato Grosso do Sul State (Conab, 2019) was used, as it was the state with the most significant number of crops evaluated.

## RESULTS AND DISCUSSION

### Characterization of research on nitrogen response by common bean under no-till

Studies evaluating the effects of N fertilization on the productivity of the common bean under NT systems have been conducted throughout Brazil (Figure 1), although they are mainly concentrated in the central-western region, especially Mato Grosso do Sul and Goiás States, accounting for 59 % of the total trials evaluated. Paraná, Minas Gerais, Mato Grosso, and Goiás States were decreasingly the largest producers of common beans in the 2019/2020 season (Conab, 2020). In fact, these states also stand out in conducting N fertilization experiments in the common bean in Brazil (Figure 1).

Of the total trials analyzed, 89 % were grown in tropical climates and only 11 % in subtropical climates (Figure 2a). Irrigation was used in 70 % of the analyzed trials (Figure 2b), and this is because most research was conducted in the winter season (dry season) of midwestern Brazil, requiring irrigation. Carioca common bean was studied in 89 % of the analyzed studies (Figure 2c), and this is also the most commonly consumed cultivar group in Brazil, especially in the southeastern and midwestern regions (Rocha, 2013), that are locations where most studies were conducted. The vast majority (92 %) of the trials that evaluated the effects of N fertilization on the common bean were conducted in Oxisols (Figure 2d), and this is because it is the soil with the highest occurrence in the country, with an even higher proportion in midwestern Brazil (Fageria and Baligar, 2008).

The evaluated database showed a predominance of grasses (88 %) preceding common bean crops, with only 10 % of legume species (Figure 2e). This scenario is theoretically of higher probability of a positive response of common bean to N application because grasses have a high C/N ratio occurring temporary immobilization of soil N. In contrast, legumes crops have a low C/N ratio, which results in net mineralization of N and higher N availability for the following crop (Amado et al., 1999).

The most used sowing season in the experiments was the third season (70 %), whose sowing is done in winter (dry season in midwestern Brazil), followed by the harvest season (18 %), and off-season (12 %) (Figure 2f). Sowing in the third season occurs from May to July, and it is entirely irrigated and represents about 19 % of the national common bean production (Conab, 2019). The first season (crop) is sown from September
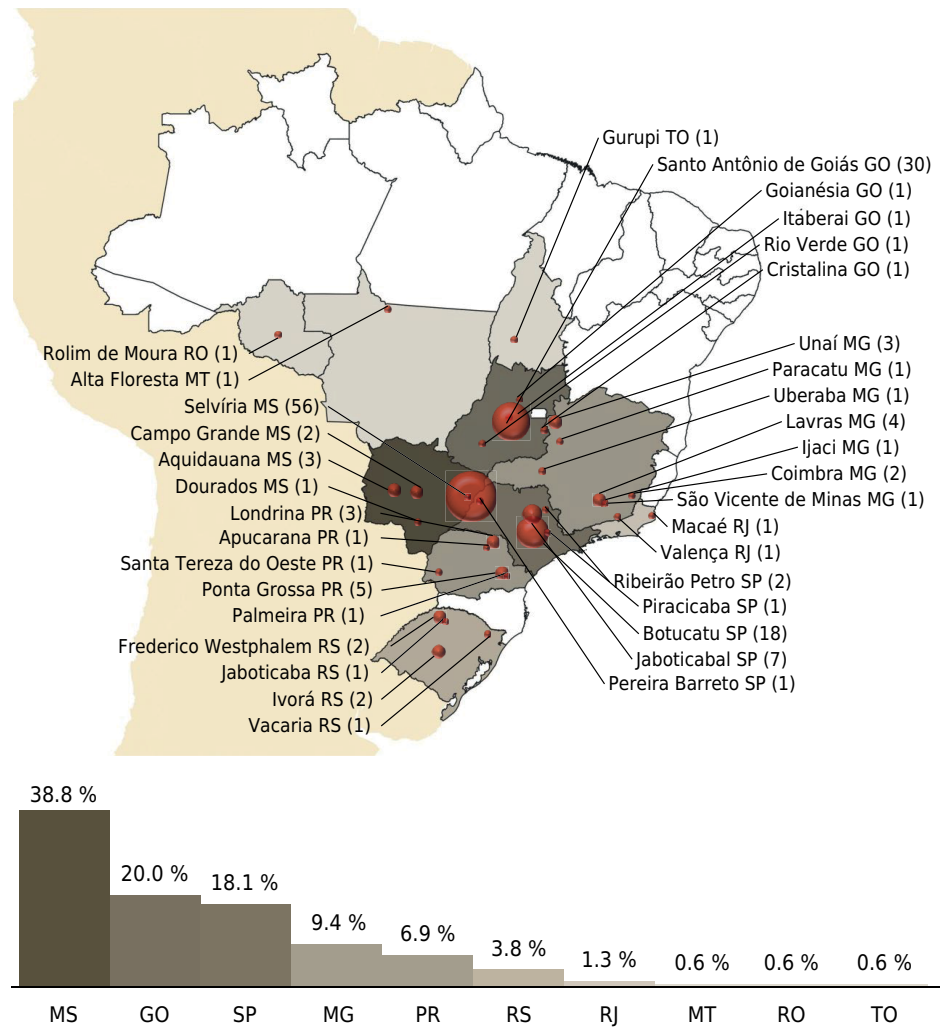
**Figure 1.** Spatial distribution and percentage of crops per state in the studies that evaluated the effects of nitrogen fertilization on common bean yields in soils under NT in Brazil. The size of the circles and the value in parentheses represent the number of crops in each location. The acronyms of the Brazilian states: MS: Mato Grosso do Sul; GO: Goiás; SP: São Paulo; MG: Minas Gerais; PR: Paraná; RS: Rio Grande do Sul; RJ: Rio de Janeiro; MT: Mato Grosso; RO: Roraima; and TO: Tocantins.

to November and usually meets its water demand naturally by rainfall. The off-season is sown from January to March soon after harvesting corn or soybean; it is commonly called the dry season because the rainfall does not always meet the water demand, requiring the sporadic use of irrigation to not compromise productivity (Silva, 2002). The crop and off-season represent roughly 45 and 36 % of the Brazilian common bean harvest, respectively (Conab, 2019).

The vast majority of research (94 %) that evaluated the effects of N fertilization on the common bean grain yield does not mention seed inoculation, and it was assumed that inoculation was performed in only 6 % of the studies (Figure 2g).

The most commonly used N source was urea, which accounted for 78 % of the data set (Figure 2h). Urea is the most used N source in Brazil due to its high N concentration (45 %) and low cost per nutrient unit (Dal Molin and Ernani, 2017). In 83 % of the trials, the effects of N doses were evaluated in only one topdressing application (i.e., with the absence of splitting the doses; Figure 2i).

Soil pH(H$_2$O) ranged from 4.5 to 6.8, although it was concentrated between 5.45 and 6.0 (Figure 3a), which is considered suitable for common bean due to the absence or low concentration of exchangeable Al$^{3+}$ (CQFS-RS/SC, 2016). Soil clay content ranged from
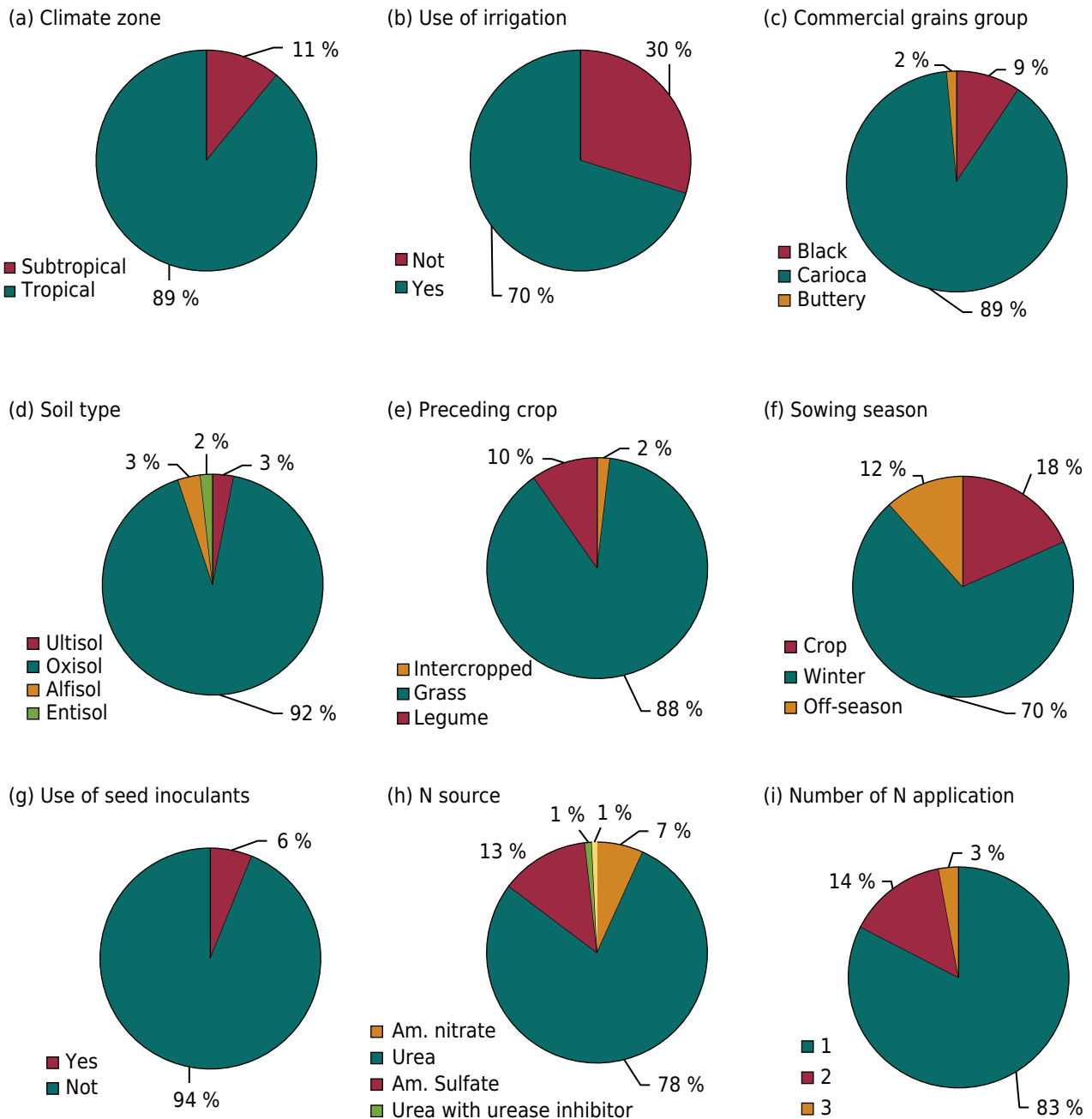
**Figure 2.** Description of the percentage of trials that evaluated the effects of N fertilization on common bean grain yield in no-till soils in Brazil regarding climate zone (a), use of irrigation (b), commercial grain group (c), soil type (d), preceding crop (e), sowing season (f), use of seed inoculants (g), N sources (h), and the number of N applications (i).

