

## Use efficiency and responsivity to nitrogen of common bean cultivars

### Eficiência de uso e responsividade ao nitrogênio de cultivares de feijoeiro comum

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Received in February 25, 2019 and approved in May 16, 2019

#### ABSTRACT

Common beans are the main source of protein in underdeveloped countries, and nitrogen (N) is one of the nutrients the most limits the productivity of this crop. This study, under field conditions, aimed to: a) determinate through efficiency indices how N is used by 16 cultivars of common beans; and b) classify these cultivars regarding use efficiency and responsivity to N application. The experimental design was in randomized blocks in split-plot scheme, with four replicates. Main plots consisted of 16 cultivars of common beans commercially classified as 'Carioca type'. Subplots comprised two rates of N: 20 and 120 kg ha<sup>-1</sup> applied as top-dressing. The evaluations were number of pods per plant and grains per pod, hundred-grain weight, shoots dry matter at full flowering, straw and grains dry matter at physiological maturity and grain yield. Based on the dry matter and its nutrient contents, the N accumulations were calculated in shoots and grains. The agronomic, physiological, agro-physiological, recovery and use efficiencies of N were calculated. Cultivar BRSMG Uai stands out by agronomic, physiological, recovery and use efficiencies of N. Genotypes BRSMG Uai, BRS FC402, IPR Campos Gerais, IPR Maracanã and TAA Bola Cheia are efficient and responsive to top-dressing N application.

**Index terms:** *Phaseolus vulgaris* L.; genotypes; dry matter; nitrogen accumulation; grain yield.

#### RESUMO

O feijão é a principal fonte de proteína dos países subdesenvolvidos, e o nitrogênio (N) é um dos nutrientes que mais limita a produtividade dessa cultura. Objetivou-se com esse trabalho, sob condição de campo: a) determinar por meio dos índices de eficiência como o N é utilizado por 16 cultivares de feijoeiro comum; and b) classificar estas cultivares em relação à eficiência de uso e responsividade à aplicação de N. O delineamento experimental foi em blocos casualizados em esquema de parcelas subdivididas, com quatro repetições. As parcelas foram constituídas por 16 cultivares de feijoeiro comum de grão comercial tipo carioca. As subparcelas foram compostas por duas doses de N: 20 e 120 kg ha<sup>-1</sup> aplicadas em cobertura. As avaliações foram número de vagens por planta e grãos por vagem, massa de cem grãos, massa seca da parte aérea no florescimento pleno, massa seca de palha e de grãos na maturidade fisiológica e produtividade de grãos. Com base na matéria seca e no teor de nutrientes, os acúmulos de N foram calculados na parte aérea e nos grãos. As eficiências agrônômicas, fisiológicas, agro-fisiológicas, recuperação e uso de N foram calculadas. A cultivar BRSMG Uai destaca-se pelas eficiências agrônômica, fisiológica, de recuperação e de utilização. Os genótipos BRSMG Uai, BRS FC402, IPR Campos Gerais, IPR Maracanã e TAA Bola Cheia são eficientes e responsivos a aplicação de N em cobertura.

**Termos para indexação:** *Phaseolus vulgaris* L.; genótipos; massa seca; acúmulo de nitrogênio; produtividade de grãos.

## INTRODUCTION

Brazil is the largest producer of common beans (*Phaseolus vulgaris* L.) in the world, with approximately 3.2 million tons of grains. The main type of common bean produced is the commercial grain 'Carioca', which represents 59% of all common bean national production (Conab, 2018). The crop has also economic and social importance due to its short cycle (65 to 95 days) and fast economic return, becoming an option for crop rotation and succession. In addition, common bean grain is the main low-

cost protein for populations of underdeveloped countries (Fageria; Melo; Oliveira, 2013; Fageria et al., 2014).

Nitrogen (N) is the nutrient extracted in largest amounts by the common bean crop, which exports on average 35 kg N per ton of grains produced (Ambrosano et al., 1997). However, more recent research indicates an average export of 25 kg N per ton of grain (Soratto et al., 2013). This element makes up proteins and important molecules such as chlorophyll. N supply is related to increase in photosynthesis, growth and duration of leaves,

number and size of vegetative and reproductive organs, and biomass production (Marschner, 2012). Common bean is N-fixing crop due to the symbiosis with bacteria of the genus *Rhizobium*, but this process is insufficient to meet crop demand (Fageria; Melo; Oliveira, 2013; Fageria et al., 2014). Thus, common bean requires at least 70 kg ha<sup>-1</sup> N through N fertilizers to obtain high grain yields, depending on the history of the area (Ambrosano et al., 1997). These N fertilizers are expensive, burn petroleum during their production, and their excessive use may contaminate water courses. Petroleum is a finite resource; its combustion pollutes atmosphere and its extraction affects marine life.

Studies aiming to increase the N efficiency use by crops are very important (Akter; Lupwayi; Balasubramanian, 2017), because they reduce costs with fertilizers, use of petroleum and pollution. These studies are in line with three Sustainable Development Goals (SDG) of the United Nations (UN): a) end hunger, achieve food security and improved nutrition and promote sustainable agriculture; b) take urgent actions to combat climate change; and c) conserve and sustainably use marine resources. Scientifically, this type of investigation also helps genetic improvement programs, which aim at genotypes that are efficient and responsive to nutrients (Silva et al., 2016).

However, most researches related to nutrient efficiency and response by common bean use lines in detriment of commercially grown genotypes (Fageria; Melo; Oliveira, 2013; Silva et al., 2016), which makes it difficult to use the results of these research by the rural producer. In addition, common bean compared to corn and soybeans is the crop that had the least increase in the efficiency of fertilizer use (kilogram of grain produced per kilogram of fertilizer) during the period from 2004 to 2017. Considering the values obtained in the years 2004 and 2017, increases in fertilizer use efficiency were 51.0, 37.9 and 19.6% for corn, soybean and bean crops, respectively (ANDDA, 2005, 2017). This statistical survey reinforces that the agricultural systems that produce beans need advances in nutrient use efficiency, such as N, and that these advances must be based on the knowledge of the efficiency and response to N by the cultivars.

