

## Full Length Research Paper

# Broadcast fertilizer rate impacts common bean grain yield in a no-tillage system

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Received 20 January, 2014; Accepted 26 March, 2015

**Increasing fertilizer rates at sowing can provide significant increases in grain yield in vegetable crops. However, very high rates can impair root development because of increased soil salinization in the rows mainly because of KCl fertilizer. Broadcast fertilization without incorporation into soil may be a viable strategy to avoid this salinization. Therefore, we conducted a study to determine the effect of different fertilizer rates applied to the soil surface without incorporation on common bean grain yield and yield components in a no-tillage system. An irrigated field experiment with a randomized block experimental design with four replications was conducted in Brazil during the 2012 and 2013 growing seasons. The treatments consisted of four fertilizer rates of an N-P-K blend that were 0, 50, 100 (15 kg ha<sup>-1</sup> of N, 90 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> and 45 kg ha<sup>-1</sup> of K<sub>2</sub>O) and 150% of the recommended fertilizer rate for in-furrow applications. Increasing broadcast fertilizer application provided a significant increase in common bean grain yield. The application of 300 kg ha<sup>-1</sup> of fertilizer (100% of the recommended fertilizer rate) on the soil surface without incorporation provided a similar result as the application of the same amount in the seed row. The results document that broadcast application of a fertilizer blend on the soil surface without incorporation is a viable management tool to increase common bean grain yield in no-tillage systems in soil with high fertility, which is based mainly on its content of organic matter, phosphorus, and base saturation.**

**Key words:** *Phaseolus vulgaris* L., surface fertilization, Cerrado, no-tillage system.

## INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an important crop in many countries as a major source of protein in human diets. In 2012, 23 million Mg of dry common bean grains were produced worldwide, with the principal producers being Myanmar (3.9 Mg), India (3.7 Mg), Brazil

(2.8 Mg), China (1.6 Mg), the USA (1.4 Mg) and Mexico (1.1 Mg) (FAOSTAT, 2013). However, despite its importance, farmers use low level of technology for common bean crops such as low fertilization rates, low quality of seeds, lack of improvement management

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**Abbreviations:** NTS, no-tillage system; SOM, soil organic matter; NPP, number of pods per plant; NGP, number of grains per pod; M100G, 100-grain weight; GY, grain yield.

practices, resulting in a global average grain yield of only 804 kg ha<sup>-1</sup> (FAOSTAT, 2013). More specifically in Brazil, this crop represented 6.08% of the entire grain production area and 1.84% of the total grain production in the 2012/2013 growing season. Common bean is the 3<sup>rd</sup> largest agricultural crop in Brazil and occupies an area of 3.16 million ha, behind only soybean (*Glycine max*) and corn (*Zea mays*) (CONAB, 2013). The average Brazilian yield of common bean was 910 kg ha<sup>-1</sup>, but there are farmers attaining grain yields greater than 3500 kg ha<sup>-1</sup> (Nascente et al., 2012a; CONAB, 2013). To achieve a higher grain yield, crop fertilization management must be improved because a properly balanced supply of nutrients and the use of fertilizers can achieve significant increases in grain yield (Miranda et al., 2000; Andrade et al., 2004; Arf et al., 2011; Nascente et al., 2012a).

Foundation fertilizer can be applied during the sowing operation or broadcast independently of the sowing operation (Guareschi et al., 2008). The former operation consists of applying the fertilizer and seeds at the same time in the seed row. This is the most widespread application used by farmers in Brazil since the invention of the seeder (Malavolta, 1981). The latter operation consists of distributing the entire or partial amount of fertilizer prior to or soon after sowing. Broadcasting the fertilizer independently allows the seeding process to occur more efficiently and does not require refreshing the supply of the seeder with fertilizer (Bergamin et al., 2008; Castoldi et al., 2012), which is more representative in the seeder than the quantity of seeds.