150 to 790 g kg$^{-1}$, although it was concentrated at the 450 to 530 g kg$^{-1}$ range (50 % of data; Figure 3b). Soil texture directly affects water retention and soil structure, and the highest the clay concentration, the greatest the water retention capacity, which can be partially made available to crops. The soil OM content found in the experiments ranged from 13 to 75 g kg$^{-1}$, and in half of the studies varied between 18 and 29 g kg$^{-1}$ (Figure 3c). Organic matter is the primary source of N in soil and important for CEC due to the many functional groups in its structure. In addition, it acts as a cementing agent in the soil structure, improving soil porosity and stimulating soil biological activity (Veloso et al., 2019).

Nitrogen doses evaluated ranged from 15 to 280 kg ha$^{-1}$, albeit 50 % of the crops applied doses between 50 and 100 kg ha$^{-1}$ (Figure 3d), which corresponds to N doses recommended by most recommendation systems in different states (Ambrosano et al.,

1997; Ribeiro et al., 1999; CQFS-RS/SC, 2016; Pauletti and Motta, 2016). In most studies, the experiments were conducted in areas managed under NT between four and eight years (Figure 3e).

## Average increase of common bean grain yield by N fertilization

Nitrogen application increased common bean grain yields in most studies (Figure 4a). The average grain yield increase with N fertilization was 18 % (357 kg ha$^{-1}$), and the average N dose to obtain this increase was 84 kg ha$^{-1}$ (Figure 3d). The results revealed that the magnitude of the effect of N fertilization on common bean yield depends not only on the dose applied but also on the technological level employed in the crops. In trials with a low technological level (low soil fertility and poor phytosanitary and crop management), where the control treatments obtained low yields, the effects of N fertilization were more significant than in places with a higher yield potential where the controls treatments obtained higher yields (Figure 4b). These data confirm the
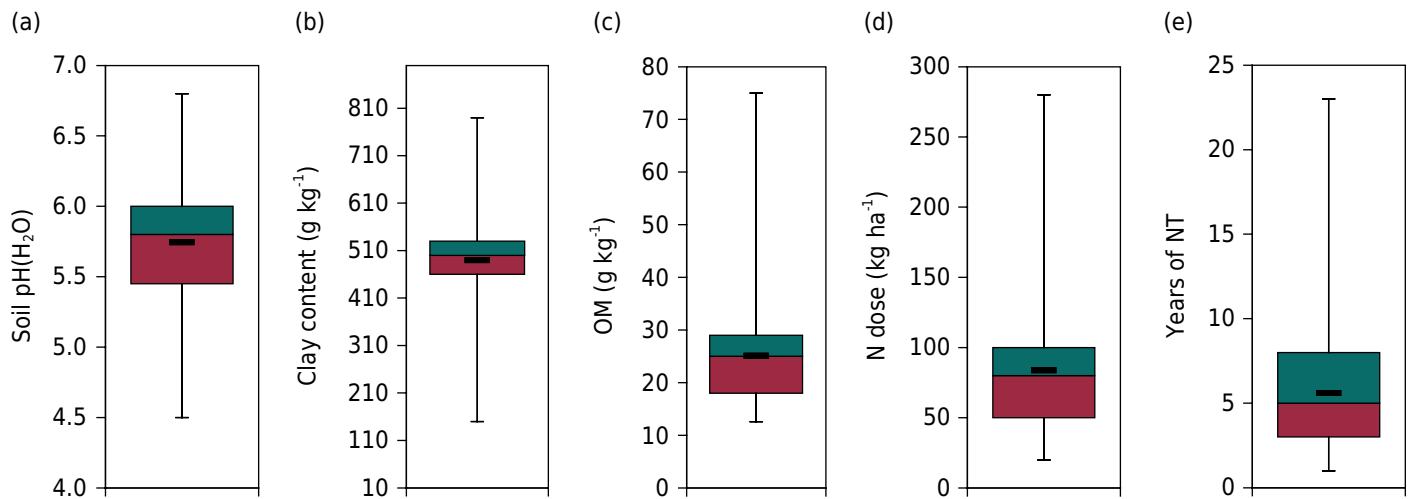


**Figure 3.** Characterization of soil attributes: pH(H$_2$O) (a); clay content (b); organic matter (c); nitrogen doses (d); and years of soil management under NT (e) in studies that evaluated bean response to N application. The central rectangle indicates the range between the first and third quartile of the database. The solid line inside the rectangle indicates the median value and the trace is the mean value. The vertical lines above and below the rectangle indicate the minimum and maximum values, respectively.
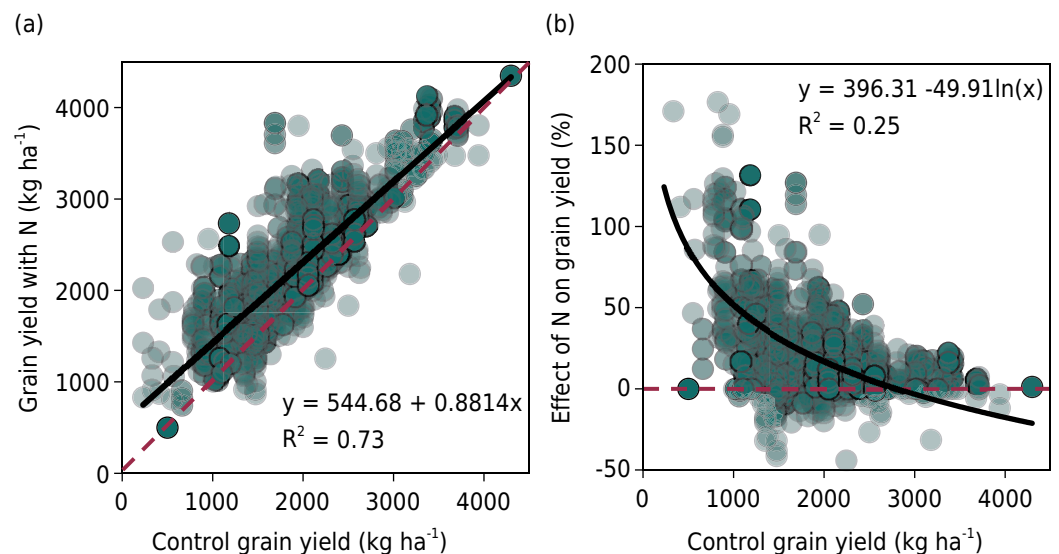


**Figure 4.** Relationship between common bean grain yields in plots with and without nitrogen application (a) and average increment in grain yield as a function of yield in the control treatment (no N) (b).

assumptions used in official recommendations (e.g., CQFS-RS/SC, 2016), in which the most significant increases by applying fertilizers occur when the soil presents lower nutrient availability to plants caused by inadequate soil management.

## Factors influencing the magnitude of the response of common bean to N fertilization

The regression tree data allowed us to determine that the soil OM content, the preceding crop, and the N dose applied were the factors that most influenced common bean responses to N fertilization (data not shown). Organic matter is the main source of N in the soil for plants and soil biota, in this way; soils with higher OM content have higher N availability for plants. In addition, OM improves soil aggregation and increases soil water availability. Therefore, cause plants to respond less to N fertilization. Among the primary references used to recommend N for common bean, only CQFS-RS/SC (2016) recognizes soil OM as a parameter to determine the N dose to be applied. Unlike what is expected and what is currently used by all recommendation manuals, the grain yield or, in the case of recommendation, the expected common bean yield did not influence the response of the crop to N fertilization.

Aiming to predict the response of common bean to nitrogen fertilization, the data compiled from the literature were divided into four different scenarios from the combination of grass and legume preceding common bean and soils with OM content above or below 20 g kg$^{-1}$ (Figure 5a), a value determined from the regression tree analysis.

In the first scenario, when the preceding crop was leguminous, and the soil had an OM content <20 g kg$^{-1}$, there was no significant difference between the doses of N. However, doses above 40 kg ha$^{-1}$ showed an increase in common bean yield, on average 296 kg ha$^{-1}$ (Figure 5a).

Nonetheless, for crops following legumes in soils with OM content >20 g kg$^{-1}$ (Figures 5b), a small dose ≤40 kg ha$^{-1}$ was enough to determine yield increment, on average at
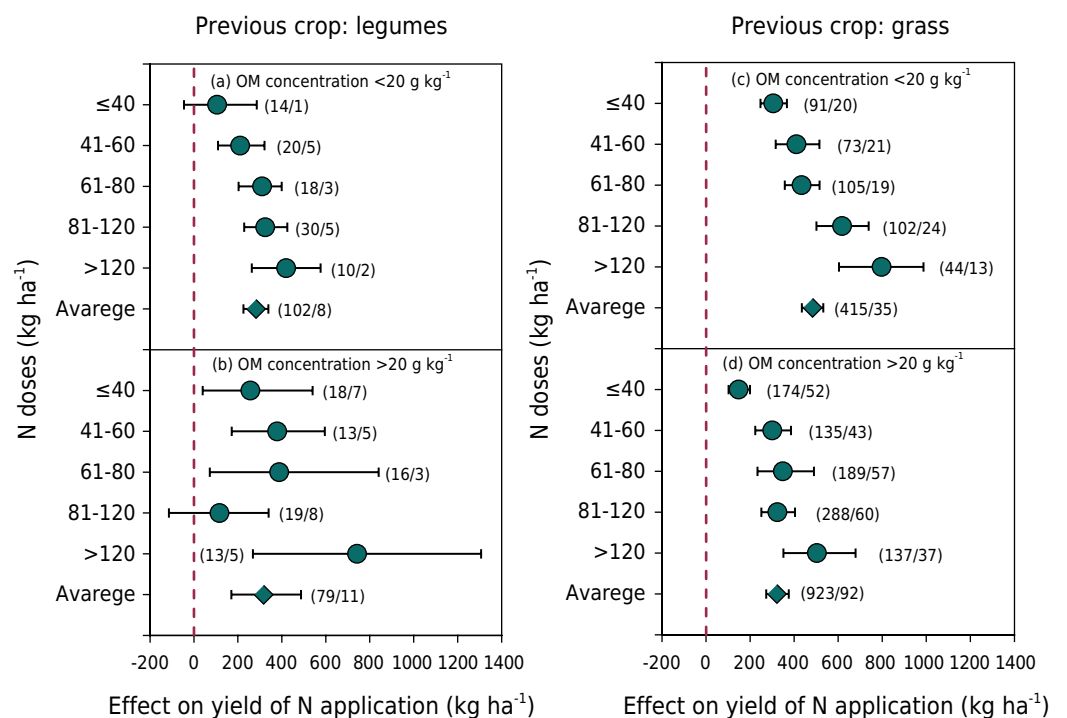


**Figure 5.** Effects of nitrogen (N) doses on common bean grain yield preceding by legumes in soils with organic matter (OM) content below (a) and above (b) 20 g kg$^{-1}$ and preceded by grasses in soils with OM content below (c) and above (d) 20 g kg$^{-1}$. Values in parentheses represent the number of observations and the trials, respectively.

