academicJournals

Vol. 10(15), pp. 1840-1851, 9 April, 2015
DOI: 10.5897/AJAR2014.8694
Article Number: 9C1854052484
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

*Full Length Research Paper*

# Soil phosphorus availability and dry bean yield as affected by the application of liquid calcium carbonate micron particles on the furrow

**Adriano Stephan Nascente* and Tarcísio Cobucci**

Brazilian Agricultural Research Corporation (EMBRAPA ), Rice and Beans Research Center, P. O. Box 179, 75375-000, Santo Antonio de Goias, State of Goias, Brazil.

Received 17 March, 2014; Accepted 7 April, 2015

**The application of calcium carbonate micron particles in the planting furrow, because of the reduced particle size may favor a faster reaction in the soil and could provide increased pH and P availability for plants such as dry bean (*Phaseolus vulgaris* L.), potentially increasing yield. A field experiment was conducted for two consecutive years with the objective to evaluate the effect of the liquid calcium carbonate micron particle application in the planting furrow on soil properties (Ph, P, Ca, K and Al content and V) and on the yield components, grain yield, and concentration and content of P in dry bean. The experimental design was a randomized complete block scheme. The treatments consisted of six rates of calcium carbonate micron particles, that is, 0, 1.05, 2.10, 4.2, 8.4 and 12.6 kg ha$^{-1}$ applied in the furrow at sowing of dry bean. Calcium carbonate increased the pH (from 4.8 to 5.3 at 0 to 0.10 m deep layer) and the P concentration in the soil (from 70 to 80 mg dm$^{-3}$ at 0 to 0.10 m deep layer) until 30 days after application. The concentration of Ca, K and the base saturation of the soil were not affected by the addition of calcium carbonate. The concentration (from 4 to 4.3 g kg$^{-1}$) and content (from 1,500 to 1,870 g ha$^{-1}$) of P in the grain and grain yield (from 3,500 to 4,100 kg ha$^{-1}$) of the dry beans increased with increasing concentration of calcium carbonate. The use of calcium carbonate micron particles in the sowing furrow is a new and effective practice that could increase crop yield in no-tillage system (NTS).**

**Key words:** Liming, Cerrado, no-tillage system, faster soil reaction.

## INTRODUCTION

The dry bean (*Phaseouls vulgaris* L.) crop has great economic importance to Brazil because the cultivated area during the 2012/2013 harvest was 3.16 million ha$^{-1}$, which yielded 3.32 million Mg ha$^{-1}$ (CONAB, 2013). However, despite the crop's importance, there was limited use of technology (new cultivars, fertilization,

*Corresponding author. E-mail: adriano.nascente@embrapa.br, Tel: +55 62 3522-2179. Fax +55 62 3533-2100.


**Abbreviations: NTS,** no-tillage system; **SOM,** soil organic matter; **V,** base saturation; **POD,** number of pods m$^{-2}$; **SEED,** number of seeds m$^{-1}$; **W100,** 100-seed weight; **YIELD,** grain yield; **$CaCO_3$,** calcium carbonate; **L,** liming.

irrigation, crop rotation, pest management) during this harvest, especially in the first (Nov-Feb) and second (Feb-May) seasons, which is cultivated mainly by smallholders, resulting in a low productivity average of 1,050 kg $ha^{-1}$. The third season (May-Aug), cultivated in the center of Brazil normally by middle to big farmers, is characterized by high use of technology such as irrigation, liming application, certified seeds and more input of fertilizers (Nascente et al., 2012), in 2012, as a result there was a yield average of 2,529 kg $ha^{-1}$. Based on these results it can be concluded there is big yield gap between use of low and high technology.

One of the factors that is important for highly yield of dry beans is the development of root system which is maximum in a pH range of 6.0 to 6.5 to achieve maximum yield potential (Silva et al., 2004; Fageria et al., 2011). Tropical soils such as the Brazilian Cerrado or the African Savannas are naturally acidic because high levels of rainfall, which over many years has leached basic ions resulting in reduced soil fertility (Caires et al., 2008). According to Souza et al. (2006), tropical soils are highly weathered and are dominated by 1:1 clay minerals such as kaolinite and iron oxides (hematite and goethite) and Al (gibbsite), which have a high P adsorption capacity. In these areas satisfactory cash crop grain yields are dependent on proper liming and soil fertilization (Rosolem, 1994; Caires et al., 2001; Alleoni et al., 2009; Souza et al., 2011). An adequate and balanced supply of nutrients provides suitable crop development with a positive impact on grain yield (Fageria et al., 2011; Mallarino and Pagani, 2012; Crusciol et al., 2013).

Soil acidity limits crop production in many areas of the world due to Al toxicity, phosphorus deficiency, and low base saturation (Fageria and Baligar, 2008; Fageria, 2008). In Brazil, the most common material used for acidity correction is limestone while Ca and Mg silicate is rarely used (Camargo et al., 2007). The application of dolomitic limestone is effective at raising the soil pH, the calcium and magnesium concentration, and the base saturation and at reducing the levels of exchangeable aluminum in the soil (Caires et al., 2003). In tropical areas soil acidity affects land area of about 2.27 billion ha, which is more frequent in Oxisols (South America and Africa) and Ultisols (South America) (Fageria and Nascente, 2014). In these areas, normally the use of dolomitic lime required large amount to increase desired soil pH for dry bean production. Fageria (2008) reported that optimum soil pH for dry bean was 6.5 in no-tillage system (NTS) in Brazilian Oxisol and to achieve this pH an average of 10 Mg lime $ha^{-1}$ is required.

In most grain producing areas under a NTS, in the beginning of the system it is recommended to make the soil correction with incorporation. Then, in the following growing seasons when necessary, soil acidity correction is achieved by applying limestone on the soil surface without incorporation (Soratto and Crusciol, 2008a; Alleoni et al., 2009). However, the reaction of limestone is generally limited to the location of application/ incorporation due to its low mobility in soil. Results of field studies show that the movement of lime in the soil profile varies according to timing and rates of liming, lime application forms, soil type, weather conditions, addition of acidic fertilizers, and cropping systems (Oliveira and Pavan, 1996; Gascho and Parker, 2001; Conyers et al., 2003; Tang et al., 2003; Caires et al., 2008; Sorrato and Crusciol, 2008a,b; Churka et al., 2013). According to Caires et al. (2003), liming, whether surface applied or incorporated into the soil (layer 0 to 0.02 m), provided a more accentuated soil acidity correction in the superficial layer (0 to 0.5 m). However, there was a stronger reaction in the 0.05 to 0.10 and 0.10 to 0.20 m layers when lime was incorporated into the soil. Caires et al. (2005) adds that the effects of surface liming on all three acidity-related variables (pH, Al, and basic cations) were significant at 0 to 0.05 and 0.05 to 0.10 m depths beginning in year 1 and also at the 0.10 to 0.20 m depth only after 2.5 years from application. As a result, there is further delay in the reaction of lime in the soil, especially soon after its application (Caires et al., 1998; Fageria and Baligar, 2008; Soratto and Crusciol, 2008b). Thus, the development of technologies that provide a better environment for crop development may soon complement the application of lime on the soil surface.