In this sense, the use and response to N application by common beans depend on morphophysiological and biochemical processes that affect absorption, assimilation to organic compounds, mobilization and redistribution of the nutrient in plant organs (Fageria; Melo; Oliveira, 2013). These processes are greatly influenced by genotypes and

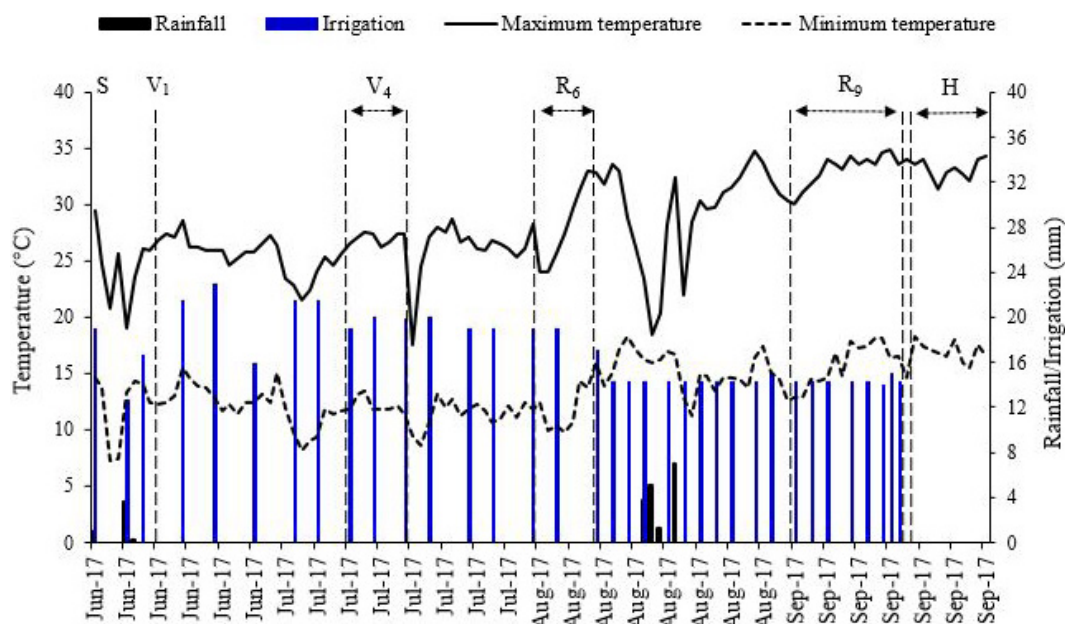
may lead to differences in terms of dry matter, production components and N accumulation in shoots and grains (Araújo; Teixeira, 2008; Fageria; Melo; Oliveira, 2013; Fageria et al., 2014). Fageria et al. (2014) verified in field condition that the cultivar BRS Estilo presented agronomic efficiency close to twice that obtained for the cultivar Pérola, 12.4 and 24.7 kg kg<sup>-1</sup>, respectively. Additionally, studies correlating these plant attributes with yield are important in order to facilitate the selection of genotypes that are efficient and responsive to N use (Fageria; Melo; Oliveira, 2013; Araújo; Teixeira, 2008). These associations depend on the phenological stage of the crop (Araújo; Teixeira, 2008).

Given the considerations above, this study aimed to: a) determine through efficiency indices how N is used by 16 cultivars of common beans; and b) classify these cultivars with regarding use efficiency and responsiveness to N application.

## MATERIAL AND METHODS

The experiment was conducted in the 2016/17 agricultural year in Jaboticabal - SP, Brazil (mean altitude of 586 meters) in a soil classified as eutroferic Red Latosol, with clay texture, on gently undulating relief with 6% slope. According to Köppen's classification, the climate of this region is Aw, humid tropical with rainy season in the summer and dry season in the winter. Rainfall, water depths by irrigation, and maximum and minimum temperatures were measured in the experiment (Figure 1).

The experimental area in the first year was under No-till system (NTS). Soil scarification was carried out on December 2, 2016, followed by application of 1 ton of limestone per hectare, with subsequent incorporation using disc plow and two passes of leveling harrow. Millet (*Pennisetum americanum* L.), ADR-300, was sown on December 12, 2016, at density of 14 kg ha<sup>-1</sup> with spacing of 0.45 m between rows in order to produce straw. Millet was desiccated at 60 days after emergence using potassium glyphosate at dose of 1.3 g ha<sup>-1</sup> of the acid equivalent. After that, millet plants were ground, producing 5.1 t ha<sup>-1</sup> straw. Chemical attributes and particle size were determined in the 0-0.20 m layer prior to common bean sowing. Results were: pH (CaCl<sub>2</sub>) 6.0; organic matter = 29 g dm<sup>-3</sup>; P (resin) = 50 mg dm<sup>-3</sup>; K = 6.4 mmol<sub>c</sub> dm<sup>-3</sup>; Ca = 33 mmol<sub>c</sub> dm<sup>-3</sup>; Mg = 14 mmol<sub>c</sub> dm<sup>-3</sup>; S = 8 mg dm<sup>-3</sup>; H+Al = 16 mmol<sub>c</sub> dm<sup>-3</sup>; CEC = 70 mmol<sub>c</sub> dm<sup>-3</sup>; V = 77%; B = 0.21 mg dm<sup>-3</sup>; Cu = 0.8 mg dm<sup>-3</sup>; Fe = 25 mg dm<sup>-3</sup>; Mn = 2.8 mg dm<sup>-3</sup>; Zn = 0.2 mg dm<sup>-3</sup>; clay = 540 g kg<sup>-1</sup>; silt = 230 g kg<sup>-1</sup> and sand = 230 g kg<sup>-1</sup>.



**Figure 1:** Rainfall (mm), water depths by irrigation (mm) and maximum and minimum temperature (°C). S = sowing;  $V_1$  = emergence of common bean plantlets;  $V_4$  = presence of third trifoliate leaf;  $R_6$  = full flowering;  $R_9$  = physiological maturity; H = harvest.

The experimental design was randomized blocks in a split-plot scheme, with four replicates. Main plots consisted of 16 cultivars of common beans of the commercial group ‘Carioca’: ANFc 9, BRSMG Uai, BRS Estilo, BRSMG Madrepérola, Pérola, BRS FC402, IAC Alvorada, IAC Milênio, IAC Sintonia, IPR Andorinha, IPR Campos Gerais, IPR Curió, IPR Celeiro, IPR Maracanã, TAA Dama and TAA Bola Cheia. Subplots comprised two levels of N fertilization as top-dressing: minimum (rate of 20 kg ha<sup>-1</sup> N) and maximum levels (rate of 120 kg ha<sup>-1</sup> N). The minimum and maximum levels were defined following suggestions of the methodology proposed by Fageria and Kluthcouski (1980) for studies of efficiency and response to nutrients. Fageria and Kluthcouski (1980) suggest that lower rate should not be so drastically reduced leading all cultivars to low efficiency, and the higher rate should allow genotypes to express its high response to nutrient application. Rate of 20 kg ha<sup>-1</sup> N is better than control (without N application as top-dressing) to differentiate the efficient cultivars, due to common bean had been conducted in first year of NTS, in which the N immobilization processes are highest to the mineralization. Each subplot was formed by five rows of common bean measuring 5 m in length and evaluations were carried out in the three central rows, disregarding 0.5 m on each end. Nitrogen rates were applied as top-dressing at stage  $V_4$  (third trifoliate leaf) along a continuous line at

0.10 m from the plant row, using Kimcoat® coated urea (45% of N) as source, followed by irrigation with 20 mm water depth for incorporation.