257 kg ha⁻¹. This result is due to the low C/N ratio of the preceding crop and the OM content being >20 g kg⁻¹, making significant amounts of N available for plants and microorganisms. However, when the crop is grown after grass in soil with low OM content, the soil N stock is lower, and thus much of the N applied at low doses is immobilized by microorganisms, reducing access to plants and their response to low N doses (Blagodatskaya and Kuzyakov, 2011). In this scenario, where the preceding crop was grass, a more significant potential response of common bean to N doses was observed if compared to growing after legumes, especially in soil with OM concentration <20 g kg⁻¹ (Figure 5c). In this scenario, a linear increase in grain yield occurred with increasing doses of N applied up to doses >120 kg ha⁻¹. Doses above 80 kg ha⁻¹ of N increased on average 707 kg ha⁻¹, although this was not the case when the common bean was grown after grasses in soils with OM content >20 g kg⁻¹, as the crop response was lower and doses between 40-60 kg ha⁻¹ did not differ from larger ones, increasing grain yield by 300 kg ha⁻¹, on average (Figure 5d).

In common bean preceded by legumes, the probability of a positive effect of N fertilization is 88 and 56 % (Figures 6a and 6b) for soils with OM content below and above 20 g kg⁻¹, respectively. Nonetheless, the probability of higher common bean grain yield by N fertilization when the preceding crop is grass in soil with OM concentration <20 g kg⁻¹
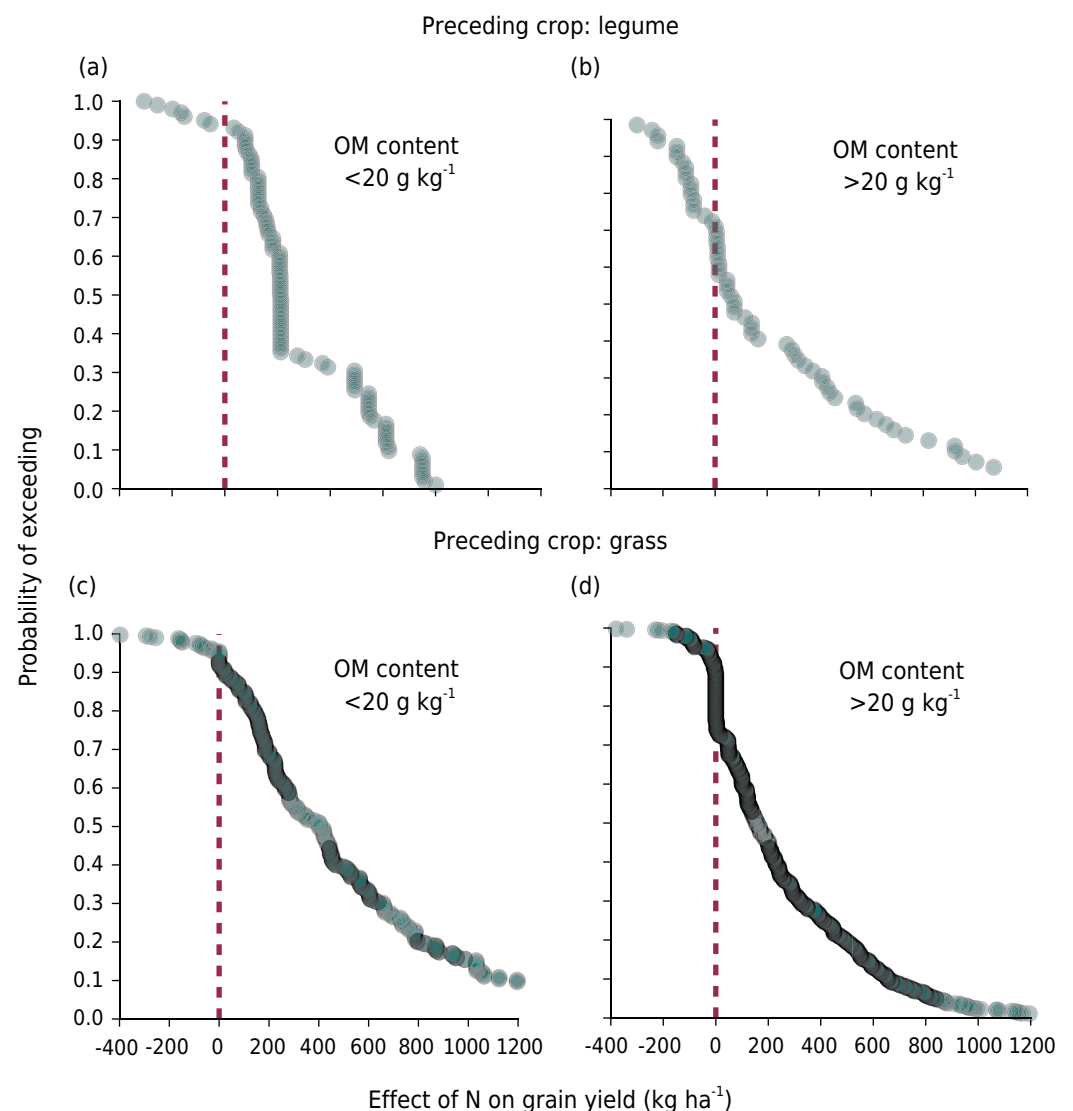


**Figure 6.** Probability of increases in common bean yield by nitrogen (N) application in crops preceded by legumes in soils with organic matter (OM) content below (a) and above (b) 20 g kg⁻¹ and preceded by grasses in soils with OM content below (c) and above (d) 20 g kg⁻¹.

is 92 % (Figure 6c), dropping to 71 % when the OM content is >20 g kg$^{-1}$ (Figure 6d). These findings confirm that the common bean responds to nitrogen fertilization in most cases, evidencing that biological nitrogen fixation and the N mineralized by OM are not enough to meet the nutritional demands of plants in most cases. Particular attention should be given to soils with OM content >20 g kg$^{-1}$ and preceded by legumes because 44 % of the trials in these environments presented no positive response to N application. In these cases, following the recommendation of CQFS-RS/SC (2016), the observation of active nodulation in the root to the 15-20 days after emergence may be important to analyze the need to add N in topdressing.

In the studies in which there was no positive effect of N application on grain yield (23 % of the data), this lack of response is attributed to several factors: among them the low yield of some cultivars (Salgado et al., 2012b; Damian et al., 2018), high biological N fixation efficiency (Maia et al., 2012; Hungria et al., 2013; Dal Molin and Ernani, 2017), soils with high OM content (Menegol et al., 2015; Dal Molin and Ernani, 2017), and the use of legume crops preceding the common bean (Arf et al., 2011a).

Contrary to expectations, full crop irrigation and N incorporation into the soil by irrigation after urea application to reduce N losses by $NH_3$ volatilization did not influence common bean response to N fertilization (Figures 7a and 7b). Under the present range soil $pH(H_2O)$ also did not significantly influence the response of common bean to N fertilization (Figure 7c), although there was a tendency for reduced response in soils with $pH(H_2O)$ >6.0. This result may be related to the higher efficiency of biological N fixation and higher N losses by volatilization in the form of $NH_3$ that occur in alkaline soils when using urea (Cunha et al., 2011; Alves et al., 2021), in addition to higher microorganism activity resulting in more significant N mineralization of soil OM.

Common bean cultivated in soils with clay content <500 g kg$^{-1}$ were more responsive to N doses (Figure 7d), and this may have occurred for several reasons, including the fact that soils with low clay content have higher hydraulic conductivity, favoring N leaching in
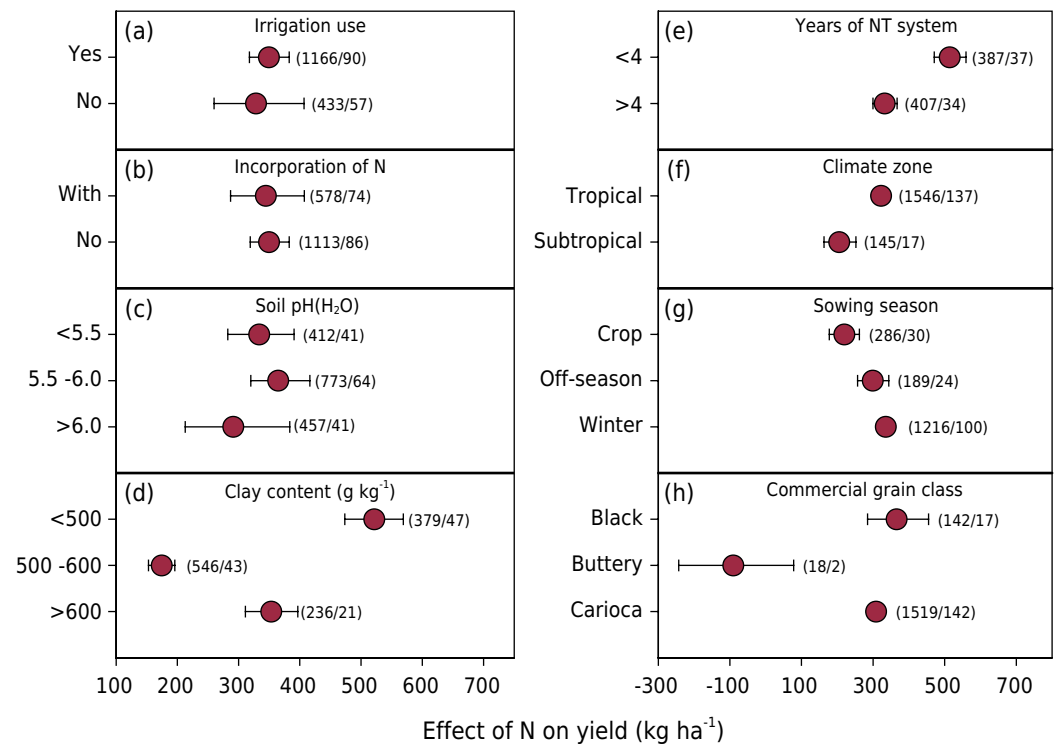


**Figure 7.** Average effect of nitrogen (N) on bean grain yield as a function of irrigation use (a), N incorporation (b), soil $pH(H_2O)$ (c), clay content (d), years of NT system (e), climatic zone (f), sowing season (g), and commercial grain class (h). Values in parentheses represent the number of observations and trials, respectively.

the form of $NO_3^-$ for the subsoil (Sangoi et al., 2003), thereby increasing the dependence on the addition of N via fertilizer. In addition, sandy soils tend to have lower OM content due to the lower physical and chemical protection effect (iron oxide presence) of OM (stabilization mechanisms) thereby reducing the amount of N mineralized by OM and made available in the soil solution. Nevertheless, in soils with clay content >600 g kg$^{-1}$, there was also a high increase in common bean grain yield due to the application of N, and this may have been due to the greater productive potential of common bean and/or greater compaction of soils with high clay content, which can limit root growth in the soil subsurface and, consequently, reduce water and nutrient uptake by plants and nodulation (Caires et al., 2016).

Cultivation time under NT of the experimental area also influenced the response of common bean to N fertilizer (Figure 7e). Crops grown in areas with <4 years of NT presented a more significant response to N doses than crops grown in areas with NT consolidated (>4 years) (cut-off level determined in the decision tree regression analysis). This result is possibly due to the slower mineralization of OM under NT (Cantarella, 2007). Research has shown that soils may present low N availability in the first years of NT due to the high immobilization of this nutrient and lower mineralization rates, generating an additional need for fertilization. However, well-managed NT leads to higher OM content and improved soil physical structure and biological activity in the long term, thus reducing the demand for external inputs (Veloso et al., 2018, 2019).