Distributing the fertilizer in the sowing operation could lead to delays because it requires increased time and the number of individuals supplying the seeders, which influences the operational capacity. Using broadcast fertilization without incorporation allows a greater seeder operational efficiency because the seeder can operate longer without having to stop for additional fertilizer. Therefore, it will help reduce operational and total costs and also enable an increase in net revenue and economic sustainability compared to the traditional cultivation system (Matos et al., 2006). The common bean in Brazil is a crop where only 0.92% of farmers produce 51.2% of total grain production (Silva and Wander, 2013). Therefore, the efficiency and flexibility of sowing is essential. In this case, broadcast fertilizer application can help to improve the possibility of success of common bean cultivation.

Additionally, distributing the fertilizer by the broadcast method decreases the risk of damaging the germination and establishment of plants. When applying greater amounts of fertilizer in the seed row, the root system of the plants can be damaged by soil salinization. In the case of potassium (K), for example, when the source is the salt potassium chloride (KCl) and the rates are greater than 50 kg ha<sup>-1</sup> of K<sub>2</sub>O, application at sowing causes damage to the seed and radicle of the soybean plant (Bergamin et al., 2008). For the common bean, Kluthcouski and Stone (2003) also indicate that greater

amounts of fertilizer closer to the seeds results in chlorosis on the primary leaves. These authors also note that mineral fertilizers primarily produce saline and osmotic effects, and these characteristics can affect the germination and development of plant seedlings and roots. In this sense, the application of mineral fertilizer broadcast without incorporation into the soil can be a viable and safe alternative for providing an adequate supply of nutrients to plants.

In common bean, studies of the application of nitrogen (N), phosphorus (P) and potassium (K) are usually performed in isolation (Arf et al., 2004, 2011; Barbosa Filho et al., 2005; Meira et al., 2005; Crusciol et al., 2007; Pelá et al., 2009; Valderrama et al., 2009; Zucarelli et al., 2011), and there are only few studies that review the mixed application of these nutrients using formulated fertilizers and even fewer studies of broadcast fertilization with plowing (Rodrigues et al., 2002; Kikuti et al., 2005; Viana et al., 2011). It is noteworthy that the application of fertilizer broadcast without incorporation has already been adopted by many farmers in Brazil, but few studies have reported its effectiveness in relation to other forms of fertilizer distribution (Guareschi et al., 2008; Castoldi et al., 2012). The objective of this study was to determine the effect of fertilizer rate under with broadcast application on the soil surface without incorporation on the yield of components and grain for the common bean.

## MATERIALS AND METHODS

The experiments were conducted at Fazenda Capivara, Embrapa Rice and Beans, located in Santo Antônio de Goiás, GO, at 16°28'00" S and 49°17'00" W and 823 m above sea level. The climate is tropical savanna and considered Aw according to the Köppen classification. There are two well-defined, normally dry seasons from May to September (autumn/winter) and two rainy seasons from October to April (spring/summer). The average annual rainfall is between 1500-1700 mm, and the average annual temperature is 22.7°C, ranging annually from 14.2 to 34.8°C (Silva et al., 2010).

The soil was classified as a clay loam (kaolinitic and thermic Typic Haplorthox) acidic soil (Embrapa, 2006). Before initiation of treatment application in May 2012 and May 2013, chemical analyses were performed on soil samples taken from 0 to 20 cm depth to characterize the experimental area (Table 1). The chemical analyses were performed according to the methodology proposed by Claessen (1997). The soil pH was determined in a 0.01 mol L<sup>-1</sup> CaCl<sub>2</sub> suspension (1:2.5 soil/solution), and the exchangeable Ca, Mg, and Al were extracted with neutral 1 mol L<sup>-1</sup> KCl in a 1:10 soil/solution ratio and determined by titration with a 0.025 mol L<sup>-1</sup> NaOH solution. Phosphorus and exchangeable K were extracted with a Mehlich 1 extracting solution (0.05 M HCl in 0.0125 M H<sub>2</sub>SO<sub>4</sub>).