The use of nano particles or micron particles could be quite significant, allowing the development of new methods and techniques in various industrial, agricultural, cosmetic, pharmaceutical, textile, and other processes (Lêdo et al., 2007; Siqueira-Batista et al., 2010). However, there is a lack of information regarding the use of small particles of lime in the planting furrow on soil chemical properties and crop response. In Brazil the lime requirement (LR) of soils is calculated for given values of base saturation, using the equation:

$$LR = [CEC * (V_2 - V_1) * (100/ENV)]/100 \qquad (1)$$

In which CEC is the cation exchange capacity, $V_1$ is the base saturation of the soil, $V_2$ is the expected value upon liming and ENV is the effective neutralizing value (Quaggio et al., 1985). The amount of limestone applied will depend on the desired saturation bases, but it usually ranges from 1 to 22 Mg $ha^{-1}$ (Miranda et al., 2005; Caires et al., 2,008; Briedis et al., 2012; Pagani and Mallarino, 2012). While the conventional liming has a particle size of 50% < 0.3 mm and 50% > 0.3 mm the micron particle has a size between from 0.0001 to 0.0002 mm. The intent of limestone broadcast is to correct the whole soil area. With the application of limestone micron particle the intent is to effect only on the sowing furrow which equates to one tenth of the soil area. Further, the intention of applying limestone as micron particle is not to have total soil correction nor to substitute the traditional limestone, but only to have better conditions to the early plant development. Because of the smaller size it is likely that the liquid liming application will provide faster soil reaction in the soil furrow than the traditional liming. However, to the best of our knowledge there is limited research about the use of liquid liming in sowing furrow. The objective of this study was to evaluate the effect of the liquid application of calcium carbonate micron particles in the sowing furrow on the pH, the concentrations of Al, P, K, and Ca, and the base saturation in the soil and on the yield components (number of pods per plant, number of seeds per pod, and mass of 100 seeds), grain yield, concentration, and grain content of dry bean.

## MATERIALS AND METHODS

### Site description

The trial was conducted in 2010 and 2011 at the Guaribas Farm, located in the city of Unaí, MG, Brazil. The geographical coordinates are Latitude: 16° 21' 27" South and Longitude: 46° 54' 22" West, with an altitude of 575 m. The average annual rainfall is approximately 1,200 mm. According to the Köppen classification (Sparovek et al., 2007), the climate is Aw, tropical savanna, and megathermic with a dry winter. During the trials, the average maximum, minimum, and mensal temperatures were 27, 16, and 21.2°C (May); 26, 13, and 19.4°C (June); 27, 12, and 19.2°C (July); and 29, 14, and 21.4°C (August), respectively. The averages of the two years for precipitation were 25 (May), 7 (June), 10 (July), and 12 mm (August).

The experimental area was grown for four years as NTS, with corn cultivated in summer and dry beans in the winter season. The soil was a sandy clay loam (kaolinitic, thermic Typic Haplorthox) with 500 g $kg^{-1}$ clay, 300 g $kg^{-1}$ silt, and 200 g $kg^{-1}$ sand. Before initiating the experiment, the soil chemical characteristics were determined (0 to 20 cm), with the following results: a pH of 4.6; a total soil organic matter content of 15 g $kg^{-1}$; a P (Mehlich 1) of 12.1 mg $kg^{-1}$; exchangeable K (0.51 $mmol_c$ $kg^{-1}$), Ca (2.4 $mmol_c$ $kg^{-1}$), Mg (0.9 $mmol_c$ $kg^{-1}$), and Al (0.3 $mmol_c$ $kg^{-1}$), with a total acidity at pH 7.0 (H+Al) of 3.6 $mmol_c$ $kg^{-1}$; and a base saturation of 51.4%. The aluminum saturation was 3.45%. The soil analysis was performed according to Embrapa (1997). The soil pH was determined in a 0.01 mol $L^{-1}$ $CaCl_2$ suspension (1:2.5 soil/solution). Exchangeable Ca, Mg, and Al were extracted with neutral 1 mol $L^{-1}$ KCl in a 1:10 soil/solution ratio and determined by titration with a 0.025 mol $L^{-1}$ NaOH solution. Phosphorus and exchangeable K were extracted with a (Mehlich 1) extracting solution (0.05 M HCl in 0.0125 M $H_2SO_4$). The extracts were colorimetrically 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). Aluminum saturation was calculated by dividing the Al concentration by the CEC. Using the Equation (1) and aiming a base saturation of 60%, and having an ENV of 70% the LR will be 911 kg $ha^{-1}$. For micron particles on the sowing furrow we calculate an application of 9.11 kg $ha^{-1}$.

### Experimental design and treatments

The experimental design was a randomized complete block design with four replications in both years, which we have new plots each year. The treatments consisted of six rates of liquid calcium carbonate, $CaCO_3$ (0, 1.05, 2.10, 4.20, 8.40, and 12.60 kg $ha^{-1}$) applied in the sowing furrow (0.03 m deep together with the dry bean seed). The plots were 40 $m^2$ (10.0 m x 4.0 m). The useful area of each plot was the two central rows, disregarding the 0.50 m on each end totalizing 9 m².

### Dry bean management

The seeding of the dry bean cultivar Pérola was performed mechanically on May 12, 2010, and May 16, 2011, using no-till seeding (Semeato, model Personale Drill 13, Passo Fundo, RS, Brazil) with a row spacing of 0.50 m and density of 8 pure live seeds $m^{-1}$. The sowing fertilization consisted of 30 kg $ha^{-1}$ N as urea, 39.3 kg $ha^{-1}$ P + 10 kg $ha^{-1}$ N as MAP, monoammonium phosphate and 50 kg $ha^{-1}$ K as potassium chloride and an application of 60 kg N $ha^{-1}$ (urea) at topdressing fertilization at 18 days after emergence (DAE) in both seasons, following recommendation of Sousa and Lobato (2003). The plant management was performed according to the crop needs. The plant emergence occurred at 7 days after sowing in both years. The full flowering stage occurred at 35 and 31 DAE in 2010 and 2011, respectively. The harvest was performed manually after physiological maturation. The dry bean season length was 104 and 101 DAE in the first and second years, respectively.

Liquid calcium carbonate solution (at a size of 0.0001-0.0002 mm and a density of 2,711 g $cm^{-3}$) was applied via a spray directly on the dry bean seeds in the sowing furrow with a StandMax Hunter CS applicator coupled to the planter during the same operation of sowing. The liquid calcium carbonate solution was acquired from a private company, which was created by suspending very finely ground limestone in water. The chemistry of liquid liming materials is the same as that of conventional liming and the rate of reaction and the neutralizing power for liquid lime are the same as for dry materials when particle sizes are the same. Each rate had a different batch of water and lime made up with the appropriate amount of lime in 60 L $ha^{-1}$ of water. The machine used to apply the liquid liming has an agitator to keep the solution in suspension during the application. The area was sprinkler irrigated (center pivot) and the irrigation was schedule based on soil water content (Reichardt, 1987; Doorenbos and Pruitt, 1976).

### Sampling and analyses

#### *Characterization of soil*

A 4.5 cm diameter galvanized-steel auger was used for sampling at depths of 0 to 0.10 and 0.10 to 0.20 m at 15 and 30 days after calcium carbonate application. For each soil horizon, eight subsamples were collected from under the dry bean plant rows and in the middle of the inter-rows (0.25 m from the plant row) of each plot. For each location (in-row and between rows), the eight subsamples were combined into a composite sample. The composite samples were air dried and sieved to pass a 2 mm mesh and later analyzed to determine the pH ($CaCl_2$ 0.01 mol $L^{-1}$), P, Al, Ca, and exchangeable K, as well as the calculated base saturation (V%) and aluminum saturation (%), according to the methodology proposed by Embrapa (1997).