Common beans grown in the tropical climatic zone showed a more significant response to N doses (Figure 7f); this result may be related to the lower OM contents (24 *vs* 32 g kg$^{-1}$) observed in these locations due to the higher temperature and precipitation, which generate increased in microbial activity under higher mineralization rate and soil weathering compared to subtropical soils (Amado et al., 1999).

Among the common bean sowing seasons, we observed that common beans grown in the third season (winter) were more responsive to N fertilization than the first season [rainy season (Figure 7g)] because, in the third season, it is possible to obtain higher yields due to use of irrigation, which increases nutrient demand. Finally, among the commercial classes of common bean, carioca and black bean showed better response to nitrogen fertilization than buttery, although the latter has a restricted number of observations, therefore making this result inconclusive (Figure 7h). Furthermore, the commercial classes black and carioca are the most consumed in Brazil and, consequently, have undergone improvements to increase their productive potential. The average grain yield of the commercial groups carioca and black was 2260 kg ha$^{-1}$ while the buttery was only 1420 kg ha$^{-1}$, the higher the grain yield, the greater the plant requirement for nutrients.

### Common bean response to application times and N sources

The time of N application did not influence common bean grain yield in 62 % of the 39 trials that evaluated this factor. Therefore, the applied dose of N is generally more important than the time of its application because even when testing contrasting application times ranging from 20 days before sowing (Silva et al., 2002), application at sowing (Silva et al., 2002), and applications at various stages of development from $V_2$ to $R_7$ (Guimarães et al., 2017), there were no significant differences in most crops. In the studies in which the time of application influenced yield (38 % of the cases), the best results were mostly obtained using doses of up to 30 kg ha$^{-1}$ at sowing and the rest of the dose between $V_3$-$V_4$, or 15 to 30 days after plant emergence (Guimarães et al., 2017; Soratto et al., 2003; Gomes Junior et al., 2005), which are similar to what is currently recommended in Brazil (Ribeiro et al., 1999; CQFS-RS/SC, 2016).

The split application of N improved common bean yields compared to the single application (Figure 8). Regardless of the dose used, the split application of N resulted in twice the

increase in yield. On average, there was a 15 % increase (293 kg ha$^{-1}$) in grain yield when N was applied in a single dose, while in two or more applications, the average increase was 32 % when N was applied (622 kg ha$^{-1}$). The positive effects of splitting may be associated with reduced N losses by leaching in the form of $NO_3^-$, volatilization in the form of $NH_3$, and denitrification in the forms of NO and $N_2O$, resulting in greater N efficiency by plants (Cantarella, 2007). Notably, N losses in the system are affected mainly by environmental conditions; thus, splitting N application reduces the probability of significant losses (Sangoi, 2003). In addition, splitting provides better synchrony between N availability in the soil and plant demand. Although the number of studies with more than one application was much lower than with only one application, our findings show that splitting, even at lower doses, provided a more significant increase in common bean grain yield (Figure 8). Currently, the main recommendations in use for common bean in Brazil (e.g., Ambrosano et al., 1997; Ribeiro et al., 1999; CQFS-RS/SC, 2016) have already recommended is splitting N doses for common bean, with small amounts at sowing and another application as topdressing, with no recommendations for splitting in two applications in topdressing.

Urea is the most used N source in Brazil due to its high N concentration (46 %) and lower cost per unit (Cunha et al., 2011; Dal Molin and Ernani, 2017). However, urea presents high potential N losses by volatilization [$NH_3$ (Oliveira et al., 2014)] compared to other sources, including ammonium sulfate and ammonium nitrate, which reduces its use efficiency. Thus, alternative sources of N have been studied and used instead of urea to reduce N losses (Dal Molin and Ernani, 2017). In addition to the sources cited, the use of urea with nitrification and urease inhibitors (stabilized) and coated urea (slow or controlled release) has shown promising results for various crops such as corn and rice (Frazão et al., 2014; Lyu et al., 2015).
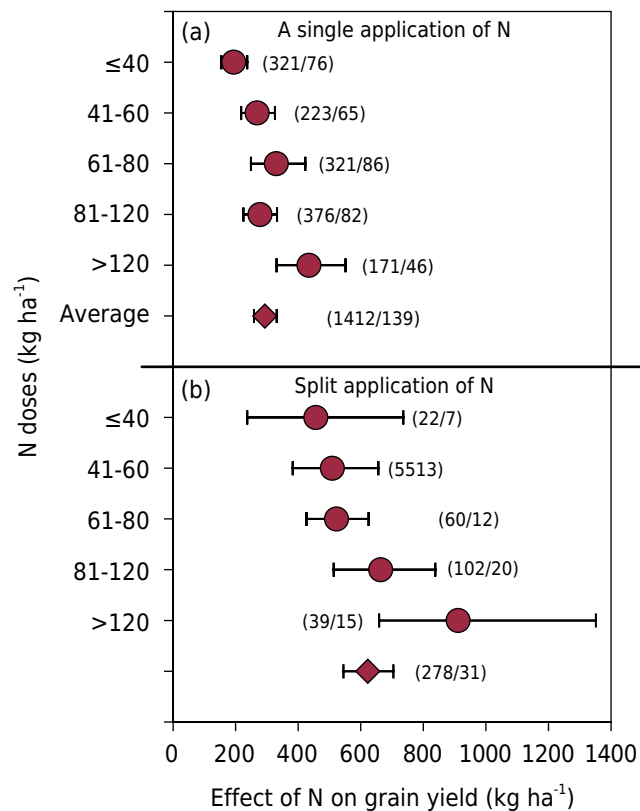


**Figure 8.** Effects of nitrogen (N) doses applied at once (a) or by splitting two or three times (b) on common bean grain yield on soils under NT in Brazil. Values in parentheses represent the number of observations and crops, respectively.

Results of 21 trials comparing N sources revealed that, compared to urea, the use of ammonium sulfate significantly reduced common bean yields by 40 kg ha$^{-1}$ on average, while ammonium nitrate increased by 56 kg ha$^{-1}$ (Figure 9b). Nevertheless, the use of urease inhibitors resulted in similar yields as common urea. Comparing the average effects of alternative N sources and urea showed no significant differences to improve common bean yields (Figure 9a). The lack of differences between N sources and urea has been attributed to climatic conditions favoring the reduction of N losses by urea (Bernardes et al., 2015; Dal Molin and Ernani, 2017), in addition to the fact that most studies were conducted in the dry season and relied on irrigation. Furthermore, the common bean crop uses soil N made available by OM mineralization and biological N fixation. Hence, small reductions in N losses by using alternative sources do not affect crop productivity, and therefore, using the source with the lowest cost per kg of N available on the market should be recommended.

### Effects of inoculating common bean seeds on grain yield

The inoculation of common bean seeds is a practice recommended by CQFS-RS/SC (2016) due to the low cost and potential to increase the efficiency of biological N fixation using selected strains. Our results encompassing 37 trials that evaluated paired treatments with and without inoculation showed an average grain yield increment of 6 % (118 kg ha$^{-1}$) but restricted to situations where N application was below 100 kg N ha$^{-1}$ (Figure 10). At N doses above 100 kg ha$^{-1}$, there was no effect of inoculation, corroborating Zeffa et al. (2018) in a meta-analysis of the effects of inoculation on corn yields. According to Zeffa et al. (2018), high N contents inhibit nitrogenase activity in bacteria, which is the enzyme responsible for converting atmospheric N into ammonium.

### Profitability of different N management in common bean

Based on the data acquired in this meta-analysis, a simplified estimate was made of the profitability of using N doses between 20 and 180 kg ha$^{-1}$ under the conditions that most influenced the size of the effects of N on the yield of the common bean crop (preceding crop and soil OM content; Figure 5). The cost of N doses ranged from R$ 52.00  (US$ 13.44) to R$ 467.00 (US$ 120.67) per hectare. The highest profitability occurred for the treatment with 180 kg ha$^{-1}$ of N with grasses preceding the common bean growing in soils with OM content <20 g kg$^{-1}$ (Figure 11). The lowest and only
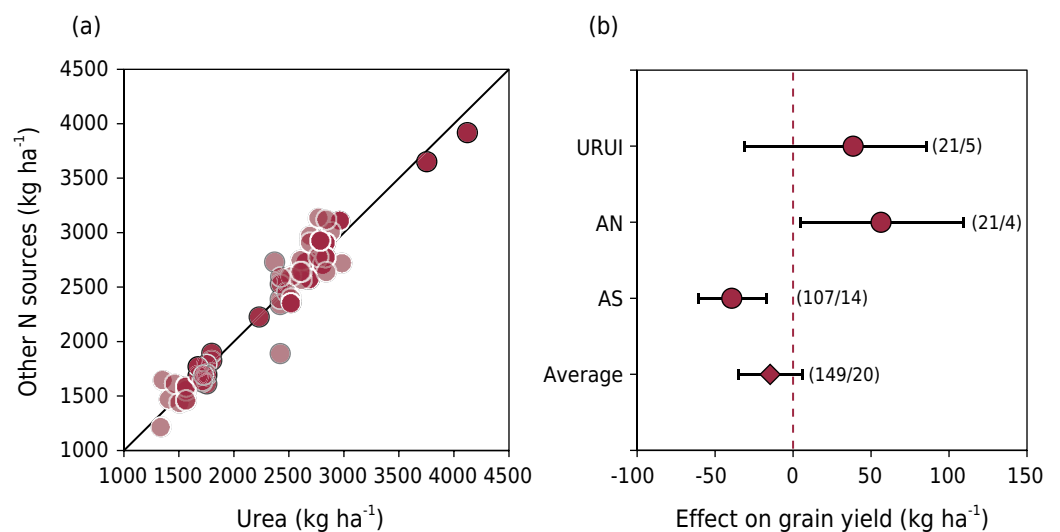