The extracts were calorimetrically analyzed for P, and flame photometry was used to analyze K. The base saturation values were calculated using the results of the exchangeable bases and total acidity at pH 7.0 (H + Al). Micronutrients were determined in the Mehlich 1 extract by atomic absorption, and the organic matter was determined by the method of Walkley and Black (1934).

The experimental area has been cultivated in a crop-livestock no-tillage system (NTS) for seven consecutive years, which consists of following the crop rotation program with soybean (summer),

**Table 1.** Chemical characteristics of soil in the area prior to fertilizer application for two growing seasons.

| Growing season 2012                           |                    |      |      |      |      |                         |
|---|--------------------|------|------|------|------|-------------------------|
| Ca  | Mg                 | Al   | H+Al | K    | CEC  | pH (CaCl <sub>2</sub> ) |
| -----cmol <sub>c</sub> dm <sup>-3</sup> ----- |                    |      |      |      |      |                         |
| 3.4   | 1.5                | 0.0  | 3.1  | 0.16 | 8.16 | 5.6                     |
| BS  | SOM <sup>1</sup>   | P    | Zn   | Cu   | Fe   | Mn                      |
| %   | g dm <sup>-3</sup> |      |      |      |      |                         |
| 62.01   | 27.0               | 7.7  | 3.8  | 2.3  | 27.1 | 34.3                    |
| -----mg dm <sup>-3</sup> -----                |                    |      |      |      |      |                         |
| Growing season 2013                           |                    |      |      |      |      |                         |
| Ca  | Mg                 | Al   | H+Al | K    | CEC  | pH (CaCl <sub>2</sub> ) |
| -----cmol <sub>c</sub> dm <sup>-3</sup> ----- |                    |      |      |      |      |                         |
| 3.2   | 1.4                | 0.0  | 3.7  | 0.38 | 8.68 | 4.9                     |
| BS  | SOM <sup>1</sup>   | P    | Zn   | Cu   | Fe   | Mn                      |
| %   | g dm <sup>-3</sup> |      |      |      |      |                         |
| 57.37   | 35.7               | 15.8 | 5.4  | 2.0  | 32.0 | 26.0                    |
| -----mg dm <sup>-3</sup> -----                |                    |      |      |      |      |                         |

<sup>1</sup>SOM – soil organic matter.

followed by rice (summer) and the common bean (winter), followed by corn and palisadegrass (*Urochloa brizantha*) [syn. *Brachiaria brizantha* (Hochst. Ex A. Rich) Stapf] (summer), followed by two years of grazing pasture.

The experimental design was a randomized block with four replications in both years (2012 and 2013). Treatments consisted of four fertilization rates: 0, 50, 100 and 150% of the recommended sowing fertilization rate for the crop (Sousa and Lobato, 2004). Thus, a fertilizer with the formula 5-30-15 (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O) was broadcast on the soil surface at 0, 150, 300 and 450 kg ha<sup>-1</sup> three days after sowing. The application of the fertilizer was performed manually over the entire surface of the plots without incorporation in the corresponding treatments. Additionally, the application of 300 kg ha<sup>-1</sup> of 5-30-15 formulated (N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O) in the sowing furrow at the same time of crop sowing was used as a control treatment with four replications in both years.

The sowing of the common bean cultivar 'Perola' was mechanically conducted on May 21<sup>st</sup>, 2012 and June 07<sup>th</sup>, 2013 in 0.50-m row spacing with a population of 240,000 seed ha<sup>-1</sup>. Each plot consisted of 10 five-meter-long rows, with a useful area of eight central rows that disregarded 0.5 m from the ends of each row.