#### *Yield components and grain yield*

The following variables were determined:

a) Number of pods per plant: The number of pods contained in 10 plants randomly collected in each experimental unit at harvest was counted. Next, number of pods per plant was transformed to pods $m^{-2}$.
b) Number of seeds per pod: The number of beans on the 10 plants used to count pods and then the seed number was divided by the number of pods per plant.
c) Mass of 100 seeds: Determined by randomly collecting and weighing 100 seeds from four samples of each experimental unit, seed weight was corrected for moisture to 130 g $kg^{-1}$ (wet basis).

**Table 1.** Analysis of variance of pH, P, Ca, K, Al saturation, and base saturation (V) in the sowing row of the soil at 15 days after calcium carbonate application as a function of blocks, year (Y), $CaCO_3$ (L) and interactions.

| Factors | pH | P | Ca | K | Al | V |
|---|---|---|---|---|---|---|
| | | mg kg$^{-1}$ | ----------------mmol$_c$ kg$^{-1}$------------- | | | % |
| | **Layer 0-0.10 m** | | | | | |
| | **F probability** | | | | | |
| Blocks | 0.081 | 0.256 | 0.599 | 0.523 | 0.331 | 0.124 |
| Year (Y) | 0.087 | 0.123 | 0.325 | 0.212 | 0.439 | 0.510 |
| $CaCO_3$ (L) | 0.001 | 0.001 | 0.117 | 0.267 | 0.016 | 0.798 |
| Y x L | 0.069 | 0.185 | 0.287 | 0.321 | 0.097 | 0.600 |
| Average | 5.0 | 66.1 | 2.9 | 228 | 2.9 | 54.3 |
| | **Layer 0.10-0.20 m** | | | | | |
| | **F probability** | | | | | |
| Blocks | 0.378 | 0.265 | 0.815 | 0.723 | 0.071 | 0.100 |
| Year (Y) | 0.420 | 0.112 | 0.524 | 0.091 | 0.218 | 0.167 |
| $CaCO_3$ (L) | 0.043 | 0.049 | 0.118 | 0.221 | 0.120 | 0.082 |
| Y x L | 0.223 | 0.101 | 0.418 | 0.210 | 0.280 | 0.212 |
| Average | 4.0 | 34.2 | 2.4 | 184 | 1.35 | 44.2 |

d) Grain yield: For this, the usable area was manually harvested, mechanical stripping, and grain weighing in each experimental unit. Then the weight of the harvested grain was calculated and the water content adjusted to 130 g kg$^{-1}$ (wet basis).

### *Concentration and content of P in dry bean seeds*

After the seed harvest, 10 random samples of 100 g of seeds were collected to determine the P concentration. The material was dried in forced ventilation at a temperature of 65°C until it reached constant weight. Then, the grain was ground and analyzed according to the methodology proposed by Malavolta et al. (1997). Briefly, P was extracted with a nitro-perchloric solution and determined by atomic absorption spectrophotometry. We calculated P content (kg ha$^{-1}$) in the seed by multiplying P concentration times the bean yield at 100% dry matter.

### Statistical analysis

The data were subjected to analysis of variance (ANOVA). If F test was significant for calcium carbonate rates then a regression analysis was performed. We used the SAS statistical package (SAS, 1999).

## RESULTS

There was no interaction between years and calcium carbonate among any of the variables evaluated (Tables 1 and 2). The application of calcium carbonate in the sowing row did not affect soil properties between rows at either sampling (15 and 30 days after lime application). However, there were significant differences ($P<0.05$) in pH, P, and Al% at 0 to 0.10 m 15 and 30 days after liquid liming application in the evaluations done in the row. The pH data from within the row sampling were fitted to quadratic equations of two depths evaluated at 15 (Figure 1A) and 30 (Figure 1B) days after calcium carbonate application. Moreover, it was verified that in-row lime application increased the amount of P in the soil up to a rate of 3,793 and 4,926 g calcium carbonate ha$^{-1}$, respectively in the layers 0 to 0.10 and 0.10 to 0.20 m in the evaluation performed 15 days (Figure 2A). When sampled at 30 days (Figure 2B) after liming application P content increased up to a rate of 1,360 and 3,532 g calcium carbonate ha$^{-1}$, respectively in the layers 0-0.10 and 0.10-0.20 m. The Al saturation data were fit to a linear equation at the 0-0.10 m depth in the evaluation performed 15 days, from 2,12 to 0,11% (Figure 3A) after calcium carbonate application. There was a linear effect in both layers (0 to 0.10, from 4.37 to 1.53% and 0.10 to 0.20 m, from 4.31 to 1.73%) at 30 days after liming application (Figure 3B).

Regarding yield components, only the number of pods m$^{-2}$ was affected by calcium carbonate application (Figure 4). The grain yield was fitted to a second-degree polynomial equation, with higher values (4,147 kg ha$^{-1}$) at a rate of 8.02 kg ha$^{-1}$ of calcium carbonate (Figure 5). In the P concentration (Figure 6) and P accumulation (Figure 7) variables in the dry bean seeds, the data fit to a quadratic plateau model. For P concentration the highest value (4.38 g kg$^{-1}$) was achieved at rate 4.99 kg ha$^{-1}$ of calcium carbonate and for P accumulation the highest value (18,686 kg ha$^{-1}$) was obtained at rate 6.59 kg ha$^{-1}$ of calcium carbonate.

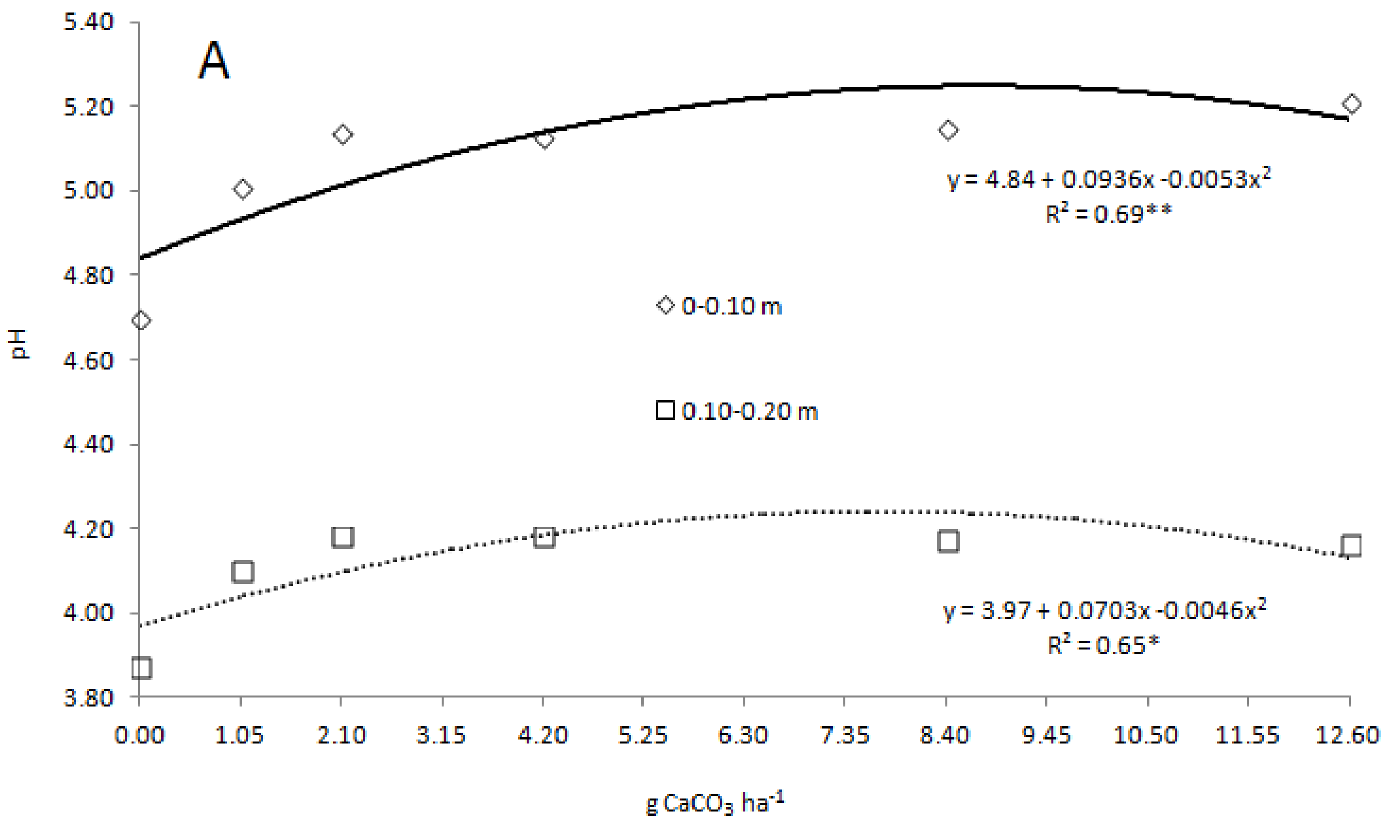
**Table 2.** Analysis of variance of pH, P, Ca, K, Al saturation, and base saturation (V) in the sowing row of the soil at 30 days after calcium carbonate application and POD (n. pods $m^{-2}$), SEED (n. seed $pod^{-1}$), W100 (100 grain weight), YIELD (grain yield), $P_{conc}$ (P concentration), and $P_{cont}$ (P content) of dry bean as a function of blocks, year (Y), $CaCO_3$ (L) and interactions.