**Figure 9.** Relationship between common bean grain yield fertilized using different N sources [Urea with urease inhibitor (URUI), ammonium nitrate (AN) and ammonium sulfate (AS)] and common urea (a) and average effect of N fertilization from different sources relative to the use of common urea as N source on grain yield (b). Values in parentheses represent the number of observations and trials, respectively.
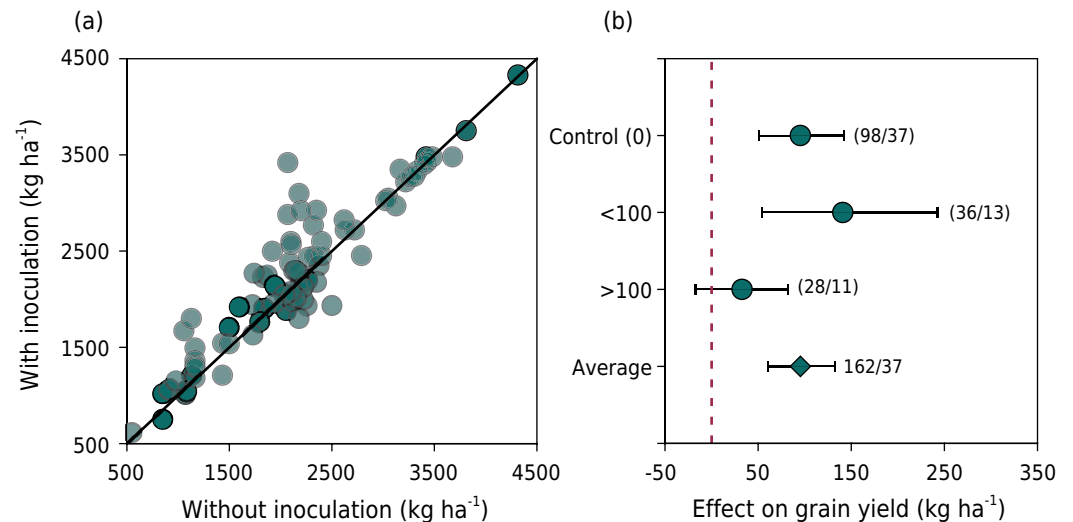
**Figure 10.** Relationship between bean grain yield with and without the use of inoculants (a) and average effect of inoculation on bean grain yield subjected to different doses of N (b). Values in parentheses represent the number of observations and trials, respectively.
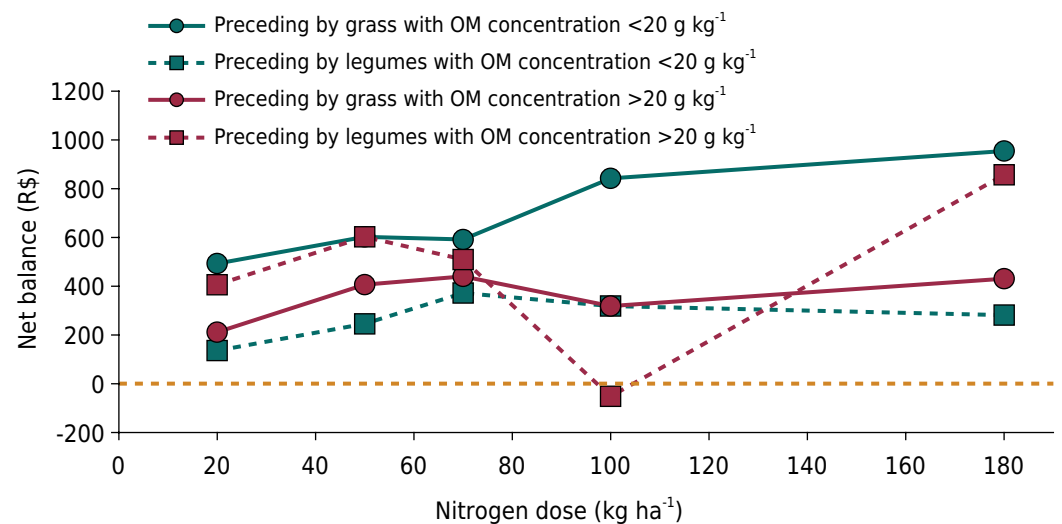


**Figure 11.** Profitability of using different nitrogen doses for common bean cultivated on soils with different organic matter (OM) concentration and preceded by grasses and legumes under no-till in Brazil. Red dashed line indicates the net balance equal to zero.

negative profitability occurred for soils with OM >20 g kg^{-1} and legumes as a preceding crop at N dose of 100 kg ha^{-1}. On average, for every R\$ 1.00 invested in N fertilization, R\$ 4.00 was obtained; this return increases to R\$ 5.50 when common bean are grown after grasses and in soils with OM content <20 g kg^{-1}. The lower the dose applied, the greater the return per amount spent with N. When using doses of 20 kg ha^{-1}, for every R\$ 1.00 invested in N, there was a R\$ 7.00 return, while for the dose of 180 kg ha^{-1}, the return of investment reduced to R\$ 2.30 for every R\$ 1.00.

Given the above, it is possible to determine the best doses for each environment. For common bean grown in soils with OM content <20 g kg^{-1} preceded by legumes, the N dose should be 70 kg ha^{-1}. However, when common bean are preceded by grass, the dose should be 100 kg N ha^{-1}. For soils with OM content >20 g kg^{-1}, the preceding crop has no significant influence on the profitability of N doses, and a dose of approximately 50 kg ha^{-1} should be recommended. These results show the importance of correct soil management, in which, in addition to minimal soil disturbance (NT), a high contribution of residues mainly with legumes is recommended to increase soil OM content and thus

reduce the N doses applied in crops and, consequently, reduce production costs and increase profitability (Veloso et al., 2018).

An expected advance for future N management in common bean is the large-scale use of sensors (e.g., chlorophyll meters) to determine the N sufficiency index (NSI) and, consequently, N application according to each area's needs and at the correct time; nevertheless, our findings are still incipient and inconclusive. Barbosa Filho et al. (2009) and Maia et al. (2012) observed the need to apply N when the NSI is below 90 %, while Silveira and Gonzaga et al. (2017) concluded it is necessary to apply N as soon as the NSI is below 95 %. Menegol et al. (2015) observed that plants with NSI <90 % also showed no positive response to N application. Thus, although this line of research is promising, further research should be conducted to enable these decision support tools at the farmer scale to improve N recommendations for the common bean crop.

## CONCLUSIONS

In general, the probability of increasing common bean yields by applying N is 77 %, with an average increase of 18 % (358 kg ha$^{-1}$). The dose of N applied, soil OM (organic matter) content, and preceding crop are the main factors influencing common bean response to N fertilization in Brazilian NT areas. Higher yield increments as a function of N fertilization were obtained in soils with low OM content (<20 g kg$^{-1}$) compared to soils with OM content >20 g kg$^{-1}$ (23.5 *vs.* 15.5 %, respectively) and in crops preceded by grass relative to legumes (18.6 *vs.* 15.3 %, respectively). The doses at which the highest profitability were obtained were 50 kg ha$^{-1}$ of N for soils with OM content >20 g kg$^{-1}$, regardless of the preceding crop. For soils with OM content <20 g kg$^{-1}$, the N doses should be 70 and 100 kg ha$^{-1}$ for crops preceded by legumes and grasses, respectively.

Timing of N application did not promote significant differences in grain yield in 62 % of the trials. However, splitting the N dose increases the increment in common bean yield from 15 % [(293 kg ha$^{-1}$) single dose] to 32 % [(622 kg ha$^{-1}$) split two or more times]. Alternative sources of N do not result in additional benefits compared to urea; therefore, urea should be the N source of choice due to its lower cost. When combined with mineral N doses below 100 kg ha$^{-1}$, seed inoculation provides to common bean an average increase in grain yield of 6 % (118 kg ha$^{-1}$) and can be a good alternative due to its low cost.

This meta-analysis confirmed the importance of N application for the common bean, with an average return of R\$ 4.00 for every R\$ 1.00 invested in fertilization. Furthermore, the N fertilization recommendations for common bean used in NT Brazilian soils could be refined considering the soil OM content and preceding crop. These data serve as a scientific basis to support updates in the official fertilization recommendations, seeking the rational management of N in the common bean crop under NT areas in Brazil.

## ACKOWLEDGEMENTS

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## REFERENCES

Afonso RJ, Arf O, Costa DSD, Barbosa RM, Buzetti S, Sá ME, Rodrigues RAF. Combinações de fontes de nitrogênio no desenvolvimento e rendimento do feijoeiro. Pesq Agropec Trop. 2011;41:391-8. https://doi.org/10.5216/pat.v41i3.12360

Alvarez ACC, Arf O, Alvarez RDCF, Pereira JCR. Resposta do feijoeiro à aplicação de doses e fontes de nitrogênio em cobertura no sistema de plantio direto. Acta Sci-Agron. 2005;27:69-75.

Alves Junior J, Andrade MJB, Carvalho JGD, Vieira NMB, Morais ARD. Adubação nitrogenada do feijoeiro, em plantio e cobertura, em plantio direto e convencional. Cienc Agrotec. 2009;33:943-9. https://doi.org/10.1590/S1413-70542009000400001

Alves LA, Ambrosini VG, Denardin LGO, Flores JPM, Martins AP, Filippi D, Bremm C, Carvalho PCF, Farias GD, Ciampitti IA, Tiecher T. Biological $N_2$ fixation by soybeans grown with or without liming on acid soils in a no-till integrated crop-livestock system. Soil Till Res. 2021;209:104923. https://doi.org/10.1016/j.still.2020.104923

Amado TJC, Mielniczuk J, Fernandes SBV, Bayer C. Culturas de cobertura, acúmulo de nitrogênio total no solo e produtividade de milho. Rev Bras Cienc Solo. 1999;23:679-86. https://doi.org/10.1590/S0100-06831999000300022

Amaral CB, Pinto CC, Flôres JA, Mingotte FLC, Lemos LB, Fornasieri D. Produtividade e qualidade do feijoeiro cultivado sobre palhadas de gramíneas e adubado com nitrogênio em plantio direto. Pesq Agropec Bras. 2016;51:1602-9. https://doi.org/10.1590/S0100-204X2016000900060

Ambrosano EJ, Wutke EB, Bulisani EA, Cantarella H. Feijão. In: Raij BV, Quaggio JA, Furlani AMC, editors. Recomendações de adubação e calagem para o Estado de São Paulo. Campinas: Instituto Agronômico; 1997. p. 194-5.

Araújo PRA, Araújo GAA, Rocha PRR, Carneiro JES. Combinações de doses de molibdênio e nitrogênio na adubação da cultura do feijoeiro-comum. Acta Sci-Agron. 2009;31:227-34. https://doi.org/10.1590/S1807-86212009000200007

Arf MV, Buzetti S, Arf O, Kappes C, Ferreira JP, Gitti DC, Yamamoto CJT. Fontes e épocas de aplicação de nitrogênio em feijoeiro de inverno sob sistema plantio direto. Pesq Agropec Trop. 2011b;41:430-8. https://doi.org/10.5216/pat.v41i3.9706

Arf O, Afonso RJ, Romanini Junior A, Silva MG, Buzetti S. Mecanismos de abertura do sulco e adubação nitrogenada no cultivo do feijoeiro em sistema plantio direto. Bragantia. 2008;67:499-506. https://doi.org/10.1590/S0006-87052008000200026

Arf O, Rodrigues RAF, Sá ME, Buzetti S, Nascimento VD. Manejo do solo, água e nitrogênio no cultivo de feijão. Pesq Agropec Bras. 2004;39:131-8. https://doi.org/10.1590/S0100-204X2004000200005

Arf O, Sá ME, Rodrigues RAF, Buzetti S, Silva FCRD, Arf MV. Preparo do solo, inoculação de sementes e doses de nitrogênio em cobertura no feijoeiro comum de inverno irrigado. Sci Agraria. 2011a;12:135-42. https://doi.org/10.5380/rsa.v12i3.34086

Arf O, Silva MG, Buzetti S, Sá ME, Teodoro PE. Influence of crop residues and nitrogen levels on agronomic performance of irrigated common bean. Glo Adv Res J Agric Sci. 2014;3:284-8.