Seedling emergence occurred at nine and eight days after sowing in 2012 and 2013, respectively. In the V<sub>4</sub> vegetative stage of the common bean (four trifoliate leaves) (Vieira et al., 2006), a topdressing fertilization of 60 kg N ha<sup>-1</sup> as urea was done for all plots. Other cultural practices were performed according to the recommendations of the crops to keep the area free of weeds, disease and insects (Vieira et al., 2006).

Supplemental water was applied to bean plots with a sprinkler irrigation system (linear move) was used, and three crop coefficients (K<sub>c</sub>) were divided into four periods between emergence and harvest to manage the application of water. In the vegetative stage, a K<sub>c</sub> value of 0.4 was used. For the reproductive phase, two values of K<sub>c</sub> were used: 0.7 to 1.0 in the initial phase and the reverse of these values in the final phase of maturation, that is, 1.0 to 0.7. Therefore, the control of irrigation respective of the depth of root system exploitation at 0.2 m was initiated with the available water capacity (AWC) at its maximum and successively subtracting the value of crop evapotranspiration until the total water reached the minimum limit of 40% of AWC (Doorenbos and Pruitt, 1976).

Plots were harvested on August 22<sup>nd</sup>, 2012 and September 9<sup>th</sup>, 2013 by hand in the useful area (eight central rows that disregarded

0.5 m from the ends of each row) and was followed by mechanized stationary thresher. The harvested common bean grains were weighed and the yield expressed as 130 g kg<sup>-1</sup>. In addition, plant population was measured counting the number of plants in 1 m<sup>2</sup> in the usable area and the following yield components were assessed: the number of pods per plant, number of grains per pod (evaluated in 10 plants per plot that were chosen at random), and weight of 100 grains (calculated from eight random samples per plot). Data were subjected to an analysis of variance (proc. GLM), and the means were compared by Tukey's test at p≤0.05. If the quantitative data (fertilizer rates) were significant, then the regression analysis was conducted (proc REG). Dunnett's test was performed at a significance of p≤0.05 to compare the fertilizer in the sowing row with each fertilizer rate applied. These analyses were done with SAS (SAS, 1999).

## RESULTS AND DISCUSSION

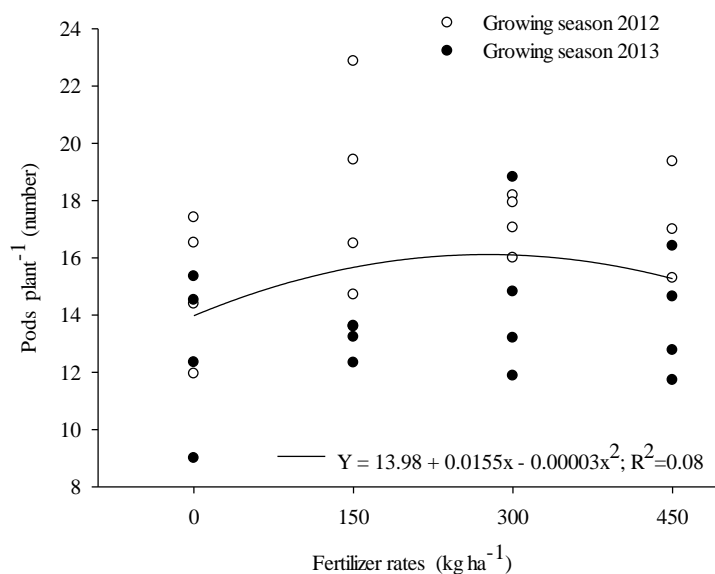
The application of increasing doses of fertilizer broadcast on the soil surface without incorporation produced significant effects for all yield components and the grain yield of the common bean (Table 2), and the data fit a quadratic regression for the number of pods per plant (Figure 1) and grains per pod (Figure 2). These results corroborate the results presented by Fageria et al. (2004), Zucareli et al. (2006), Pelá et al. (2009) and Zucareli et al. (2011), who reported significant increases in yield components with increasing rates of fertilizer application. The only yield component that was not affected by the rate of fertilizer application was the 100-grain weight, and this variable is characteristic of cultivars with little variation as a result of environmental conditions (Pelá et al., 2009). Moreover, Valderrama et al. (2009) and Melém Júnior et al. (2011) also found no significant difference on the 100-grain weight with increasing rates of fertilizer application.