| Factors | Variables | | | | | |
|---|---|---|---|---|---|---|
| | Layer 0-0.10 m | | | | | |
| | pH | P | Ca | K | Al | V |
| | | mg $kg^{-1}$ | ----------------mmol$_c$ $kg^{-1}$------------- | | | % |
| | F probability | | | | | |
| Blocks | 0.097 | 0.632 | 0.770 | 0.084 | 0.415 | 0.718 |
| Year (Y) | 0.212 | 0.091 | 0.520 | 0.181 | 0.513 | 0.216 |
| $CaCO_3$ (L) | 0.001 | 0.001 | 0.891 | 0.334 | 0.001 | 0.717 |
| Y x L | 0.184 | 0.081 | 0.599 | 0.202 | 0.415 | 0.177 |
| Average | 4.5 | 16.3 | 2.4 | 154 | 4.5 | 49.1 |
| | Layer 0.10-0.20 m | | | | | |
| | F probability | | | | | |
| Blocks | 0.147 | 0.351 | 0.067 | 0.219 | 0.348 | 0.555 |
| Year (Y) | 0.198 | 0.112 | 0.328 | 0.097 | 0.087 | 0.181 |
| $CaCO_3$ (L) | 0.001 | 0.029 | 0.277 | 0.528 | 0.001 | 0.811 |
| Y x L | 0.318 | 0.218 | 0.310 | 0.187 | 0.101 | 0.213 |
| Average | 4.2 | 7.4 | 2.5 | 103 | 5.8 | 42.2 |
| | Variables | | | | | |
| **Factors** | **POD** | **SEED** | **W100** | **YIELD** | **$P_{conc}$** | **$P_{cont}$** |
| | F probability | | | | | |
| Blocks | 0.314 | 0.359 | 0.999 | 0.999 | 0.999 | 0.999 |
| Year (Y) | 0.104 | 0.247 | 0.245 | 0.114 | 0.281 | 0.097 |
| $CaCO_3$ (L) | 0.002 | 0.999 | 0.999 | 0.001 | 0.047 | 0.024 |
| Y x L | 0.062 | 0.846 | 0.987 | 0.1305 | 0.323 | 0.087 |
| Average | 291.9 | 4.78 | 27.9 | 3,826 | 4.12 | 1.68 |

## DISCUSSION

The variable analyzed in soil samples between the plant rows was unaffected by the application of calcium carbonate and also Ca, K, Al saturation, and base saturation at both layers in rows. These results indicate that the action of the calcium carbonate in micron particles occurred only near the application area. Furthermore, the low amount of liming material applied (12.6 kg $ha^{-1}$ at the maximum rate used) was not enough to cause significant changes in these nutrients, which usually ranges from 1 to 22 Mg $ha^{-1}$ (Miranda et al., 2005; Caires et al., 2008; Briedis et al., 2012; Pagani and Mallarino, 2012).

There was a greater P availability in the sowing furrow in the two periods after the calcium carbonate application, which may be due to the release of P fixed to Al or Fe (Souza et al., 2006). Fageria (2009) reported that Mehlich 1 extracting P increased significantly in no-tillage system when soil pH was raised from 5 to 7.5 in the Brazilian Oxisol. Lopes and Cox (1979) add that the process of P adsorption by the oxides, hydroxides and oxyhydroxides of iron and aluminum is among the main factors involved in the insolubilization of this nutrient in tropical soils. Thus, it is likely that the application of lime in the planting furrow caused the precipitation of Al and Fe in the forms of $AlOH_3$ and $FeOH_3$ and provided the increased availability of P in the early crop development only in this sowing furrow, which provided better condition to the plant development. The increase in the soil pH by liming increases the activity and concentration of the $OH^-$ ion in the soil solution, and it promotes the precipitation of Fe and Al, reducing the precipitation of P-Fe and P-Al (Mendez and Kamprath, 1978; Mcbride, 1994; Alleoni et al., 2009). It is noteworthy that the calcium in high pH (above 6.0-6.5) can form compounds with the phosphorus and precipitate it, which made P unavailable to plants. However, the pH values for the occurrence of these reactions are rarely found in soils under Cerrado (Malavolta et al., 1997). These results (precipitation of Fe and Al) were confirmed when it was found that increasing the rate of limestone in the furrow provided increases in the pH and reduced Al saturation in the 0 to 0.10 m layer. Davenport and Bair (2012) also reported an increased P