Barbosa Filho MP, Cobucci T, Fageria NK, Mendes PN. Determinação da necessidade de adubação nitrogenada de cobertura no feijoeiro irrigado com auxílio do clorofilômetro portátil. Cienc Rural. 2008;38:1843-8. https://doi.org/10.1590/S0103-84782008000700007

Barbosa Filho MP, Cobucci T, Fageria NK, Mendes PN. Época de aplicação de nitrogênio no feijoeiro irrigado monitorada com auxílio de sensor portátil. Cienc Agrotec. 2009;33:425-31. https://doi.org/10.1590/S1413-70542009000200010

Barbosa Filho MP, Fageria NK, Silva OF. Fontes e métodos de aplicação de nitrogênio em feijoeiro irrigado submetido a três níveis de acidez do solo. Cienc Agrotec. 2004;28:785-92. https://doi.org/10.1590/S1413-70542004000400009

Barbosa Filho MP, Fageria NK, Silva OF. Fontes, doses e parcelamento da adubação nitrogenada em cobertura para feijoeiro comum irrigado. Cienc Agrotec. 2005;29:69-76. https://doi.org/10.1590/S1413-70542005000100008

Barbosa GF, Arf O, Nascimento MS, Salatiér B, Freddi OS. Nitrogênio em cobertura e molibdênio foliar no feijoeiro de inverno. Acta Sci-Agron. 2010;32:117-23. https://doi.org/10.4025/actasciagron.v32i1.1605

Bernardes TG, Silveira PM, Carvalho MTM, Madari BE, Carvalho MCS. Productivity of irrigated beans due to sources of stabilized nitrogen fertilizer and controlled release. Rev Ceres. 2015;62:614-20. https://doi.org/10.1590/0034-737X201562060015

Binotti FFS, Arf O, Cardoso ED, Sá ME, Buzetti S, Nascimento V. Fontes e doses de nitrogênio em cobertura no feijoeiro de inverno irrigado no sistema plantio direto. Biosci J. 2010;26:770-8.

Binotti FFS, Arf O, Cardoso ED, Sá ME, Buzetti S. Manejo do nitrogênio em cobertura do feijoeiro de inverno no sistema plantio direto. Rev Agr Neo. 2014;1:58-64. https://doi.org/10.32404/rean.v1i1.226

Binotti FFS, Arf O, Romanini Junior A, Fernandes FA, Sá ME, Buzetti S. Manejo do solo e da adubação nitrogenada na cultura de feijão de inverno e irrigado. Bragantia. 2007;66:121-9. https://doi.org/10.1590/S0006-87052007000100015

Binotti FFS, Arf O, Sá ME, Buzetti S, Alvarez ACC, Kamimura KM. Fontes, doses e modo de aplicação de nitrogênio em feijoeiro no sistema plantio direto. Bragantia. 2009;68:473-81. https://doi.org/10.1590/S0006-87052009000200022

Blagodatskaya E, Kuzyakov Y. Priming effects in relation to soil conditions–mechanisms. In: Gliński J, Horabik J, Lipiec J, editors. Encyclopedia of Agrophysics. Dordrecht: Springer; 2011. p. 657-67. https://doi.org/10.1007/978-90-481-3585-1_128

Bordin L, Farinelli R, Penariol FG, Fornasieri Filho D. Sucessão de cultivo de feijão-arroz com doses de adubação nitrogenada após adubação verde, em semeadura direta. Bragantia. 2003;62:417-28. https://doi.org/10.1590/S0006-87052003000300008

Brito LF, Pacheco RS, Souza BF, Ferreira EPB, Straliotto R, Araújo AP. Resposta do feijoeiro comum à inoculação com rizóbio e suplementação com nitrogênio mineral em dois biomas brasileiros. Rev Bras Cienc Solo. 2015;39:981-92. https://doi.org/10.1590/01000683rbcs20140322

Caires EF, Zardo Filho R, Barth G, Joris HA. Optimizing nitrogen use efficiency for no-till corn production by improving root growth and capturing $NO_3$–N in subsoil. Pedosphere. 2016;26:474-85. https://doi.org/10.1016/S1002-0160(15)60058-3

Cantarella H. Nitrogênio. In: Novais RF, Alvarez V VH, Barros NF, Fontes RL, Cantarutti RB, Neves JCL, editors. Fertilidade do solo. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2007. p. 375-470.

Carmeis Filho ACA, Cunha TPL, Mingotte FLC, Amaral CB, Lemos LB, Fornasieri Filho D. Adubação nitrogenada no feijoeiro após palhada de milho e braquiária no plantio direto. Rev Caatinga. 2014;27:66-75.

Carvalho MAC, Furlani Junior E, Arf O, Sá ME, Paulino HB, Buzetti S. Doses e épocas de aplicação de nitrogênio e teores foliares deste nutriente e de clorofila em feijoeiro. Rev Bras Cienc Solo. 2003;27:445-50. https://doi.org/10.1590/S0100-06832003000300006

Comissão de Química e Fertilidade do Solo - CQFS-RS/SC. Manual de calagem e adubação para os Estados do Rio Grande do Sul e de Santa Catarina. 11. ed. Porto Alegre: Sociedade Brasileira de Ciência do Solo - Núcleo Regional Sul; 2016.

Companhia Nacional de Abastecimento - Conab. Preços agropecuários [internet]. Brasília, DF: Conab; 2019 [cited 2019 Jun 08]. Available from: https://www.conab.gov.br/info-agro/precos?view=default.

Companhia Nacional de Abastecimento - Conab. Série histórica das safras: Feijão total (1ª, 2ª e 3ª safras) [internet]. Brasília, DF: Conab; 2020 [cited 2020 Jun 08]. Available from: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=20.

Costa RSS, Arf O, Orioli Júnior V, Buzetti S. População de plantas e nitrogênio para feijoeiro cultivado em sistema de plantio direto. Rev Caatinga. 2009;22:39-45.

Crusciol CAC, Soratto RP, Silva LM, Lemos LB. Fontes e doses de nitrogênio para o feijoeiro em sucessão a gramíneas no sistema plantio direto. Rev Bras Cienc Solo. 2007;31:1545-52. https://doi.org/10.1590/S0100-06832007000600031

Cunha PCR, Silveira PM, Ximenes PA, Souza RF, Alves Júnior J, Nascimento JL. Fontes, formas de aplicação e doses de nitrogênio em feijoeiro irrigado sob plantio direto. Pesq Agropec Trop. 2011;41:80-6. https://doi.org/10.5216/pat.v41i1.7515

Cunha TPL, Mingotte FLC, Carmeis Filho ACA, Chiamolera FM, Lemos LB, Fornasieri Filho D. Agronomic performance of common bean in straw mulch systems and topdressing nitrogen rates in no-tillage. Rev Ceres. 2015;62:489-95. https://doi.org/10.1590/0034-737X201562050010

Dal Molin SJ, Ernani PR. Rendimento do feijoeiro comum em função da aplicação de fertilizantes minerais nitrogenados em cobertura. Rev Cienc Agrovet. 2017;16:231-8. https://doi.org/10.5965/223811771632017231

Damian JM, Santi AL, Cherubin MR, Pias OHC, Simon DH, Silva RF. Doses e épocas de aplicação de nitrogênio em feijão no período de safrinha. Rev Agrarian. 2018;11:105-13. https://doi.org/10.30612/agrarian.v11i40.4700

Fageria NK, Baligar VC. Ameliorating soil acidity of Tropical Oxisols by liming for sustainable crop production. Adv Agron. 2008;99:345-99. https://doi.org/10.1016/S0065-2113(08)00407-0

Farinelli R, Lemos LB, Penariol FG, Egéa MM, Gasparoto MG. Adubação nitrogenada de cobertura no feijoeiro, em plantio direto e convencional. Pesq Agropec Bras. 2006;41:307-12. https://doi.org/10.1590/S0100-204X2006000200016

Fernandes FA, Arf O, Silva Binotti FF, Junior AR, Sá ME, Buzetti S, Rodrigues RAF. Molibdênio foliar e nitrogênio em feijoeiro cultivado no sistema plantio direto. Acta Sci-Agron. 2005;27:7-15. https://doi.org/10.4025/actasciagron.v27i1.1906

Ferreira MMR, Arf O, Gitti DC, Ferreira LHZ, Silva JC. Reguladores vegetais e nitrogênio em cobertura em feijoeiro de inverno no sistema plantio direto. Rev Agrarian. 2013;6:268-80.

Ferreira PAA, Silva MAP, Cassetari A, Ruffini M, Moreira FMS, Andrade MJB. Inoculação com cepas de rizóbio na cultura do feijoeiro. Cienc Rural. 2009;39:2210-2. https://doi.org/10.1590/S0103-84782009000700041

Fiorentin CF, Lemos LB, Jardim CA, Fornasieri Filho D. Formação e manutenção de palhada de gramíneas concomitante à influência da adubação nitrogenada em cobertura no feijoeiro irrigado em sistema de semeadura direta. Bragantia. 2011;70:917-24. https://doi.org/10.1590/S0006-87052011000400026

Flôres JA, Amaral CB, Pinto CC, Mingotte FLC, Lemos LB. Agronomic and qualitative traits of common bean as a function of the straw and nitrogen fertilization. Pesq Agropec Trop. 2017;47:195-201. https://doi.org/10.1590/1983-40632016v4743979

Fonseca GG, Oliveira DP, Soares BL, Ferreira PAA, Teixeira CM, Martins FAD, Moreira FMS, Andrade MJB. Resposta de cultivares de feijoeiro-comum à inoculação das sementes com duas estirpes de rizóbio. Biosci J. 2013;29:1778-87.

Fornasieri Filho D, Xavier MA, Lemos LB, Farinelli R. Resposta de cultivares de feijoeiro comum à adubação nitrogenada em sistema de plantio direto. Científica. 2007;35:115-21. https://doi.org/10.15361/1984-5529.2007v35n2p115+-+121

Franco E, Andrade CAB, Scapim CA, Freitas PSL. Resposta do feijoeiro à aplicação de nitrogênio na semeadura e cobertura no sistema plantio direto. Acta Sci-Agron. 2008;30:427-34. https://doi.org/10.4025/actasciagron.v30i3.3556

Frazão JJ, Silva ÁR, Silva VL, Oliveira VA, Corrêa RS. Fertilizantes nitrogenados de eficiência aumentada e ureia na cultura do milho. Rev Bras Eng Agr Amb. 2014;18:1262-7. https://doi.org/10.1590/1807-1929/agriambi.v18n12p1262-1267

Gerlach GAX, Arf O, Corsini DCDC, Silva JC, Coletti AJ. Análise econômica da produção de feijão em função de doses de nitrogênio e coberturas vegetais. Pesq Agropec Trop. 2013;43:42-9. https://doi.org/10.1590/S1983-40632013000100005

Gitti DC, Arf O, Buzetti S, Ferreira MMR, Kappes C, Kaneko FH, Rodrigues RAF. Aplicação de paclobutrazol e doses de nitrogênio em feijão de inverno cultivado em sistema plantio direto. Sci Agrar Paranaensis. 2012;11:35-46. https://doi.org/10.18188/sap.v11i3.5678

Gomes Junior FG, Lima ER, Sá ME, Arf O, Rapassi RMA. Rendimento do feijoeiro de inverno em resposta à época de semeadura e adubação nitrogenada em cobertura em diferentes estádios fenológicos. Acta Sci-Biol Sci. 2005;27:77-81. https://doi.org/10.4025/actasciagron.v27i1.2150

Gomes Junior FG, Sá ME, Muraishi CT. Adubação nitrogenada no feijoeiro em sistema de semeadura direta e preparo convencional do solo. Acta Sci-Agron. 2008a;30:673-80. https://doi.org/10.4025/actasciagron.v30i5.5967

Gomes Junior FG, Sá ME, Valério Filho WV. Nitrogênio no feijoeiro em sistema de plantio direto sobre gramíneas. Acta Sci-Agron. 2008b;30:387-95. https://doi.org/10.4025/actasciagron.v30i3.3549

Guimarães RAM, Braz AJBP, Simon GA, Ferreira CJB, Braz GBP, Silveira PM. Resposta de cultivares de feijoeiro a adubação nitrogenada em diferentes estádios fenológicos. Gl Sci Technol. 2017;10:136-48.