With respect to grain yield, a positive increase in yield

**Table 2.** Plant population (PP), Number of pods per plant (NPP), number of grains per pod (NGP) 100-grain weight (M100G), and grain yield (GY) of the common bean (*Phaseolus vulgaris*) as a function of the fertilizer rates broadcast on the soil surface without incorporation and differences of each fertilizer rate in relation to the control treatment (300 kg ha<sup>-1</sup> of fertilizer applied at sowing furrow). Santo Antonio de Goias, GO, Brazil. Growing seasons 2012 and 2013.

| Treatments                             | PP                            | NPP                | NGP              | M100G              | GY                  |
|--|-------------------------------|--------------------|------------------|--------------------|---------------------|
| Fertilizer rate (kg ha <sup>-1</sup> ) | n° m <sup>2</sup>             | n°                 | n°               | (grams)            | kg ha <sup>-1</sup> |
| 0                                      | 20*                           | 13.9               | 4.3              | 26.68*             | 3377                |
| 150                                    | 21*                           | 15.3* <sup>2</sup> | 4.7              | 27.39              | 3742                |
| 300                                    | 21*                           | 15.8*              | 5.0*             | 26.83*             | 4024*               |
| 450                                    | 21*                           | 16.0*              | 5.1*             | 26.50*             | 4167*               |
| Control <sup>3</sup>                   | 22*                           | 15.9               | 5.1              | 26.59              | 4053                |
| <b>Growing season</b>                  |                               |                    |                  |                    |                     |
| 2012                                   | 21 <sup>a</sup>               | 13.6 <sup>b1</sup> | 4.6 <sup>a</sup> | 26.27 <sup>a</sup> | 3584 <sup>b</sup>   |
| 2013                                   | 23 <sup>a</sup>               | 17.0 <sup>a</sup>  | 4.9 <sup>a</sup> | 27.40 <sup>a</sup> | 4070 <sup>a</sup>   |
| <b>Factors</b>                         |                               |                    |                  |                    |                     |
|  | ANOVA – Probability of F test |                    |                  |                    |                     |
| Fertilizer rate                        | 0.7984                        | <0.001             | 0.0459           | 0.8005             | 0.0089              |
| Year                                   | 0.1147                        | <0.001             | 0.2501           | 0.0961             | 0.0229              |
| Fertilizer rate x year                 | 0.5149                        | 0.4747             | 0.6555           | 0.5080             | 0.8048              |
| Coefficient of variation (%)           | 7.2                           | 8.4                | 14.9             | 6.8                | 16.1                |

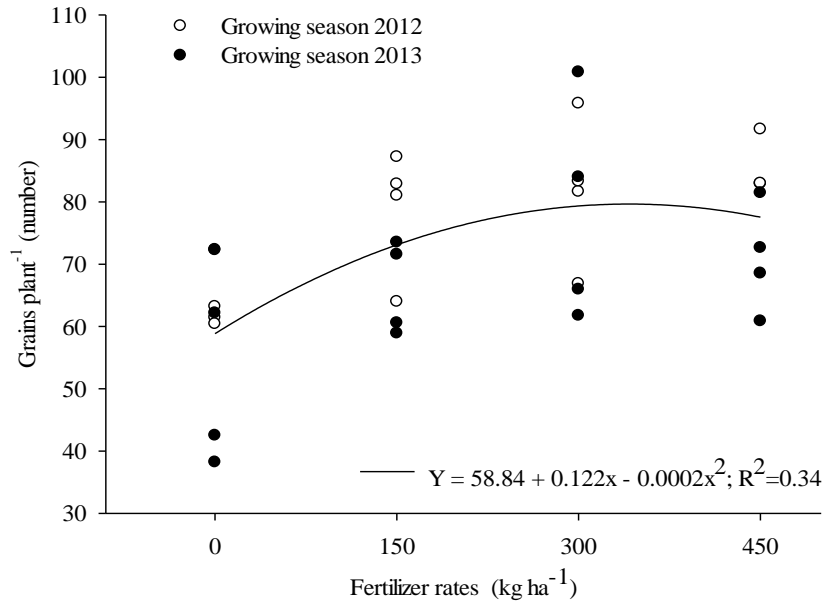
<sup>1</sup>Means followed by the same letter in a column do not differ by Tukey's test for  $p \leq 0.05$ . <sup>2</sup>Means followed by \* do not differ by the control treatment according to the Dunnett test at  $p \leq 0.05$ . <sup>3</sup>(300 kg ha<sup>-1</sup> in the sowing furrow).