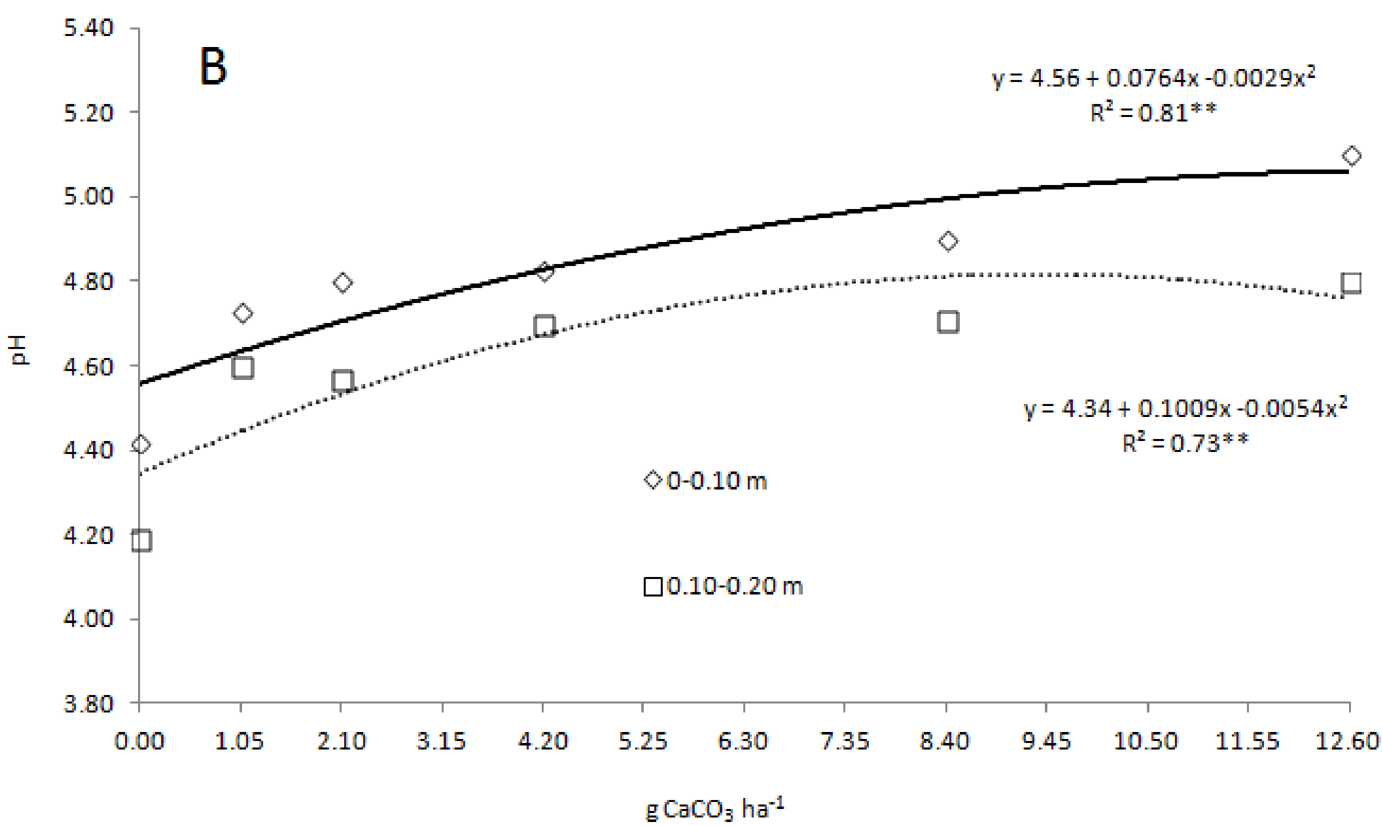




**Figure 1.** pH values within the rows at 0-0.10 and 0.10 to 0.20 m soil layers as affected by the calcium carbonate rates at 15 (A) and 30 (B) days after application. Average of two growing seasons (2010 and 2011).

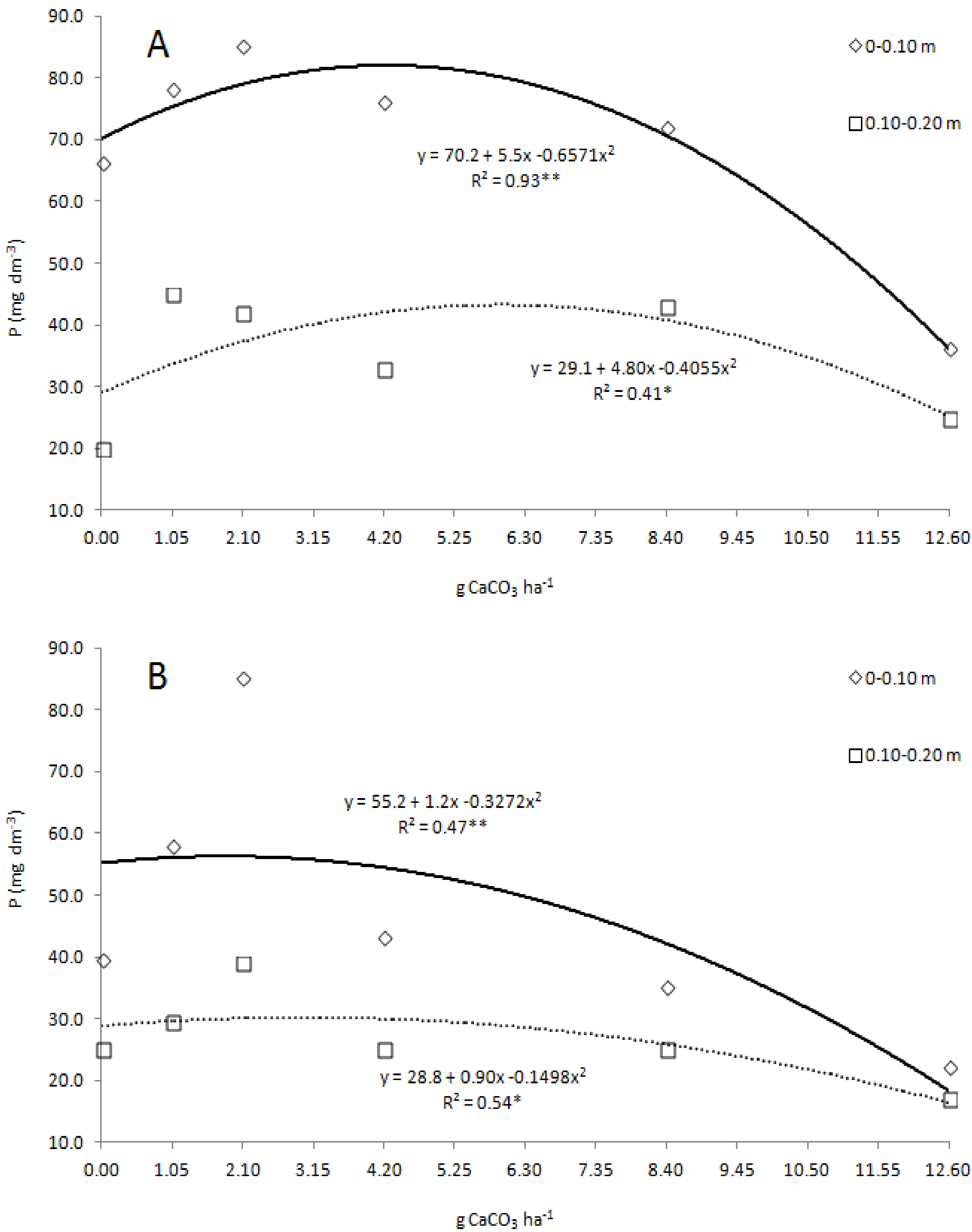



**Figure 2.** P values within the rows at 0-0.10 and 0.10 to 0.20 m soil layers as affected by the calcium carbonate rates at 15 (A) and 30 (B) days after application. Average of two growing seasons (2010 and 2011).