Common bean cultivars were manually sown under millet straw on June 8, 2017, at spacing of 0.45 m between rows and using 12 seeds per meter. The grooves for sowing of the common bean were made with the aid of a seeder-fertilizer with systems of seeding and closure of grooves decoupled. At phenological stage  $V_2$  (pair of cotyledon leaves), thinning was carried out in the subplots (leaving 11 plants per meter) with the aim of standardize the population. Final population was between 222.000 and 244.000 plants ha<sup>-1</sup> for the cultivars. Fertilization at planting was carried out using 210 kg ha<sup>-1</sup> of the formulation 04-20-20 (5.1% Ca, 4% S, 0.05% B, 0.06% Mn and 0.27% Zn).

The control of weeds was carried out with the application of herbicide bentazone + imazamoxi (628 g ha<sup>-1</sup> of a.e.) at 17 days after emergence (DAE) of common bean seedlings at the  $V_3$  phenological stage. The control of pests and diseases was carried out with the following sprays: thiamethoxam (250 g ha<sup>-1</sup> of a.e.) at 17 DAE; pyraclostrobin (75 g ha<sup>-1</sup> of a.e.) + metconazole (40 g ha<sup>-1</sup> of a.e.) and chlorpyrifos (600 g ha<sup>-1</sup> of a.e.) at 31 DAE; cyantraniliprole (55 g ha<sup>-1</sup> of a.e.) and thiamethoxam (250 g ha<sup>-1</sup> of a.e.) at 40 DAE; pyriproxyfen (25 g ha<sup>-1</sup> of

a.e.) + acetamiprid (60 g ha<sup>-1</sup> of a.e.), and pyraclostrobin (75 g ha<sup>-1</sup> of a.e.) + metconazole (40 g ha<sup>-1</sup> of a.e.) at 47 DAE; pyraclostrobin (75 g ha<sup>-1</sup> of a.e.) and lambda-cyhalothrin (21 g ha<sup>-1</sup> of a.e.) + thiamethoxam (28 g ha<sup>-1</sup> of a.e.) at 68 DAE; pyraclostrobin (75 g ha<sup>-1</sup> of a.e.) + metconazole (40 g ha<sup>-1</sup> of a.e.), and lambda-cyhalothrin (32 g ha<sup>-1</sup> of a.e.) + thiamethoxam (42 g ha<sup>-1</sup> of a.e.) and teflubenzon g ha<sup>-1</sup> of a.e.) to the 81 DAE.

Irrigation was applied by conventional sprinklers with variable interval according to the needs of the crop. Cultivars reached R<sub>9</sub> with 79 (BRSMG Madrepérola, IPR Andorinha and IPR Curió), 89 (ANFc 9; IAC Sintonia, IPR Campos Gerais and IPR Celeiro), 91 (IAC Alvorada, IAC Milênio, IPR Maracanã and TAA Bola Cheia), and 94 (BRSMG Uai, BRS Estilo, Pérola, BRS FC402 and TAA Dama) days after emergence. The cumulative water depths were 480, 538, 552 and 580 mm for the cultivars with cycle of 79, 89, 91, and 94 DAE, respectively.

At full flowering stage (R<sub>6</sub>), common bean population was determined by counting the plants in two 5-m-long rows. At this time, five consecutive plants were collected in each subplot, disregarding the roots. Their shoots were washed in distilled water, dried in forced air circulation oven at 65 °C for 72 h and then weighed; the data were transformed to kg ha<sup>-1</sup> of dry matter. Subsequently, the material was ground and subjected to chemical analysis to determine N concentrations (Malavolta; Vitti; Oliveira, 1997). These results were used to estimate the accumulated amounts of this nutrient per area.

Upon physiological maturity stage (R<sub>9</sub>), when crop still had many leaves, a similar procedure to that of R<sub>6</sub> was performed. However, grains were separated from the straw (branches, leaves and pod shells). Then, samples were washed, dried, weighed, ground and digested, to estimate dry matter and N accumulation per area of straw and grains. At this phenological stage, 10 consecutive plants were also collected to determine number of pods per plant, number of grains per pod and hundred-grain mass. Grain yield was obtained after manual removal and mechanical threshing of plants from the two central rows of each subplot, with determination of moisture content of the grains, corrected to 0.13 kg kg<sup>-1</sup> (wet basis).

Agronomic (AE), physiological (PE), agro-physiological (APE), recovery (RE) and use (UE) efficiency indices were calculated by adapted methodology of Fageria, Melo and Oliveira (2013), in which the values obtained for the control treatment in the original methodology were replaced in the calculations by those verified in the low N rate (20 kg ha<sup>-1</sup> of N). Efficiencies were calculated by the following equations:

$$AE = (Y_{HR} - Y_{LR}) / (HR - LR) \quad (1)$$

$$PE = (SDM_{HR} - SDM_{LR}) / (NAS_{HR} - NAS_{LR}) \quad (2)$$

$$APE = (Y_{HR} - Y_{LR}) / (NAS_{HR} - NAS_{LR}) \quad (3)$$

$$RE = (NAS_{HR} - NAS_{LR}) / (HR - LR) \quad (4)$$

$$UE = PE \times RE \quad (5)$$

In which, Y<sub>HR</sub> = grain yield at high rate; Y<sub>LR</sub> = grain yield at low rate; SDM<sub>HR</sub> = shoot dry matter at high rate; SDM<sub>LR</sub> = shoot dry matter at low rate; NAS<sub>HR</sub> = N accumulation in the shoots at high rate; NAS<sub>LR</sub> = N accumulation in the shoots at low rate; HR = high N rate applied; LR = low N rate applied. Cultivars were classified with respect to efficiency and responsivity to N according to Fageria and Kluthkouscki (1980).

The data were subjected to analysis of variance by F test, and means were grouped by Scott-Knott test. When F was significant for the interaction between N rate and cultivar, a simple-effect analysis was carried out. The study of simple correlation was conducted between grain yield and straw dry matter with the other variables analyzed.