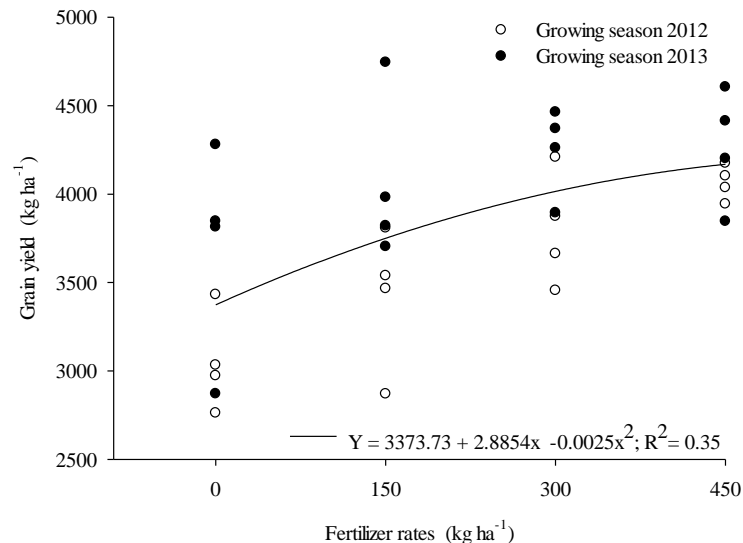
**Figure 1.** Number of pods per plant in the common bean crop as a function of the fertilizer rates broadcast on the soil surface without incorporation. Santo Antonio de Goias, GO, Brazil, growing seasons 2012 and 2013.

was found with increasing fertilizer rates, and the data fit a quadratic function (Figure 3). The grain yield of the common bean is a function of its yield components, such as the number of pods per plant, number of grains per

pod and 100-grain weight (Araújo et al., 1996). The grain yield can be explained by the results obtained for the number of pods per plant and number of grains per pod because the other factors were fixed or unchanged.



**Figure 2.** Number of grains per plant in the common bean crop as a function of the fertilizer rates broadcast on the soil surface without incorporation. Santo Antonio de Goias, GO, Brazil, growing seasons 2012 and 2013.



**Figure 3.** Grain yield in the common bean crop as a function of the fertilizer rates broadcast on the soil surface without incorporation. Santo Antonio de Goias, GO, Brazil, growing seasons 2012 and 2013.

Other authors also reported an increase in grain yield of the common bean because of the increased rate of fertilizer application (Pelá et al., 2009; Fageria et al., 2010; Zucareli et al., 2010, 2011; Melém Junior et al., 2011). It is noteworthy that these authors obtained their results by applying the fertilizer at sowing, and there are virtually no results (data) for the broadcast application of fertilizer to the soil surface without incorporation for the

common bean.

