



## **Phosphate Fertilization in Amaranth Culture cv. BRS Alegria in Second Harvest in the Cerrado**

**Fábio Kempim Pittelkow<sup>1\*</sup>, Aloisio Bianchini<sup>2</sup>, Pedro Silvério Xavier Pereira<sup>3</sup>,  
Luana Maria de Rossi Belufi<sup>1</sup>, Maria das Graças de Assis Bianchini<sup>4</sup>  
and Rodrigo Pengo Rosa<sup>1</sup>**

<sup>1</sup>*Foundation for Research and Technological Development Rio Verde, Lucas do Rio Verde, Mato Grosso, Brazil.*

<sup>2</sup>*Department of Agronomy and Zootechny, Federal University of Mato Grosso, Cuiaba, Mato Grosso, Brazil.*

<sup>3</sup>*Department of Tropical Agriculture, Federal University of Mato Grosso, Cuiaba, Mato Grosso, Brazil.*

<sup>4</sup>*Department of Nutrition, Federal University of Mato Grosso, Cuiaba, Mato Grosso, Brazil.*

### **Authors' contributions**

*This work was carried out in collaboration among all authors. Authors FKP and LMRB performed the experiment and wrote the first draft of the manuscript. Authors AB, MGAB, PSXP and RPR discussed the results, corrected and improved the writing of the manuscript in Portuguese and English versions. All authors read and approved the final manuscript.*

### **Article Information**

DOI: 10.9734/JEAI/2019/v39i430339

#### Editor(s):

(1) Dr. Peter A. Roussos, Assistant Professor, Laboratory Pomology, Agricultural University of Athens, Greece.

#### Reviewers:

(1) Jaime Cuauhtemoc Negrete, Autonomous Agrarian Antonio Narro University, Mexico.

(2) Grace O. Tona, Ladoke Akintola University of Technology, Nigeria.

(3) Akinyemi Bosede Kemi, Benue State University, Nigeria.

Complete Peer review History: <http://www.sdiarticle3.com/review-history/49828>

**Original Research Article**

**Received 28 April 2019**

**Accepted 07 July 2019**

**Published 24 July 2019**

### **ABSTRACT**

Vegetable species, capable of diversifying production in the second crop of the Cerrado, producing grains rich in protein and providing dry matter for off-season, are most welcome. The amaranth presents these characteristics, however its cultivation is little known in Brazil. The adequate availability of nutrients for this plant, under cerrado conditions, has not yet been defined and these soils, in turn, are of low natural fertility, deficient, mainly, in phosphorus. Before this senary, the present work was developed with the objective of evaluating agronomic and productive aspects of amaranth cv. BRS Alegria, cultivated in succession to soybean, underwent increasing doses of

\*Corresponding author: E-mail: [fabio@fundacaorioverde.com.br](mailto:fabio@fundacaorioverde.com.br);

phosphorus. The experimental design was a randomized complete block design with five levels of phosphorus (0, 30, 60, 100 and 150 kg.ha<sup>-1</sup> of phosphorus - triple superphosphate) applied in the sowing furrow, with four replications. Plant height was evaluated; stem diameter; panicle length; final population of plants; phosphorus content in leaf tissue; mass of dry matter of panicle, stem, leaf and total and; grain yield. The model with higher R<sup>2</sup> in the regression analysis was selected to express the behavior of the phosphorus doses on the evaluated characteristics. The phosphorus applied in the sowing furrow increases productivity and phosphorus content in the amaranth foliar tissue in succession to the soybean crop. The highest estimated productivity of amaranth grains was obtained with 98.7 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>, with values close to the level of economic response to the application of the input.

**Keywords:** *Amaranthus cruentus*; biomass and grain yield; phosphate.

## 1. INTRODUCTION

The agricultural exploration in the Brazilian Cerrado is structured in the cultivation of soybean, corn and cotton in succession crop/second crop. The insertion of new plant species producing high aggregate and residual value of straw in appreciable quantity and quality, aiming the maintenance of the system throughout the agricultural years is a necessity. In this sense, the amaranth culture presents favorable development under conditions of high temperatures and low precipitation [1], with biomass production and forage potential [2] and [3].