## RESULTS AND DISCUSSION

Straw dry matter of common bean at R<sub>9</sub> was significantly influenced by the singles effects of N rates and cultivars without interaction (Table 1). Nitrogen rate of 120 kg ha<sup>-1</sup> caused average increase of 39.5% in straw production, compared with the application of 20 kg ha<sup>-1</sup>. Nitrogen is related to increasing net photosynthesis mainly due to increase chlorophyll content and growth and duration of leaves, resulting in increments in the quantity and size of vegetative and reproductive organs and, consequently, in the dry matter of the plants (Marschner, 2012). Crusciol et al. (2007) and Soratto et al. (2017) observed linear increments in common bean dry matter with increasing rates of N as top-dressing. The highest values of dry matter were obtained by cultivars IPR Maracanã, followed by BRSMG Madrepérola, Pérola, IAC Milênio and BRSMG Uai.

Grain yield was affected by the interaction between N rates and cultivars (Table 1). Based on the interaction, cultivars could be grouped in four groups regarding response to N. Group I corresponds to genotypes that produced little (less than 1,960 kg ha<sup>-1</sup>) at low level of the nutrient, but whose yield had significantly increased with increasing N rates. This

group comprises IAC Alvorada, IAC Milênio, IPR Curió and TAA Dama. Group II contains cultivars that produced well at both low and high N rates, that is, with grain yields above 1,960 and 2,500 kg ha<sup>-1</sup> in the low and high N rates, respectively. These cultivars are BRSMG Uai, Pérola, BRS FC402, IPR Campos Gerais, IPR Maracanã and TAA Bola Cheia. Group III is formed by the materials that produced well at low N level (more than 1,960 kg ha<sup>-1</sup>), but whose yields did not increase significantly at high level of this nutrient. Cultivars in this group are BRS Estilo, BRSMG Madrepérola, IAC Sintonia and IPR Andorinha. Group IV corresponds to cultivars that have low yield (less than 1,960 kg ha<sup>-1</sup>) at both low and high N rates, namely, ANFc 9 and IPR Celeiro.

Average yield grains obtained for the Group II (2,949 kg ha<sup>-1</sup>) was 586 kg ha<sup>-1</sup> higher than the average yield of the Sao Paulo state (Conab, 2018). These results are very satisfactory because high technology and N rates close to 100 kg ha<sup>-1</sup>, as top-dressing, are used in common bean cultivation in this state (Ambrosano et al., 1997). Therefore, cultivars belonging to group III should be prioritized due to the higher efficiency and response to N. Identification of common bean cultivars with respect to efficiency and responsivity to nutrients is of great importance because it can increase in the profits of the rural producers and benefit genetic improvement programs in the selection of genotypes (Fageria; Melo; Oliveira, 2013; Silva et al., 2016).

**Table 1:** Straw dry matter of common bean at physiological maturity (R<sub>9</sub>) and grain yield as a function of cultivars and nitrogen (N) rates applied as top-dressing.

Cultivars	Straw dry matter at R <sub>9</sub> (kg ha <sup>-1</sup> )	Yield (kg ha <sup>-1</sup> )	
		N20	N120
ANFc 9	1.626c	1.783cA	1.959eA
BRSMG Uai	1.783b	2.440aB	3.172aA
BRS Estilo	1.427c	2.152bA	2.159dA
BRSMG Madrepérola	2.004b	1.994bA	2.116dA
Pérola	1.816b	2.682aA	2.857aA
BRS FC402	1.372c	2.163bB	2.798bA
IAC Alvorada	1.242c	1.847cB	2.360cA
IAC Milênio	1.795b	1.598dB	2.583bA
IAC Sintonia	1.424c	2.166bB	2.452cA
IPR Andorinha	1.483c	2.070bA	2.304cA
IPR Campos Gerais	1.431c	2.274bB	2.978aA
IPR Curió	1.338c	1.172eB	1.498fA
IPR Celeiro	1.560c	1.647dA	1.732eA
IPR Maracanã	2.399a	2.187bB	2.906aA
TAA Dama	1.341c	1.568dB	2.403cA
TAA Bola Cheia	1.270c	2.511aB	2.980aA
CV% - C	29.39		23.29
N rates (kg ha <sup>-1</sup> )			
N20	1.321b		2.016b
N120	1.843a		2.454a
CV% - N	17.22		7.31
F test			
Cultivar (C)	3.57**		5.06**
N rate (N)	117.68**		229.68**
C x N	1.60 <sup>NS</sup>		6.81**

Means followed by different letters, lowercase in columns and uppercase in rows, differ by Scott-Knott test at 0.05 probability level. <sup>NS</sup> Not significant by F test. \*\* Significant by F test (p < 0.01). \* Significant by F test (p < 0.05).

Cultivars which most produced straw dry matter fitted in three out of the four groups related to higher use efficiency and/or responsivity to N (Groups I, II and III). According to Fageria and Kluthkouski (1980), efficient cultivars are those which produce well at low level of the nutrient, whereas responsive cultivars are those whose yields increase at increasing levels of the element. Thus, it was observed that straw dry matter was positively correlated with grain yield (Table 2). This effect is due to the fact that taller plants with more branches result in higher number of reproductive structures (Crusciol et al., 2007) and consequently higher yields, which can be confirmed by the positive correlation between straw dry matter at  $R_9$  and number of pods per plant, number of grains per pod and hundred-grain weight (Table 2). In this experiment, there were higher coefficients of correlation and significance level of straw dry matter with number of pods per plant ( $r=0.57^{**}$ ) and grains per pod ( $r=0.30^{**}$ ), compared to hundred-grain weight ( $r=0.21^*$ ). Fageria, Melo and Oliveira, (2013) observed under greenhouse conditions that straw dry matter represented 83% of the variability in grain production. In addition, these authors also found that the number of pods per plant is the production component most correlated with yield.

However, the different responses to N by the cultivars do not occur only due to the production of straw dry matter. Other morphological, physiological and biochemical mechanisms are also responsible for the differentiation with respect to N use by genotypes, with effects on the production components and, consequently, on yield (Fageria; Melo; Oliveira, 2013). Number of pods per plant was significantly influenced by interaction between N rates and cultivares (Table 3). The number of grains per pod was only affected by the cultivar, whereas hundred-grain weight was affected by the simple factors rate and cultivar. Lack of significant differences for N in the number of grains per pod is due to the fact that this variable has high genetic heritability, with little influence of the

environment (Nascente; Stone; Melo, 2017). These results corroborate those of Crusciol et al. (2007) and Flôres et al. (2017), who found no increments in the number of grains per pod with N supply.