Hungria M, Nogueira MA, Araujo RS. Co-inoculation of soybeans and common beans with rhizobia and azospirilla: Strategies to improve sustainability. Biol Fert Soils. 2013;49:791-801. https://doi.org/10.1007/s00374-012-0771-5

Kaneko FH, Arf O, Gitti DC, Arf M, Ferreira JP, Buzetti S. Mecanismos de abertura de sulcos, inoculação e adubação nitrogenada em feijoeiro em sistema plantio direto. Bragantia. 2010;69:125-33. https://doi.org/10.1590/S0006-87052010000100017

Kihara J, Sileshi GW, Nziguheba G, Kinyua M, Zingore S, Sommer R. Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa. Agron Sustain Dev. 2017;37:25. https://doi.org/10.1007/s13593-017-0431-0

Lião LM, Choze R, Cavalcante PPA, Santos SDC, Ferri PH, Ferreira AG. Perfil químico de cultivares de feijão (*Phaseolus vulgaris*) pela técnica de high resolution magic angle spinning (HR-MAS). Quim Nova. 2010;33:634-8. https://doi.org/10.1590/S0100-40422010000300028

Lobo TF, Grassi Filho H, Büll LT. Efeito do nitrogênio e do lodo de esgoto nos fatores produtivos do feijoeiro. Rev Ceres. 2012;59:118-24. https://doi.org/10.1590/S0034-737X2012000100017

Lock RH, Frazer P, Morgan KL, Lock EF, Lock DF. Statistics: Unlocking the power of data. 2nd ed. Nova Jersey: Wiley; 2017.

Lopes AS, Oliveira GQ, Souto Filho SN, Goes RJ, Camacho MA. Manejo de irrigação e nitrogênio no feijoeiro comum cultivado em sistema plantio direto. Rev Cienc Agron. 2011;42:51-6. https://doi.org/10.1590/S1806-66902011000100007

Lovato T, Mielniczuk J, Bayer C, Vezzani F. Adição de carbono e nitrogênio e sua relação com os estoques no solo e com o rendimento do milho em sistemas de manejo. Rev Bras Cienc Solo. 2004;28:175-87. https://doi.org/10.1590/S0100-06832004000100017

Lyu X, Yang Y, Li Y, Fan X, Wan Y, Geng Y, Zhang M. Polymer-coated tablet urea improved rice yield and nitrogen use efficiency. Agron J. 2015;107:1837-44. https://doi.org/10.2134/agronj14.0629

Maia SCM, Soratto RP, Nastaro B, Freitas LB. The nitrogen sufficiency index underlying estimates of nitrogen fertilization requirements of common bean. Rev Bras Cienc Solo. 2012;36:183-92. https://doi.org/10.1590/S0100-06832012000100019

Meira FA, Sá ME, Buzetti S, Arf O. Doses e épocas de aplicação de nitrogênio no feijoeiro irrigado cultivado em plantio direto. Pesq Agropec Bras. 2005;40:383-8. https://doi.org/10.1590/S0100-204X2005000400010

Menegol DR, Pias OHC, Santi AL, Cherubin MR, Berghetti J, Simon DH. Índice de suficiência de clorofila no manejo da adubação nitrogenada do feijoeiro comum. Rev Agro@mbiente On-line. 2015;9:119-28. https://doi.org/10.18227/1982-8470ragro.v9i2.2259

Mingotte FLC, Yada MM, Jardim CA, Fiorentin CF, Lemos LB, Fornasieri Filho D. Sistemas de cultivo antecessores e doses de nitrogênio em cobertura no feijoeiro em plantio direto. Biosci J. 2014;30:696-706.

Monteiro PFC, Angulo Filho R, Monteiro ROC. Efeitos da irrigação e da adubação nitrogenada sobre as variáveis agronômicas da cultura do feijão. Irriga. 2010;15:386-400. https://doi.org/10.15809/irriga.2010v15n4p386

Muller F, Zanão Junior LA. Produtividade de cultivares de feijoeiro em função da época de aplicação da adubação nitrogenada de cobertura em sistema de plantio direto. Acta Iguazu. 2015:4:45-57.

Nascente AS, Carvalho MCS, Melo LC, Rosa PH. Nitrogen management effects on soil mineral nitrogen, plant nutrition and yield of super early cycle common bean genotypes. Acta Sci-Agron. 2017;39:369-78. https://doi.org/10.4025/actasciagron.v39i3.32781

Nascimento MS, Arf O, Barbosa GF, Buzetti S, Nascimento RS, Castro RM. Nitrogênio em cobertura e molibdênio via foliar em feijoeiro de inverno no sistema plantio direto. II-Características agronômicas e produtividade. Sci Agraria. 2009;10:351-8. https://doi.org/10.5380/rsa.v10i5.15187

Nascimento MS, Arf O, Silva MG. Resposta do feijoeiro à aplicação de nitrogênio em cobertura e molibdênio via foliar. Acta Sci-Agron. 2004;26:153-9. https://doi.org/10.4025/actasciagron.v26i2.1877

Oliveira JA, Stafanato JB, Goulart RS, Zonta E, Lima E, Mazur N, Pereira CG, Souza HN, Costa FGM. Volatilização de amônia proveniente de ureia compactada com enxofre e bentonita, em ambiente controlado. Rev Bras Cienc Solo. 2014;38:1558-64. https://doi.org/10.1590/S0100-06832014000500021

Pacheco A, Lopes AS, Oliveira GQ, França A, Silva LE. Manejo da irrigação e adubação nitrogenada na cultura do feijoeiro: Componentes de produtividade e eficiência no uso da água. Agrarian. 2016;9:263-73.

Pacheco A, Oliveira GQ, Lopes AS, Barbosa AS. Manejos de irrigação e nitrogênio na produção de feijoeiro sob plantio direto. Pesq Agropec Trop. 2012;42:323-30. https://doi.org/10.1590/S1983-40632012000300004

Pasqualini D. Potencial da fixação biológica de nitrogênio em feijão em função da diversidade de bactéria e da planta [dissertation]. Lages: Universidade do Estado de Santa Catarina; 2008.

Pauletti V, Motta ACV. Manual de adubação e calagem para o estado do Paraná. Curitiba: Núcleo Estadual Paraná da Sociedade Brasileira de Ciência do Solo; 2017.

Pelegrin R, Mercante FM, Otsubo IMN, Otsubo AA. Resposta da cultura do feijoeiro à adubação nitrogenada e à inoculação com rizóbio. Rev Bras Cienc Solo. 2009;33:219-26. https://doi.org/10.1590/S0100-06832009000100023

Perez AAG, Soratto RP, Manzatto NP, Souza EFC. Extração e exportação de nutrientes pelo feijoeiro adubado com nitrogênio, em diferentes tempos de implantação do sistema plantio direto. Rev Bras Cienc Solo. 2013;37:1276-87. https://doi.org/10.1590/S0100-06832013000500017

Pias OHC, Tiecher T, Cherubin MR, Silva AGB, Bayer C.  Does gypsum increase crop grain yield on no-tilled acid soils? A meta-analysis. Agron J. 2020;112:675-92. https://doi.org/10.1002/agj2.20125

Piaskowski SR, Ronzelli Júnior P, Daros E, Koehler HS. Adubação nitrogenada em cobertura para o feijoeiro em plantio direto na palha. Sci Agraria. 2001;2:67-72.

Pittelkow CM, Liang X, Linquist BA, Van Groenigen KJ, Lee J, Lundy ME, Gestel NV, Six J, Venterea RT, Van Kessel C. Productivity limits and potentials of the principles of conservation agriculture. Nature. 2015;517:365-8. https://doi.org/10.1038/nature13809

Rabelo ACR, Ribeiro DF, Rezende RM, Alcantra E, Freitas AS. Adubação nitrogenada na cultura do feijoeiro. Rev Vale. 2017;15:825-41. https://doi.org/10.5892/ruvrd.v15i1.3141

Rapassi RMA, Sá ME, Tarsitano MAA, Carvalho MAC, Proença ER, Neves CMTC, Colombo ECM. Análise econômica comparativa após um ano de cultivo do feijoeiro irrigado, no inverno, em sistemas de plantio convencional e direto, com diferentes fontes e doses de nitrogênio. Bragantia. 2003;62:397-404. https://doi.org/10.1590/S0006-87052003000300006

Ribeiro AC, Guimarães PTG, Alvarez V VH. Recomendações para o uso de corretivos e fertilizantes 1999 em Minas Gerais - 5ª Aproximação. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais; 1999.

Rocha A. Variedades de feijão - conheça as que são mais consumidas no Brasil [internet]. [cited 2019 May 28]. Portal Agropecuário; 2013. Available from: https://www.portalagropecuario.com.br/agricultura/variedades-de-feijao-conheca-as-que-sao-mais-consumidas-no-brasil/.

Rojas CAL, Bayer C, Fontoura SMV, Weber MA, Vieiro F. Volatilização de amônia da ureia alterada por sistemas de preparo de solo e plantas de cobertura invernais no Centro-Sul do Paraná. Rev Bras Cienc Solo. 2012;36:261-70. https://doi.org/10.1590/S0100-06832012000100027

Romanini Junior A, Arf O, Binotti FFS, Sá ME, Buzetti S, Fernandes FA. Avaliação da inoculação de rizóbio e adubação nitrogenada no desenvolvimento do feijoeiro, sob sistema plantio direto. Biosci J. 2007;23:74-82.

Sabundjian MT, Arf O, Kaneko FH, Ferreira JP. Adubação nitrogenada em feijoeiro em sucessão a cultivo solteiro e consorciado de milho e *Urochloa ruziziensis*. Pesq Agropec Trop. 2013;43:292-9. https://doi.org/10.1590/S1983-40632013000300007

Sabundjian MT, Arf O, Meirelles FC, Nascimento VD, Kaneko FH, Tarumoto MB. Fertilização nitrogenada no desempenho agronômico do feijoeiro de inverno em sucessão a gramíneas de verão. Rev Cienc Agrar. 2016;59:152-61. https://doi.org/10.4322/rca.2203

Salgado FHM, Silva J, Oliveira TC, Barros HB, Passos NG, Fidelis RR. Eficiência de genótipos de feijoeiro em resposta à adubação nitrogenada. Pesq Agropec Trop. 2012b;42:368-74. https://doi.org/10.1590/S1983-40632012000400007

Salgado FHM, Silva J, Oliveira TC, Tonello LP, Passos NG, Fidelis RR. Efeito do nitrogênio em feijão cultivado em terras altas no sul do estado de Tocantins. Ambiência. 2012a;8:125-36.