The cultivation of amaranth, still incipient in Brazil, presents the perspective of establishing itself as an alternative for the rotation of crops, diversifying the productive systems and creating opportunity for healthier diets [4].

In Brazil, Embrapa Cerrados (DF) tested several amaranth genetic materials for food production, grain diversification and green manuring in the off-season, as well as no-till use [5,6,7]. The cultivar BRS Alegria is available for seed commercialization [3]. Early sowing and the occurrence of rainfall in April and May contribute to the development of cover crops in the off season [8].

Grains and leaves of amaranth have high crude protein levels ranging from 18.88% [9] to 21.92% [10], allied to the high biological quality measured by the essential amino acids, also supplying fibers and minerals, mainly calcium. Therefore, the demand for and insertion of this pseudocereal in foods for healthy eating grows [11,12,13]. With the greater demand for healthier diets, especially for people with gluten intolerance, amaranth grain can be used in the

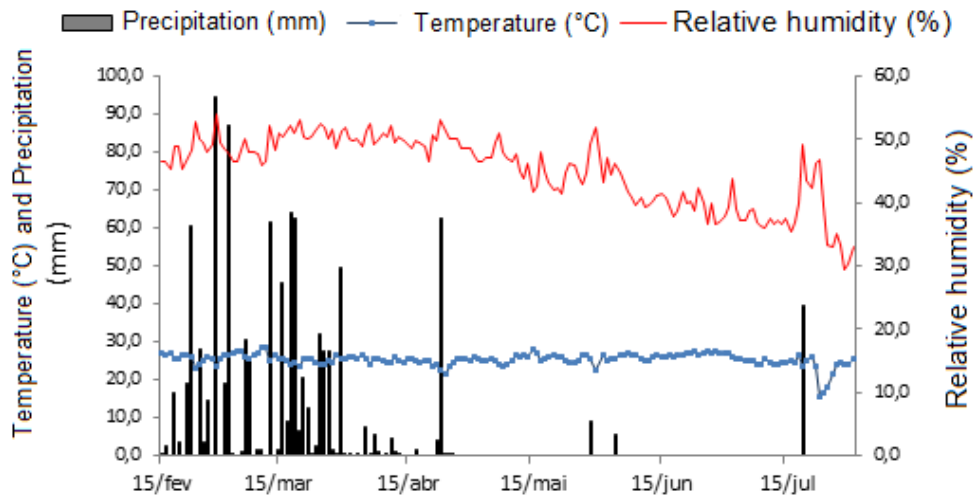
manufacture of flour, breakfast cereals, pasta and biscuits [11,12,14].

The Brazilian soils are of low natural fertility, especially in phosphorus (P), because the clay fraction has minerals with high adsorption capacity of this element and the strong interaction of the element with the soil [15,16]. Phosphorus is found at low concentrations in the soil solution, causing limitation of biomass productivity in tropical soils [15]. In the literature, the reported cases where the effect of P doses on amaranth culture [17] and [18] were studied under field conditions. Therefore, the information on residual P, after soybean cultivation, is not sufficient for a correct positioning on its management in the amaranth culture in succession, when aiming at economic yield.

The objective of this work was to evaluate the agronomic and productive aspects of amaranth cv. 'BRS Alegria' cultivated in succession to soybean cultivation under increasing doses of P in Dystrophic Yellow Red Latosol in Lucas do Rio Verde, Mato Grosso, Brasil.

## 2. MATERIALS AND METHODS

The experiment was installed at the Rio Verde Technological Research and Development Foundation, located at the geographical coordinates 12°59'48 "S and 55°57'49" W, with an altitude of 387 meters, in the municipality of Lucas do Rio Verde – Mato Grosso, Brasil, on a dystrophic Yellow Red Latosol [19], in no-till sowing of the soybean crop. Chemical and granulometric analysis (0 to 0.2m depth) revealed the following results: pH in CaCl<sub>2</sub> = 5.5; P = 12.1 mg dm<sup>-3</sup>; K = 109.0 mg dm<sup>-3</sup>; Ca<sub>2</sub> + = 2.5 cmolc dm<sup>-3</sup>; Mg 2 + = 1.1 cmolc dm<sup>-3</sup>; Al<sub>3</sub> + = 0.0 cmolc dm<sup>-3</sup>; H + Al = 2.5 cmolc dm<sup>-3</sup>; V% = 61; Sand = 571 g kg<sup>-1</sup>; Silt = 104 g kg<sup>-1</sup> and Clay = 325 g kg<sup>-1</sup>.