The number of pods per plant increased with the N rate of 120 kg ha<sup>-1</sup> in comparison to the application of 20 kg ha<sup>-1</sup> for the cultivars of Group I (IAC Alvorada, IAC Milênio, and TAA Dama) and of Group II (BRSMG Uai, Pérola, BRS FC402, IPR Campos Gerais, IPR Maracanã and TAA Bola Cheia), except for IPR Curió (Group I), in which this variable did not change. However, the lack of significant differences at N rate of 20 kg ha<sup>-1</sup>, as a function of cultivars, along with the effects of only simple factors for the other production components, compromise the understanding on the low and high efficiencies of these genotypes. For Group III, the number of pods per plant did not change with increasing N rates in the cultivars BRS Estilo and BRSMG Madrepérola, but increased by 4.2 and 3.6 times in IAC Sintonia and IPR Andorinha, respectively. In group IV, the ANFc9 did not have significant alteration for this variable, but it was included among the cultivars with the lowest number of pods per plant at the highest rate with 7.7. On the other hand, IPR Celeiro, also of Group IV, had its number of pods per plant increased significantly with the increase of the N rate.

For the number of grains per pod, the cultivars were separated into four groups by the statistical test and characterized as superior, intermediate superior, intermediate inferior and inferior. The cultivars BRSMG Uai, BRSMG Madrepérola, IPR Campos Gerais, IPR Maracanã, IPR Campos Gerais and TAA Bola Cheia were classified as superior. The cultivars BRS Estilo, Pérola, BRS FC402, IAC Sintonia, IPR Andorinha and TAA Dama were classified as intermediate superior. ANFc 9, IAC Alvorada and IPR Celeiro were considered as intermediate inferior. IAC Milênio and IPR Curió were identified as inferior. It is worth mentioning that the cultivars of Group II obtained the highest numbers of grains per pod.

**Table 2:** Coefficients of correlation (r) of grain yield and straw dry matter at physiological maturity ( $R_9$ ) with the numbers of pods per plant (NPP) and grains per pod (NGP), hundred-grain weight (HGW), straw dry matter at  $R_9$  (SDM  $R_9$ ), nitrogen (N) accumulation in the shoots at  $R_9$  (NAS  $R_9$ ), N accumulation in the grains at  $R_9$  (NAG  $R_9$ ), and N accumulation in the shoots at full flowering ( $R_6$ ) (NAS  $R_6$ ) of common bean.

Coefficient of correlation (r)	NPP	NGP	HGW	SDM $R_9$	NAS $R_9$	NAG $R_9$	NAS $R_6$
Grain yield	0.50**	0.50**	0.22*	0.40**	0.54**	0.57**	0.50**
Straw dry matter ( $R_9$ )	0.57**	0.30**	0.21*	-	0.85**	0.70**	0.29*

\*\* Significant ( $p < 0.01$ ). \* Significant ( $p < 0.05$ ).

**Table 3:** Number of pods per plant, number of grains per pod, hundred-grain weight in common bean as a function of cultivars and nitrogen (N) rates applied as top-dressing.

Cultivars	Pods per plant		Grains per pod	Hundred-grain weight (g)
	N20	N120		
ANFc 9	6.4aA	7.7bA	3.5c	26.18c
BRSMG Uai	8.2aB	10.9aA	4.4a	25.66c
BRS Estilo	7.5aA	7.8bA	4.0b	26.54c
BRSMG Madrepérola	6.4aA	7.8bA	4.5a	25.48c
Pérola	6.1aB	10.0aA	3.9b	28.40b
BRS FC402	5.4aB	10.8aA	4.0b	24.57d
IAC Alvorada	6.1aB	9.9aA	3.6c	29.29a
IAC Milênio	8.0aB	10.5aA	3.2d	29.53a
IAC Sintonia	5.7aB	9.9aA	3.9b	26.13c
IPR Andorinha	7.0aA	8.5bA	3.8b	26.72c
IPR Campos Gerais	6.2aB	8.4bA	4.2a	24.04d
IPR Curió	6.6aA	6.4bA	3.1d	23.87d
IPR Celeiro	6.0aB	9.6aA	3.7c	23.70d
IPR Maracanã	7.2aB	10.8aA	4.3a	25.21c
TAA Dama	5.6aB	8.8bA	3.9b	25.76c
TAA Bola Cheia	5.5aB	8.2bA	4.2a	27.37b
CV% - C		22.03	10.12	6.25
N rates (kg ha <sup>-1</sup> )				
N20		6.5b	3.8a	25.65b
N120		9.1a	3.9a	26.65a
CV% - N		18.61	9.55	5.36
F test				
Cultivar (C)		2.05*	8.35**	9.61**
N rate (N)		105.03**	2.17 <sup>NS</sup>	16.25**
C x N		2.12*	0.72 <sup>NS</sup>	1.58 <sup>NS</sup>

Means followed by different letters, lowercase in columns and uppercase in rows, differ by Scott-Knott test at 0.05 probability level. <sup>NS</sup> Not significant by F test. \*\* Significant by F test ( $p < 0.01$ ). \* Significant by F test ( $p < 0.05$ ).

Hundred-grain weight was also classified in the same number of groups that the grain yield (Table 3). The group classified as superior contained the cultivars IAC Alvorada and IAC Milênio; the intermediate superior, Pérola and TAA Bola Cheia; the intermediate inferior, ANFc 9, BRSMG Uai, BRS Estilo, IAC Sintonia, IPR Andorinha, IPR Maracanã and TAA Dama; and the inferior, BRS FC402, IPR Campos Gerais, IPR Curió and IPR Celeiro. In this classification, the cultivars of Group II fit in the groups intermediate to inferior for hundred-grain weight. Regarding the effect of N rate, it was observed that

the application of 120 kg ha<sup>-1</sup> N led to average increase of 1 g in the hundred-grain weight. This nutrient, after being absorbed, associates with organic compounds, originating the proteins that cause increased mass in the grains (Perez et al., 2013; Amaral et al., 2016).

The results obtained by the hundred-grain weight follow a response pattern contrary to those obtained for the other production components, in which the most efficient and N-responsive cultivars had higher numbers of pods per plant and grains per pod. This effect can be explained by the mechanism of adjustment in the source-sink balance for

the photoassimilates (Binotti, 2015), in which the increase in the number of pods per plant and grains per pod (sink) causes the amount of photoassimilates distributed to each grain to be lower.

In addition, in the grain filling stage, the assimilates produced in a branch are mostly distributed within the same branch of common beans (Binotti, 2015). Thus, plants with high number of pods and grains per pod may have a reduced value of hundred-grain weight. Under the conditions of this experiment, the analysis of correlations revealed that grain yield was more associated with the number of pods per plant ( $r = 0.50^{**}$ ), grains per pod ( $r = 0.50^{**}$ ) and hundred-grain weight ( $r = 0.22^*$ ), respectively.