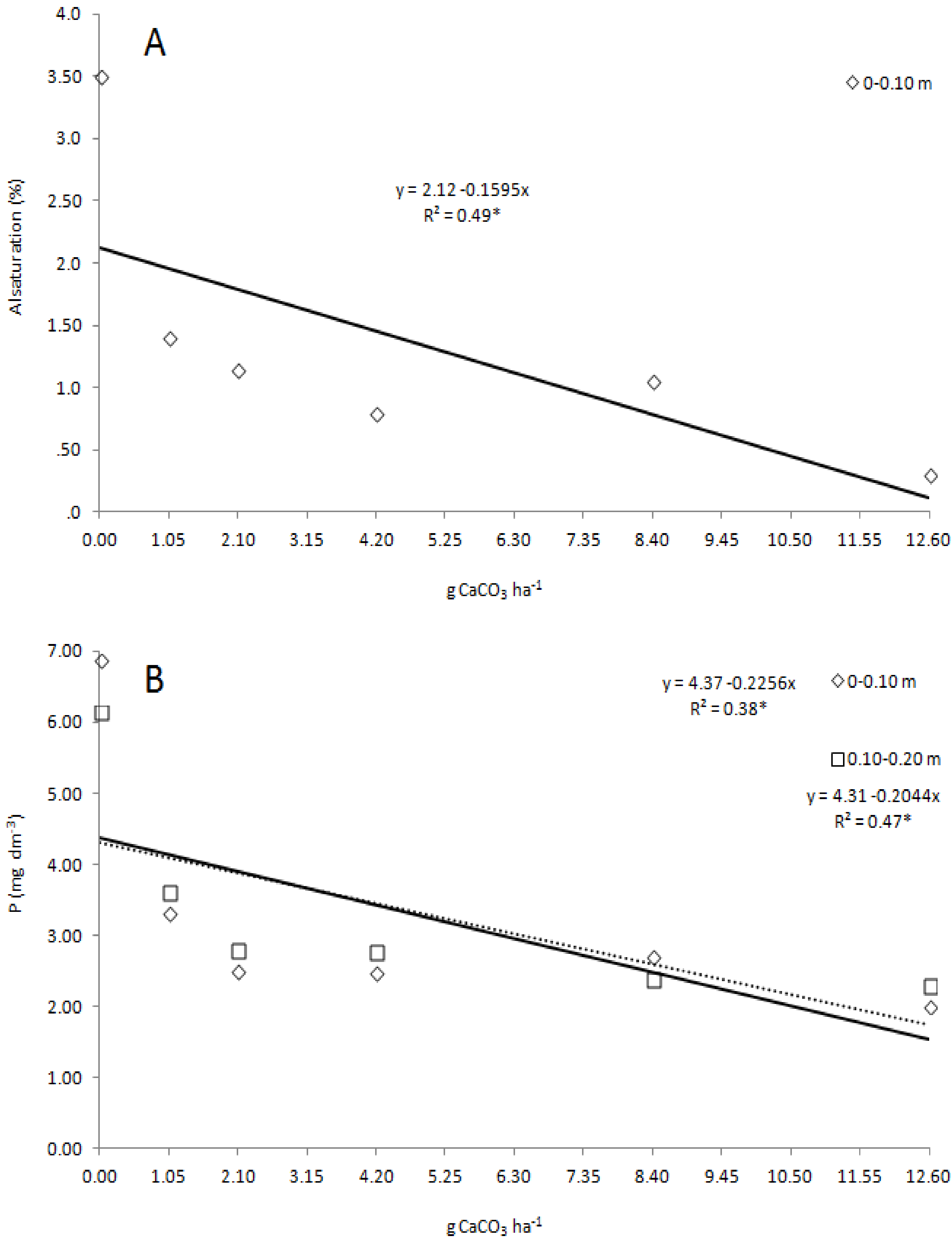



**Figure 3.** Al saturation values within the rows at 0-0.10 and 0.10 to 0.20 m soil layers as affected by the rates of calcium carbonate at 15 (A) and 30 (B) days after application. Average of two growing seasons (2010 and 2011).

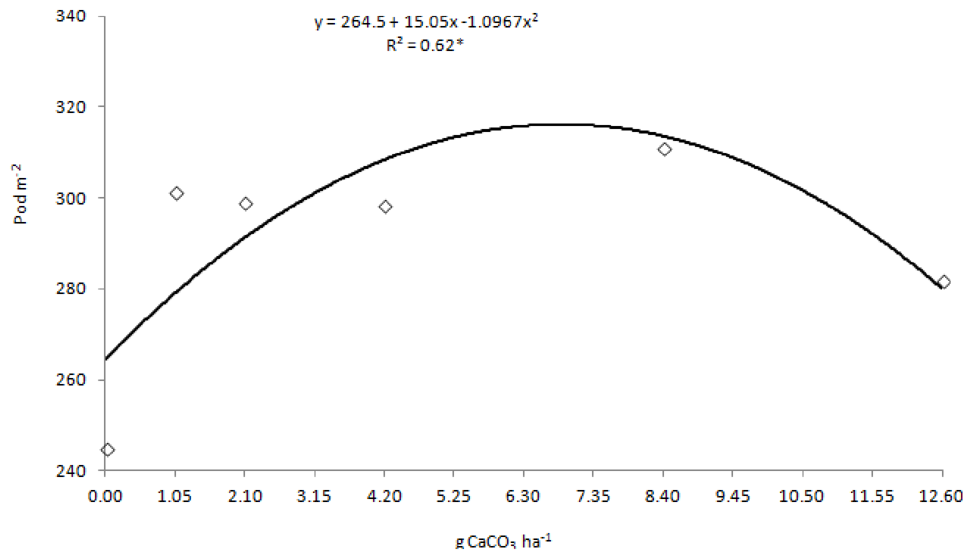



**Figure 4.** Number of pods $m^{-2}$ of dry bean as affected by calcium carbonate rates. Average of two growing seasons (2010 and 2011).

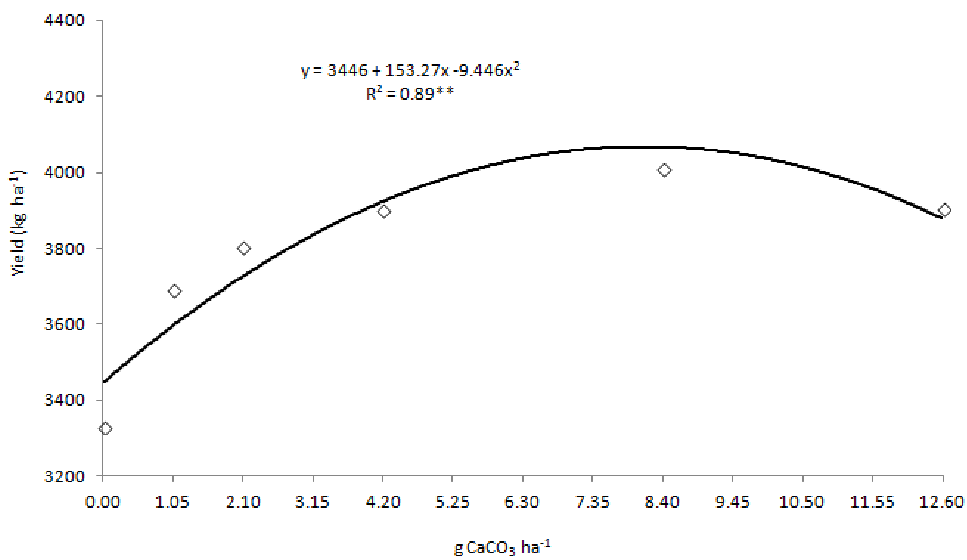



**Figure 5.** Grain yield of dry bean as affected by calcium carbonate rates. Average of two growing seasons (2010 and 2011).

availability with increasing pH when the initial pH is low. Our results allow us to conclude that the application of calcium carbonate micron particles can provide a faster reaction in the planting furrow than the traditional liming applied at the soil surface without plowing, which normally take one year to correct the soil acidity at the depth 0 to 0.05 m (Caires et al., 2003, 2005). The liquid liming provided a greater availability of P in the furrow in the early stages of plant development. As a suggestion for new research application of conventional lime to the surface and liquid lime in the sowing furrow until the conventional lime has a chance to increase pH is a potential area of study. Thus, this combination with traditional liming and liquid liming can provide more promising results than simply applying liming on the soil surface, which, in NTS, takes even longer to react with the soil (Caires et al., 2008; Briedis et al., 2012).