Applying 300 kg ha<sup>-1</sup> of fertilizer in the sowing furrow gave similar results to those for broadcasting 300 and 450 kg ha<sup>-1</sup> of the fertilizer without incorporation (Table 2). In similar studies of soybean, Bergamin et al. (2008) and Gareschi et al. (2008) reported no differences between broadcast fertilizer application and application in seed row. Kurihara and Hernani (2013) also indicated

that the application of fertilizer on the soil surface may favor the farmer because it produces increased operational income during the seeding process by eliminating the need to replenish with fertilizers, especially when using bagged products (60 kg bags), which require more spent not planting.

Kurihara and Hernani (2013) indicated that switching from banding adequate rate of fertilizer in the seed row to broadcast application with incorporation in the soil should provide medium to high fertility. These researchers reported significant reductions in grain yield for the soybean in soils with low fertility when the fertilizer was applied to the soil surface without plowing instead of in the sowing furrow, especially for P levels in the soil. In this sense, it appears that the experimental area in the present study had high fertility (Table 1), which is based mainly on its content of organic matter, phosphorus, and base saturation (Sousa and Lobato, 2004). Our results are appropriate for similar sites with medium or high fertility levels, but similar studies should be done on lower fertility sites before extrapolating our results to that type of site. There were higher values for the number of pods per plant<sup>-1</sup> and grains per pod<sup>-1</sup> in 2013 compared to 2012, which resulted in a higher grain yield (Table 2). These results may be a reflection of better soil fertility when the experiment was conducted in 2013 (Table 1) than in 2012.

A major concern when distributing fertilizer by the broadcast method has to do with concentrations of P, a nutrient that is immobile in soil and remains in the upper soil layers (0 to 0.05 m), which hinders its uptake by crops (Caires et al., 2003). However, the use of forage grasses that have root systems that explore a greater soil volume and can absorb nutrients at both the soil surface and at depths can provide greater nutrient cycling than may be possible by subsequent crops (Nascente et al., 2012b, 2013); thus, the use of forage grasses could be a viable alternative to minimize the problem of P concentrations at the soil surface. The area where the trials were performed was also used in the integrated crop livestock area; therefore, the rotation of crops and animal foraging could have provided a greater utilization of soil resources (Kluthcouski et al., 2003).

Another concern regarding the use of broadcast fertilization is in areas with inclines and where the indiscriminate removal of soil conservation practices, such as in terraced plots, could lead to significant nutrient losses (Bertol et al., 2007). Therefore, the adoption of soil conservation practices and the use of cover crops are important for minimizing potential losses from excessive rain and runoff (Bezerra and Cantalice, 2006).

Broadcast fertilization for common bean crops is a relatively new research area in Brazil and our results from two years can provide a viable alternative to farmers for improving their operating performance and increasing the grain yield of common bean. Special attention should be given when thinking in broadcast fertilization in very

sloped ground. In this kind of soil it is necessary the use of appropriate soil conservation practices to prevent fertilizer loss, soil erosion, and potential environmental contamination. Besides, the use of broadcast fertilization is a more viable practice in soils with medium to high fertility (Kurihara and Hernani, 2013), and another advantage of using the distribution of fertilizer by broadcasting it on the soil surface without incorporation is the reduced of risk of damage that larger quantities of fertilizers, especially the K effects, can cause to the roots of crops (Kluthcouski and Stone, 2003).

## Conclusion

The application of increasing fertilizer rates broadcast on the soil surface provides significant increases in the number of pods per plant and number of grains per pod and as a result the yield grain of the common bean. The application of 300 kg ha<sup>-1</sup> of fertilizer on the soil surface without incorporation provided similar bean yield as the application of the same fertilizer in the sowing furrow (300 kg ha<sup>-1</sup>). Our results indicate that broadcasting fertilizer on the soil surface without incorporation is a viable management technique that can increase yield of the common bean in no-tillage systems in soil with high fertility. Additional studies are required to determine efficacy of broadcast fertilization without incorporation on bean yield in soils with lower fertility.

## Conflict of Interest

The authors have not declared any conflict of interest.

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