N accumulation in the shoots of common bean at  $R_9$  was significantly influenced by the simple factors N rate and cultivar (Table 4). For this variable, the cultivars were divided into two groups by the statistical test. The highest values were obtained by the materials BRSMG Uai, BRS Estilo, Pérola, IAC Milênio, IPR Maracanã and TAA Dama. Lowest N accumulations were observed in early materials (IPR Andorinha and IPR Curió), although they did not differ significantly from the other cultivars classified as inferior. Increasing N rate also led to average increase of  $23.5 \text{ kg ha}^{-1}$  N in the shoot of common bean in  $R_9$ . The mean value of N accumulation for the N rate of  $120 \text{ kg ha}^{-1}$  as top-dressing, at the end of the common bean cycle, was lower than that cited in the literature under the recommended rate of this nutrient,  $90 \text{ kg ha}^{-1}$  (Soratto et al., 2013). These authors observed increments of  $101.2$  and  $116.8 \text{ kg ha}^{-1}$  N for the cultivars Pérola and IAC Alvorada at  $R_9$ , respectively.

Such inferiority in the extraction of the nutrient is explained by the different managements adopted and by the reduced accumulation that occurred until  $R_6$ , as a result of low temperatures during the vegetative stage (Figure 1). The mean N accumulation with the highest rate, at  $R_6$ , was below the values of  $77.8$  and  $50.7 \text{ kg ha}^{-1}$  of this nutrient observed by Flôres et al. (2017) and Perez et al. (2013) for IAC Imperador and Pérola, respectively. However, the experimental areas in their studies had been under no-till system for longer times (4 and 23 years), N rates at sowing and pre-sowing ( $20$  and  $60 \text{ kg ha}^{-1}$  N) were superior, and the nutrient was split-applied as top-dressing. These factors contribute to lower immobilization, better N use and, consequently, greater extraction.

In this experiment, minimum air temperatures below  $12 \text{ }^\circ\text{C}$  were observed from sowing until  $R_6$  (24 days). In the same period, temperatures lower than  $10 \text{ }^\circ\text{C}$  occurred three times. Common bean is sensitive to excessive cold, and its growth is reduced by temperatures lower than  $12 \text{ }^\circ\text{C}$  (Crookston et al., 1975) and paralyzed at temperatures below  $10 \text{ }^\circ\text{C}$  (Wutke et al. 2000). Under cold

weather, there is a reduction in the formation of lateral or axillary branches, leaf area index and photosynthetic rate (Fancelli; Dourado-Neto, 1999) and, consequently, lower accumulations. Early cultivars were more harmed by the effects of low temperatures. These materials, for exhibiting determinate growth habit (Type I), did not produce new branches and leaves after  $R_6$ , which led to reduced shoot dry matter and low N accumulation at the end of the cycle. On the other hand, cultivars with indeterminate growth habit (Types II and III), which produce new branches and leaves in the reproductive period, were able to recover. Higher biomass accumulations have been associated with longer cycle of common beans (Araújo; Teixeira 2008).

N extractions at  $R_9$  and  $R_6$  were positively correlated with common bean yield and straw dry matter (Table 2). The coefficients of correlation between N accumulation at  $R_9$  and yield, and between this variable and straw dry matter, were higher than those found for production components, which is explained by the fact that yield is a combination of these components. Nascente, Carvalho and Rosa (2016) concluded that cultivars which absorb more N are more productive and that stresses related to this nutrient affect N redistribution to reproductive structures. In addition, the level of association between N accumulation in the shoots at  $R_6$  was higher for yield than for straw dry matter, but both were lower than those found at  $R_9$ . Such inferiority of the coefficients for flowering, compared to maturity, can be explained by the large number of events, depending on genetic and environmental factors, which occur from one phenological stage to the other, leading to reduction in the correlations. Araújo and Teixeira (2008) did not find significant correlations between N accumulation in the shoots at  $R_6$  with the production of grains and straw, but these variables were associated ( $p < 0.05$ ) at the grain filling stage ( $R_8$ ). These results confirm that common bean can uptake N even at the reproductive stage (Araújo; Teixeira, 2008). Fageria, Melo and Oliveira (2013) observed that the values of N accumulation in straw and grains vary with the genotypes.

N accumulation in the grains at  $R_9$  was significantly influenced by interaction (Table 4). All cultivars increased N removal by the grains with increasing rates, except IPR Campos Gerais, in which the values did not change. At the lowest rate, the genetic materials were separated into three groups. The cultivars BRS Estilo, Pérola, BRS FC402, IAC Milênio and IPR Maracanã were considered as superior. The genetic materials classified as intermediate for this variable were BRSMG Uai, IAC Sintonia, IPR Campos Gerais, TAA Dama and TAA Bola Cheia. These cultivars were also classified as Group III due to their yield (high efficiency). The early cultivars IPR Andorinha and IPR Curió were in the group with the lowest amount



of N accumulated in the grains. At the highest rate, the cultivars BRSMG Uai, BRS Estilo, Pérola, BRS FC 402, IPR Maracanã and TAA Dama had the greatest exports.

Based on the study of correlation, N accumulation at  $R_9$  is the variable most strongly associated with yield, and with high correlation with straw dry matter (Table 2). These results corroborate those of Fageria, Melo and Oliveira (2013), who observed in regression studies higher coefficients of

determination between the N accumulated in the grain and grain production ( $R^2 = 0.91^{**}$ ) than between N accumulation in the shoots and yield of common beans ( $R^2 = 0.41^{**}$ ). N accumulation in the grains can be an interesting agronomic characteristic for the selection of efficient genotypes with respect to N use, mainly because there is a simultaneous improvement for high yield and protein in the grains (Fageria; Melo; Oliveira, 2013).