Sangoi L, Ernani PR, Lech VA, Rampazzo C. Volatilização de N-NH$_3$ em decorrência da forma de aplicação de ureia, manejo de resíduos e tipo de solo, em laboratório. Cienc Rural. 2003;33:687-92. https://doi.org/10.1590/S0103-84782003000400016

Sant'Ana EVP, Santos AB, Silveira PM. Adubação nitrogenada na produtividade, leitura SPAD e teor de nitrogênio em folhas de feijoeiro. Pesq Agropec Trop. 2010;40:491-6. https://doi.org/10.1590/S1983-40632010000400012

Santi AL, Basso CJ, Lamego FP, Flora LPD, Amado TJC, Cherubin MR. Épocas e parcelamentos da adubação nitrogenada aplicada em cobertura na cultura do feijoeiro, grupo comercial preto e carioca, em semeadura direta. Cienc Rural. 2013;43:816-22. https://doi.org/10.1590/S0103-84782013005000045

Santi AL, Dutra LMC, Martin TN, Bonadiman R, Bellé GL, Della Flora LP, Jauer A. Adubação nitrogenada na cultura do feijoeiro em plantio convencional. Cienc Rural. 2006;36:1079-85. https://doi.org/10.1590/S0103-84782006000400006

Santos AB, Fageria NK. Manejo do nitrogênio para eficiência de uso por cultivares de feijoeiro em várzea tropical. Pesq Agropec Bras. 2007;42:1237-48. https://doi.org/10.1590/S0100-204X2007000900004

Schoninger EL, Lange A, Menegon TG, Caione G. Produtividade da cultura do feijoeiro submetido a doses de fósforo e nitrogênio. Agrarian. 2015;8:387-98.

Silva CC, Silveira PM. Influência de sistemas agrícolas na resposta do feijoeiro (*Phaseolus vulgaris* L.) irrigado à adubação nitrogenada em cobertura. Pesq Agropec Trop. 2000;30:87-96.

Silva EF, Marchetti ME, Souza LCF, Mercante FM, Rodrigues ET, Vitorino ACT. Inoculação do feijoeiro com *Rhizobium tropici* associada à exsudato de *Mimosa flocculosa* com diferentes doses de nitrogênio. Bragantia. 2009b;68:443-51. https://doi.org/10.1590/S0006-87052009000200019

Silva GM, Stone LF, Moreira JAA. Manejo da adubação nitrogenada no feijoeiro irrigado sob plantio direto. Pesq Agropec Trop. 2002;32:1-5.

Silva JGD. Árvore do conhecimento - Feijão [internet]. Brasília, DF: Agência Embrapa de Informação Tecnológica; 2002 [cited 2019 May 28]. Available from: https://www.agencia.cnptia.embrapa.br/gestor/feijao/arvore/CONTAG01_88_1311200215104.html.

Silva MG, Arf O, Sá ME, Rodrigues RAF, Buzetti S. Nitrogen fertilization and soil management of winter common bean crop. Sci Agric. 2004;61:307-12. https://doi.org/10.1590/S0103-90162004000300012

Silva TRB, Arf O, Soratto RP. Adubação nitrogenada e resíduos vegetais no desenvolvimento do feijoeiro em sistema de plantio direto. Acta Sci-Agron. 2003;25:81-7. https://doi.org/10.4025/actasciagron.v25i1.2447

Silva TRB, Freitas LB, Maia SCM. Coberturas vegetais e adubação nitrogenada no feijoeiro comum em sistema plantio direto. Agrarian. 2009a;2:7-16.

Silva TRB, Grutka GHH, Maia SCM, Freitas LB. Nitrogênio em cobertura no feijoeiro cultivado em plantio direto sobre diferentes coberturas vegetais. Acta Sci-Agron. 2009c;31:107-11. https://doi.org/10.4025/actasciagron.v31i1.6637

Silva TRB, Lemos LB, Tavares CA. Produtividade e característica tecnológica de grãos em feijoeiro adubado com nitrogênio e molibdênio. Pesq Agropec Bras. 2006;41:739-45. https://doi.org/10.1590/S0100-204X2006000500004

Silveira PM, Braz AJBP, Didonet AD. Uso do clorofilômetro como indicador da necessidade de adubação nitrogenada em cobertura no feijoeiro. Pesq Agropec Bras. 2003;38:1083-7. https://doi.org/10.1590/S0100-204X2003000900009

Silveira PM, Braz AJBP, Kliemann HJ, Zimmermann FJP. Adubação nitrogenada no feijoeiro cultivado sob plantio direto em sucessão de culturas. Pesq Agropec Bras. 2005;40:377-81. https://doi.org/10.1590/S0100-204X2005000400009

Silveira PM, Gonzaga ACO. Portable chlorophyll meter can estimate the nitrogen sufficiency index and levels of topdressing nitrogen in common bean. Pesqui Agropec Trop. 2017;47:1-6. https://doi.org/10.1590/1983-40632016v4742128

Soares BL, Ferreira PAA, Rufini M, Martins FAD, Oliveira DP, Reis RP, Andrade MJB, Moreira FMS. Agronomic and economic efficiency of common-bean inoculation with rhizobia and mineral nitrogen fertilization. Rev Bras Cienc Solo. 2016;40:e0150235. https://doi.org/10.1590/18069657rbcs20150235

Soratto RP, Arf O, Rodrigues RAF, Buzetti S, Silva TRB. Resposta do feijoeiro ao preparo do solo, manejo de água e parcelamento do nitrogênio. Acta Sci-Agron. 2003;25:89-96. https://doi.org/10.4025/actasciagron.v25i1.2453

Soratto RP, Carvalho MAC, Arf O. Nitrogênio em cobertura no feijoeiro cultivado em plantio direto. Rev Bras Cienc Solo. 2006a;30:259-66. https://doi.org/10.1590/S0100-06832006000200007

Soratto RP, Carvalho MAC, Arf O. Teor de clorofila e produtividade do feijoeiro em razão da adubação nitrogenada. Pesq Agropec Bras. 2004;39:895-901. https://doi.org/10.1590/S0100-204X2004000900009

Soratto RP, Catuchi TA, Souza EFC, Garcia JLN. Plant density and nitrogen fertilization on common bean nutrition and yield. Rev Caatinga. 2017;30:670-8. https://doi.org/10.1590/1983-21252017v30n315rc

Soratto RP, Crusciol CAC, Silva LM, Lemos LB. Aplicação tardia de nitrogênio no feijoeiro em sistema de plantio direto. Bragantia. 2005;64:211-8. https://doi.org/10.1590/S0006-87052005000200007

Soratto RP, Crusciol CAC, Silva LM, Lemos LB. Parcelamento da adubação nitrogenada de cobertura no feijoeiro em sistema de plantio direto. Científica. 2006b;34:223-8. https://doi.org/10.15361/1984-5529.2006v34n2p223+-+228

Soratto RP, Fernandes AM, Pilon C, Crusciol CAC, Borghi E. Épocas de aplicação de nitrogênio em feijoeiro cultivado após milho solteiro ou consorciado com braquiária. Pesq Agropec Bras. 2013;48:1351-9. https://doi.org/10.1590/S0100-204X2013001000006

Soratto RP, Fernandes AM, Souza EFC, Souza-Schlick GD. Produtividade e qualidade dos grãos de feijão em função da aplicação de nitrogênio em cobertura e via foliar. Rev Bras Cienc Solo. 2011;35:2019-28. https://doi.org/10.1590/S0100-06832011000600018

Souza EFC, Soratto RP, Pagani FA. Aplicação de nitrogênio e inoculação com rizóbio em feijoeiro cultivado após milho consorciado com braquiária. Pesq Agropec Bras. 2011;46:370-7. https://doi.org/10.1590/S0100-204X2011000400005

Souza JEB, Ferreira EPB. Improving sustainability of common bean production systems by co-inoculating rhizobia and azospirilla. Agr Ecosyst Environ. 2017;237:250-7. https://doi.org/10.1016/j.agee.2016.12.040

Stone LF, Moreira JAA. Resposta do feijoeiro ao nitrogênio em cobertura, sob diferentes lâminas de irrigação e preparos do solo. Pesq Agropec Bras. 2001;36:473-81. https://doi.org/10.1590/S0100-204X2001000300011

Teixeira CM, Carvalho GJ, Furtini Neto AE, Andrade MJB, Fontanetti A. Produtividade e teores foliares de nutrientes do feijoeiro sob diferentes palhadas e doses de nitrogênio em semeadura direta. Acta Sci-Agron. 2008;30:123-30. https://doi.org/10.4025/actasciagron.v30i1.1160

Teixeira CM, Carvalho GJ, Silva CA, Andrade MJB, Paes JMV. Nutrição mineral do feijoeiro em influência de nitrogênio e palhadas de milheto solteiro e consorciado com feijão-de-porco. Acta Sci-Agron. 2010;32:511-9. https://doi.org/10.4025/actasciagron.v32i3.4392

Valadão FCA, Jakelaitis A, Conus LA, Borchartt L, Oliveira AA, Valadão Junior DD. Inoculação das sementes e adubações nitrogenada e molíbdica do feijoeiro-comum, em Rolim de Moura, RO. Acta Amaz. 2009;39:741-7. https://doi.org/10.1590/S0044-59672009000400002

Valderrama M, Buzetti S, Benett CGS, Andreotti M, Arf O, Sá ME. Fontes e doses de nitrogênio e fósforo em feijoeiro no sistema plantio direto. Pesq Agropec Trop. 2009;39:191-6. https://doi.org/10.5216/pat.v39i3.4987

Veloso MG, Angers DA, Tiecher T, Giacomini S, Dieckow J, Bayer C. High carbon storage in a previously degraded subtropical soil under no tillage with legume cover crops. Agr Ecosyst Environ. 2018;268:15-23. https://doi.org/10.1016/j.agee.2018.08.024

Veloso MG, Cecagno D, Bayer C. Legume cover crops under no-tillage favor organomineral association in microaggregates and soil C accumulation. Soil Till Res. 2019;190:139-46. https://doi.org/10.1016/j.still.2019.03.003

Venturini SF, Antoniolli ZI, Steffen RB, Venturini EF, Giracca EMN. Efeito do vermicomposto, uréia e inoculação com *Rhizobium phaseoli* na cultura do feijão. Rev Cienc Agrovet. 2005;4:52-9.

Wang J, Zou J. No-till increases soil denitrification via its positive effects on the activity and abundance of the denitrifying community. Soil Biol Biochem. 2020;142:107706. https://doi.org/10.1016/j.soilbio.2020.107706

Yagi R, Andrade DS, Waureck A, Gomes JC. Nodulações e produtividades de grãos de feijoeiros diante da adubação nitrogenada ou da inoculação com *Rhizobium freirei*. Rev Bras Cienc Solo. 2015;39:1661-70. https://doi.org/10.1590/01000683rbcs20140342

Zeffa DM, Fantin LH, Santos OJAP, Oliveira ALM, Canteri MG, Scapim CA, Gonçalves LSA. The influence of topdressing nitrogen on *Azospirillum* spp. inoculation in maize crops through meta-analysis. Bragantia. 2018;77:493-500. https://doi.org/10.1590/1678-4499.2017273