Increasing the amount of lime increased the number of pods produced and as a result increased the grain yield. The number of pods is the yield component that most affects the grain yield (Valderrama et al., 2009; Nascente et al., 2012). Furthermore, the increase in grain yield may have been due to the greater P availability for the dry bean crop at the early development stage. Phosphorus

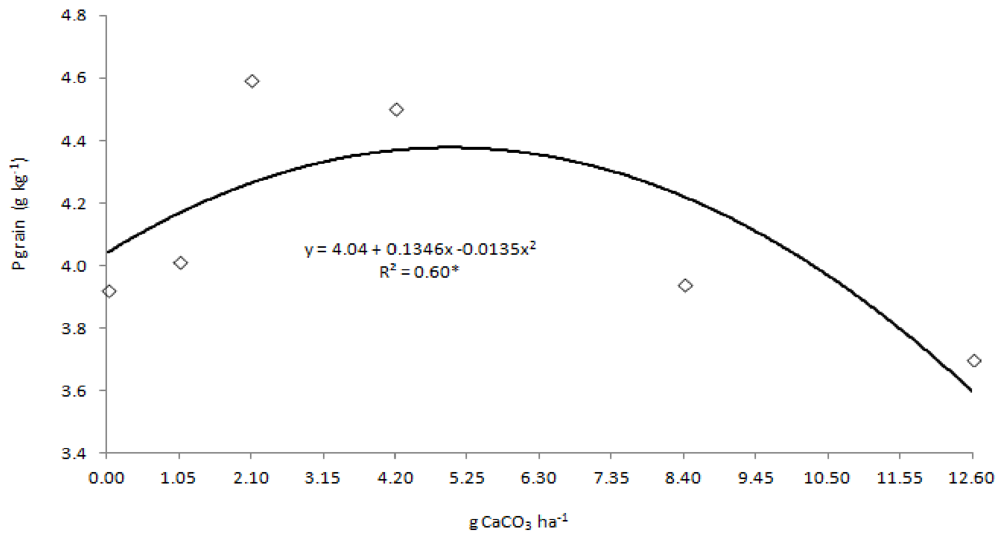



**Figure 6.** Phosphorus concentration of dry bean grains as affected by calcium carbonate rates. Average of two growing seasons (2010 and 2011).

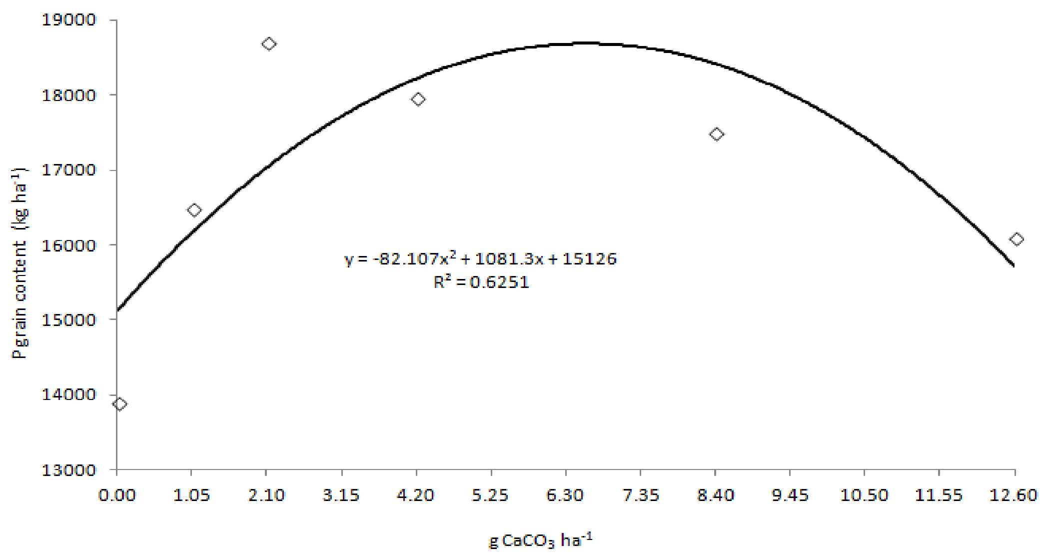



**Figure 7.** Phosphorus content of dry bean grains as affected by calcium carbonate rates. Average of two growing seasons (2010 and 2011).

availability in dry bean crops has shown significant positive responses in grain yield (Miranda et al., 2000; Silva et al., 2001; Zucareli et al., 2011). Valderrama et al. (2009), working with dry bean cv. Perola at NTS, reported a crop response to a rate of 120 kg ha$^{-1}$ of P. However, in our trial there are others factors that influenced the dry bean yield once the P data showed that the highest P levels occurred near the 2.1 kg rate. On the other hand, the highest yield of the pods and grain were at the 8.4 kg rate. It could be the decrease in soluble Al or the increase in the availability of Ca, Mg and K to the soil or other not evaluated causes. According to Caires et al. (2008) the liming application provides increasing in the soil availability of P, Ca, Mg and K, which causes reduction in the Al content and increases pH levels.

## Conclusions

The application of small amounts of lime in the form of micron particles was efficient at increasing the availability of P, raising the pH of the soil, reducing the saturation of

Al in the planting furrow, and increasing the yield and the concentration and accumulation of nutrients in the grain.

## Conflict of Interest

The authors have not declared any conflict of interest.

### REFERENCES


Alleoni LRF, Cambri M, Caires EF, Garbuio FJ (2009). Acidity and aluminum speciation as affected by surface liming in tropical no-till soils. Soil Sci. Soc. Am. J. 74(3):1010-1017.

Bair KE, Davenport JR (2012). Influence of recent acidification on available phosphorus indices and sorption in Washington State soils. Soil Sci. Soc. Am. J. 76(2):515-521.

Churka Blum S, Caires EF, Alleoni LRF (2013). Lime and phosphogypsum application and sulfate retention in subtropical soils under no-till system. J. Soil Sci. Plant Nutr. 13(2):279-300.

Briedis C, Sá JCM, Caires EF, Navarro JF, Inagaki TM, Boer A, Ferreira AO, Quadros Neto C, Canalli LB, Santos JB (2012). Changes in organic matter pools and increases in carbon sequestration in response to surface liming in na oxisol under long-term- no-till. Soil Sci. Soc. Am. J. 76(1):151-160.

Caires EF, Chueiri WA, Madruga EF, Figueiredo A (1998). Changes in soil chemical characteristics by surface application of lime and gypsum and soybean response in no-tillage system. Rev. Bras. Cienc. Solo, 22(1):27-34.

Caires EF, Fonseca AF, Feldhaus IC, Blum J (2001). Root growth and nutrient uptake by soybean as affected by lime and gypsum, under a no-tillage system. Rev. Bras. Cienc. Solo, 25(4):1029–1040.

Caires EF, Blum J, Barth G, Garbuio FJ, Kusman MT (2003). Changes in chemical soil characteristics and soybean response to lime and gypsum applications in a no-tillage system. Rev. Bras. Cienc. Solo, 27(2):275-286.