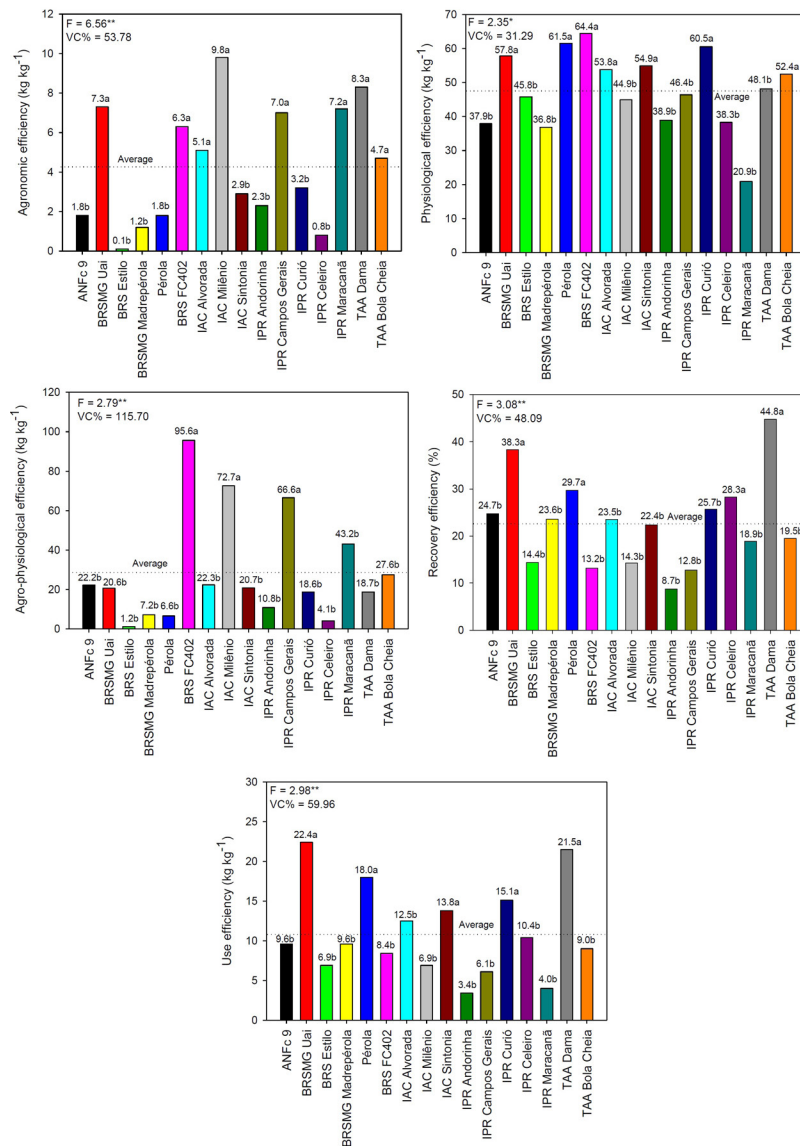
**Table 4:** Nitrogen (N) accumulation in the shoots and grains of common bean at physiological maturity ( $R_9$ ), and in the shoots at full flowering ( $R_6$ ) as a function of cultivars and N rates applied as top-dressing.

Cultivars	N accumulation in the shoots ( $R_9$ ) (kg ha <sup>-1</sup> )	N accumulation in the grains ( $R_9$ ) (kg ha <sup>-1</sup> )		N accumulation in the shoots ( $R_6$ ) (kg ha <sup>-1</sup> )
		N20	N120	
ANFc 9	50.7b	25.3cB	43.6dA	36.8a
BRSMG Uai	68.2a	38.2bB	70.1aA	25.6b
BRS Estilo	62.3a	43.8aB	56.1bA	23.6b
BRSMG Madrepérola	58.4b	25.3cB	40.4dA	22.3c
Pérola	68.9a	43.8aB	68.7aA	31.3a
BRS FC402	58.4b	45.6aB	56.9bA	29.1a
IAC Alvorada	50.8b	30.3cB	52.4cA	22.1c
IAC Milênio	62.7a	40.4aB	53.2cA	26.5b
IAC Sintonia	54.1b	34.5bB	51.9cA	31.0a
IPR Andorinha	43.3b	20.5cB	35.5dA	26.7b
IPR Campos Gerais	52.5b	34.8bA	39.8dA	27.0b
IPR Curió	43.3b	16.9cB	38.3dA	16.3d
IPR Celeiro	50.9b	24.1cB	41.8dA	25.6b
IPR Maracanã	72.7a	46.5aB	58.0bA	27.1b
TAA Dama	67.5a	36.5bB	75.1aA	28.0b
TAA Bola Cheia	54.4b	32.2bB	49.0cA	31.7a
CV% - C	30.89		34.67	20.46
N rates (kg ha <sup>-1</sup> )				
N20	45.7b		33.7b	22.2b
N120	69.2a		51.9a	31.7a
CV% - N	16.57		17.70	19.49
F test				
Cultivar (C)	2.04*		3.53**	5.85**
N rate (N)	196.32**		186.07**	105.24**
C x N	1.72 <sup>NS</sup>		2.37*	2.03*

Means followed by different letters, lowercase in columns and uppercase in rows, differ by Scott-Knott test at 0.05 probability level. <sup>NS</sup> Not significant by F test. \*\* Significant by F test ( $p < 0.01$ ). \* Significant by F test ( $p < 0.05$ ).

Agronomic (AE), physiological (FE), agro-physiological (APE), recovery (RE) and use (UE) efficiencies were significantly affected by the cultivars (Figure 2). For all these indices, the genetic materials were separated into two groups: inferior and superior. Highest AE values were obtained by BRSMG Uai, BRS FC402, IAC Alvorada, IAC Milênio, IPR Campos Gerais, IPR Maracaná, TAA Dama and TAA Bola Cheia. This efficiency varied from 0.1 to 9.8 kg of grain produced

per kg of N applied through fertilizer, reinforcing the importance of this parameter in the selection of the cultivar (Fageria; Melo; Oliveira, 2013) and fertilization management (Amaral et al., 2016). The mean value for this index was 47% lower than the 8.2 kg kg<sup>-1</sup> reported by Fageria, Melo and Oliveira (2013). However, the experiment of these authors was conducted in pots in a greenhouse, in which N losses and environmental stresses are smaller.



**Figure 2:** Agronomic (AE), physiological (PE), agro-physiological (APE), recovery (RE) and use (UE) efficiencies of common bean cultivars. Means followed by different lowercase letters in columns differ by Scott-Knott test at 0.05 probability level. \*\* Significant by F test (p < 0.01). \* Significant by F test (p < 0.05).

Among the cultivars previously classified as responsive to N (Groups I and II), based on the yield by the statistical test, only Pérola had low AE, indicating strong correlation between yield and this index. Fageria, Melo and Oliveira (2013) observed that all efficiencies contribute to grain production. However, the highest coefficients of determination were found by these authors between common bean yield and agronomic efficiency ( $R^2 = 0.57^{**}$ ), followed by use efficiency ( $R^2 = 0.47^{**}$ ), agro-physiological efficiency ( $R^2 = 0.37^{**}$ ), recovery efficiency ( $R^2 = 0.34^{**}$ ) and physiological efficiency ( $R^2 = 0.27^{**}$ ).

Highest PE values were obtained by BRSMG Uai, Pérola, BRS FC402, IAC Alvorada, IAC Sintonia, IPR Curió and TAA Bola Cheia, which ranged from 20.9 to 64.4 kg of shoot dry matter produced per kg of nutrient extracted. This index was high for IPR Curió, although it is an early material whose N accumulation was greatly affected by the cold weather. However, this efficiency is calculated based on the relationship between the differences of biological production (straw and grains) and N accumulation in the shoots at high and low rates of the nutrient. Thus, this cultivar may have had its index increased because its shoot dry matter increased by 1.506 kg ha<sup>-1</sup> from 20 to 120 kg ha<sup>-1</sup> N. Such gain is higher than the average increase of 1.146 kg ha<sup>-1</sup> of the experiment.

The genotypes considered as superior for APE were BRS FC402, IAC Milênio and IPR Campos Gerais, and this index varied from 1.2 to 95.6 kg of grains produced per kg of N accumulated in the shoots (Figure 2). Akter, Lupwayi and Balasubramanian (2017) attributed these differences in the response for this efficiency to different genetics regarding N metabolism, capacity of distribution and redistribution of the absorbed nutrient among plant organs, photosynthetic efficiency and environmental factors. The APE is an important characteristic of the plant which can be used in genetic improvement (Akter; Lupwayi; Balasubramanian, 2017).

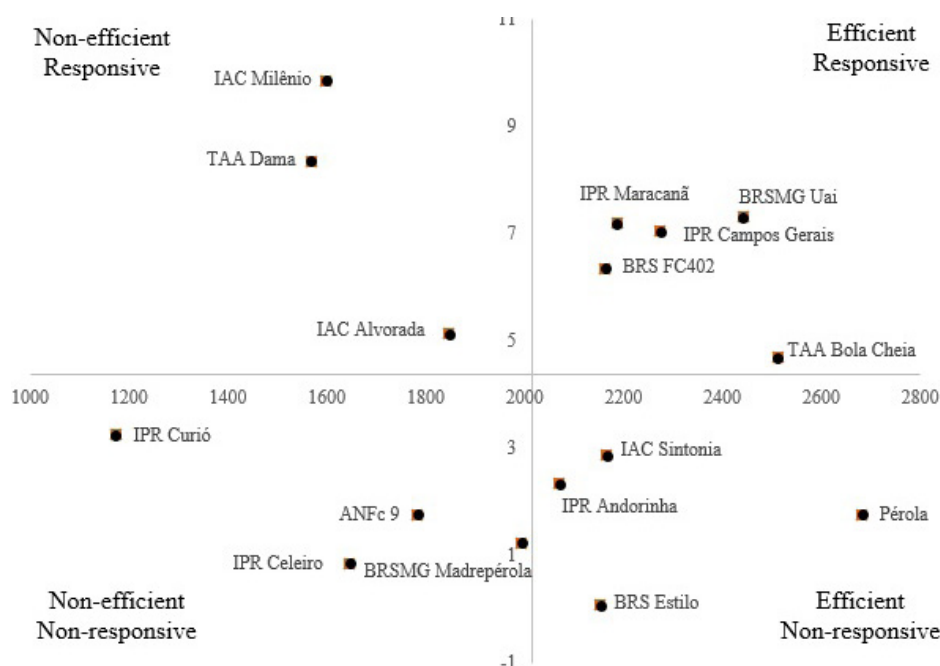
The cultivars with highest RE were BRSMG Uai, Pérola, IPR Celeiro and TAA Dama, and this index ranged from 8.7 to 44.8 kg N accumulated in the shoots per kg of the nutrient applied. IPR Andorinha and IPR Curió were classified as inferior, which may be associated with lower root growth and consequently reduced absorption. Lower masses of roots have been related to genotypes with determinate growth habit (Araújo; Teixeira, 2008). The cultivars BRSMG Madrepérola and IPR Maracanã showed low N recovery, which may be related to the semi-early aspect of these genotypes. However, IPR Maracanã

had cycle of 91 days under the experimental conditions. In addition, this index is influenced by the differences in biological N fixation (BNF) among the cultivars. Fageria et al. (2014) observed higher BNF for Pérola than for BRS Estilo in the average of two agricultural years, which helps elucidate the differences between these materials regarding RE. Highest UE values were obtained by BRSMG Uai, Pérola, IAC Sintonia, IPR Curió and TAA Dama. The mean values ranged from 4.0 to 22.4 kg of shoot dry matter per kg of N applied.

The high yields observed for BRSMG Uai were related to its high values of four out of the five efficiencies, namely: AE, PE, RE and UE. Thus, this cultivar is able to better recover the N applied through fertilizer, convert this accumulated nutrient into leaves, branches and pods, and consequently produce more grains. The cultivar Pérola, despite having shown high PE, RE and UE, had reduced values related to grain yield (AE and APE). These results indicate that this material uses the accumulated N more for the development and growth of branches, leaves and pods than for grain formation and filling. In addition, the cultivar BRSMG Uai was registered more recently than the cultivar Pérola, which may indicate the advance of crop breeding for efficiency and response to N.

The chart proposed by Fageria and Kluthcouski (1980) allowed us to classify as efficient in N use, genotypes with grain yields at the lowest N rate higher than the average in this condition, and as responsive to N, genotypes with agronomic efficiency above the average of the experiment (Figure 3).

Efficient and responsive cultivars were BRSMG Uai, BRS FC 402, IPR Maracanã, IPR Campos Gerais and TAA Bola Cheia. Efficient and non-responsive cultivars were BRS Estilo, Pérola, IAC Sintonia and IPR Andorinha. Non-efficient and responsive genotypes were IAC Alvorada, IAC Milênio and TAA Dama. ANFc 9, BRSMG Madrepérola, IPR Curió and IPR Celeiro were identified as non-efficient and non-responsive, representing 25% of the genetic group. Practical implications of these results are that cultivars classified as efficient in the use of N are interesting for agricultural systems that receive less amount of nitrogen fertilizers, as in the case of some family farmers or those farmers who opt for reduction of investments in fertilizers. Nitrogen responsive genotypes are good options for agricultural systems with high N inputs via fertilizers and high technology, because higher yields can be achieved. In this sense, the choice for efficient and N-responsive cultivars should be prioritized since they minimize the probability of errors in nutritional management with N.



**Figure 3:** Use efficiency and response to top-dressing application of nitrogen (N) by common bean cultivars. Grain yield at low N rate is found on X-axis whereas agronomic efficiency is on Y-axis. The point of origin of the axes represents the average efficiency and average response of the cultivars.

## CONCLUSIONS

The cultivar BRSMG Uai stands out in four of the five efficiencies: agronomic (AE), physiological (PE), recovery (RE) and use (EU) of N. Genotypes BRSMG Uai, BRS FC402, IPR Campos Gerais, IPR Maracanã and TAA Bola Cheia are efficient and responsive to N application as top-dressing. Efficient and non-responsive cultivars are BRS Estilo, Pérola, IAC Sintonia and IPR Andorinha. Genetic materials considered as non-efficient and responsive are IAC Alvorada, IAC Milênio and TAA Dama. ANFc 9, BRSMG Madrepérola, IPR Curió and IPR Celeiro are identified as non-efficient and non-responsive.

## ACKNOWLEDGEMENT

The authors are grateful to the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting a doctoral scholarship to the first author.

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