Caires EF, Alleoni LRF, Cambri MA, Barth G (2005). Surface application of lime for crop grain production under a no-till system. Agron. J. 97(3):791–798.

Caires EF, Garbuio FJ, Churka S, Barth G, Correa JCL (2008). Effect of soil acidity amelioration by surface liming on no-till corn, soybean and wheat root growth and yield. Eur. J. Agron. 28(1):57–64.

Camargo MS, Pereira HS, Korndörfer GH, Queiroz AA, Reis CB (2007). Soil reaction and absorption of silicon by rice. Sci. Agric. 64(2):176-180.

CONAB (2013). Acompanhamento de safra brasileira: grãos, décimo segundo levantamento, setembro 2013 / Companhia Nacional de Abastecimento. Brasília: Conab, 2011. Disponível em: < http://www.conab.gov.br/OlalaCMS/uploads/arquivos/13_10_16_14_32_01_boletim_portugues_-_setembro_2013.pdf>. Accessed in October 22nd, 2013.

Conyers MK, Heenan DP, McGhie WJ, Poile GP (2003). Amelioration of acidity with time by limestone under contrasting tillage. Soil Till Res. 72(1):85-94.

Crusciol CAC, Nascente AS, Soratto RP, Rosolem CA (2013). Upland rice growth and mineral nutrition as affected by cultivars and sulfur availability. Soil Sci. Soc. Am. J. 77(1):328-335.

Doorenbos J, Pruitt WO (1976). Las necesidades de agua de los cultivos. FAO, Roma (Estúdio FAO Riego y Drenage, P. 24).

EMBRAPA (1997). Manual of soil analysis methods. National Research Center of Soil, Rio de Janeiro, RJ, Brazil.

Fageria NK (2008). Optimum soil acidity indices for dry bean production on an Oxisol in no-tillage system. Commun. Soil Sci. Plant Anal. 39(5/6):845-857.

Fageria NK, Baligar VC (2008). Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. Adv. Agron. 99:345–399.

Fageria NK (2009). The use of nutrients in crop production. CRC Press, Boca Raton, Florida.

Fageria NK, Baligar VC, Jones CA (2011). Growth and mineral nutrition of field crops. CRC Press, Boca Raton, FL.

Fageria NK, Nascente AS (2014). Management of Soil Acidity of South American Soils for Sustainable Crop Production. Adv. Agron. 128:221-275.

Gascho GJ, Parker MB (2001). Long-term liming effects on Coastal Plain soils and crops. Agron. J. 93(6):1305-1315.

Lêdo JCS, Hossne WS, Pedroso MZ (2007). Introduction to nanotechnology-provoked bioethical questions. Bioethikos 1:61-67.

Lopes AS, Cox FR (1979). Relação de características físicas, químicas e mineralógicas com fixação de fósforo em solos sob cerrados. Rev. Bras. Cienc. Solo 3(1):82-88.

Malavolta E, Vitti GC, Oliveira SA (1997). Avaliação do estado nutricional das plantas: princípios e aplicações. 2nd ed. POTAFOS, Piracicaba, SP, Brazil.

McBride MB (1994). Environmental chemistry of soils. University Press, New York.

Mendez J, Kamprath J (1978). Liming of latosols and the effect on phosphorus response. Soil Sci. Soc. Am. J. 42(1):86-88.

Miranda LN, Azevedo JA, Miranda JCC, Gomes AC (2000). Productivity of dry bean in relation to phosphate fertilizer and irrigation in a Cerrado soil. Pesq. Agropec. Bras. 35(4):703-710.

Miranda LN, Miranda JCC, Rein TA, Gomes AC (2005). Lime under no-tillage and conventional planting systems for soybean and corn in Red Latosol (Oxisol). Pesq. Agropec. Bras. 40(6):563-572.

Nascente AS, Kluthcouski J, Crusciol CAC, Cobucci T, Oliveira P (2012). Fertilization of dry bean cultivars in tropical lowlands. Pesq. Agropec. Trop. 42(4):407-415.

Oliveira EL, Pavan MA (1996). Control of soil acidity in no-tillage system for soybean production. Soil Tillage Res. 38(1/2):47-57.

Pagani A, Mallarino AP (2012). Soil pH and crop grain yield as affected by the source and rate of lime. Soil Sci. Soc. Am. J. 76(5):1877-1886.

Quaggio JA, van Raij B, Malavolta E (1985). Alternative use of the SMP-buffer solution to determine lime requirement of soils. Com. Soil Sci. Plant Anal. 16(3):245-260.

Reichardt K (1987). The water in agricultural system. Manole, São Paulo, SP, Brazil.

Rosolem CA, Assis JS, Santiago AD (1994). Root growth and mineral nutrition of corn hybrids as affected by phosphorus and lime. Commun. Soil Sci. Plant Anal. 25(13/14):2491–2499.

Rosolem CA, Rosseto CAV, Fernandes DM, Ishimura I (1993). Potassium fertilization, root morphology and potassium absorption by soybean. J. Plant Nutr. 16(3):479–492.

SAS Institute (1999). Procedure guide for personal computers. Version 5. Cary, USA.

Silva EB, Resende JCF, Cintra WBR (2001). Response of dry bean to phosphorus doses in sandy soil. Cienc. Rural 31(6):973-977.

Silva LM, Lemos LB, Crusciol CAC, Feltran JC (2004). Root system of dry bean cultivars as response of liming. Pesq. Agropec. Bras, 39(7):701-707.

Siqueira-Batista R, Silva LM, Souza RRM, Prado HJP, Silva CA, Roças G, Oliveira AL, Helayel-Neto JA (2010). Nanoscience and nanotechnology as topical themes for a discussion on science, technology, society and environment. Cienc. Edu. 16(2):479-490.

Soratto RP, Crusciol CAC (2008a). Chemical soil attributes as affected by lime and phosphogypsum surface application in a recently established no-tillage system. Rev. Bras. Cienc. Solo 32(2):675-688.

Soratto RP, Crusciol CAC (2008b). Dolomite and phosphogypsum surface application effects on annual crops nutrition and yield. Agron. J. 100(2):261–270.

Sousa DMG Lobato E (2003) Cerrado: soil correction and fertilization. Embrapa Cerrados, Planaltina, DF, Brazil.

Souza FS, Faquin V, Torres PRF, Baliza DP (2006). Liming and organic fertilizer: influence on phosphorus adsorption in soils. Rev. Bras. Cienc. Solo 30(6):975-983.

Souza HA, Natale W, Rozane DE, Hernandes A, Romualdo LM (2011). Liming and fertilization with boron in production of bean. Rev. Cienc. Agron. 42(2):249-257.

Sparovek G, De Jong van Lier Q, Dourado Neto D (2007). Computer assisted Köppen climate classification for Brazil. Int. J. Climatol. 27(2):257-266.

Tang C, Rengel Z, Diatloff E, Gazey CR (2003). Responses of wheat and barley to liming on a sandy soil with subsoil acidity. Field Crop

Res. 80(3):235-244.
Valderrama M, Buzetti S, Benett CGS, Andreotti M, Arf O, Sá ME (2009). Sources and doses of nitrogen and phosphorus in no till dry beans. Pesq. Agropec. Trop. 39(3):191-196.
Zucareli C, Prando AM, Ramos Jr EU, Nakagawa J (2011). Phosphorus on the productivity and seed quality of bean Carioca Precoce cultivated during the rainy season. Cienc. Agron. 42(1):32-38.