**Fig. 1. Mean daily temperature (°C), atmospheric relative humidity (%) and total daily rainfall (mm) between 15/02 and 26/07/2013 in Lucas do Rio Verde, Mato Grosso, Brazil**

The experimental design was in randomized complete blocks, with five treatments and four replications. The treatments consisted of five doses of P applied in the pre-sowing groove (0, 30, 60, 100 and 150 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>, in the form of triple superphosphate) after demarcation of plots and rows of sowing. The experimental plot consisted of five rows of sowing, 5.0 m long and spaced 0.45 m apart. The meteorological data of temperature, atmospheric relative humidity and rainfall during the execution of the experiment are in Fig. 1.

Seeding was performed on 05/03/2013 manually by adopting the seed mix with sand, in the proportion of 1:250, and a device made with disposable bottles (PET) with a hole in the lid (Fig. 2) allowing sowing in the appropriate quantity of the mixture aiming to reach the population of 180,000 plants per hectare.



**Fig. 2. Apparatus developed for sowing amaranth using pet bottle in Lucas do Rio Verde, Mato Grosso, Brazil**

Pest and disease control was performed as needed through periodic assessments. Weed control was performed by desiccation before sowing with 2.0 L ha<sup>-1</sup> glyphosate. They were applied from 0.5 L ha<sup>-1</sup> of haloxifope® to the control of monocotyledonous plants at 25 days after emergence (DAE) and manual weeding to control dicotyledons. At 20 DAE, manual thinning of the plants was performed aiming at plant density of 180,000 plants per hectare. At 25 DAE, 60 and 60 kg ha<sup>-1</sup> of N and K<sub>2</sub>O in the form of urea and potassium chloride, respectively, were applied.

The evaluated characteristics were: plant height (AP, in meters); stem diameter (DC, in millimeters); panicle length (CP, in millimeters); mass of panicle dry matter (MSP, in g); mass of the stem dry matter (MSC, in g); mass of leaf dry matter (MSF, in g); mass of the total dry matter (MST, in g); final population of plants (POP, in plants ha<sup>-1</sup>); phosphorus content in leaf tissue (P content in mg kg<sup>-1</sup>) and productivity (PROD, in kg ha<sup>-1</sup>).

For the evaluation of the P content in the leaf tissue, sampling was performed at 55 DAE, according to Fig. 3. The collected material was ground (Willey, sieve with a mesh of 0.33 mm) for laboratory determinations. The concentration of phosphorus (P) was determined according to Malavolta et al. [20]. For the evaluation of AP, DC, CP, MSP, MSC, MSF, five plants were sampled in the two central lines of each plot at 90 DAE. The agronomic components were separated and subjected to drying in a forced ventilation oven at 65°C until reaching a constant

mass and then weighed. MST was obtained from the sum of MSP, MSC and MSF.

For the evaluations of POP and PROD were considered all plants of two central lines of the plot, neglected three lateral lines and 1.5 m of the extremities. The harvested material was manually harvested and the grain cleaning performed through a wind tunnel adapted to a domestic fan.

The dose to obtain the maximum economic efficiency of P was calculated by equating the first derivative of the regression equation with the relation between input prices (US\$/kg P<sub>2</sub>O<sub>5</sub>) and product (US\$/kg amaranth grains) [21]. The price considered in the analysis for source of phosphorus was the one practiced in Lucas do Rio Verde-MT and converted to US\$ in December 2013, at US\$ 2.32. For amaranth grains, the value considered was US\$ 5.00/kg of grains, raised in retail as being the average price paid to the grain producer in Brasília, DF.

The experimental data were submitted to analysis of variance and regression, when significant F was the Tukey test at 5% probability for comparison of means. The significant regression model with the highest coefficient of determination was selected to express the behavior of the P doses on the characteristics evaluated through the SisVar v.4.2 computational application [22].

### 3. RESULTS AND DISCUSSION

The plant population remained within the expected range in all experimental plots (Fig. 4),



32 DAE

with 177,000 plants.ha<sup>-1</sup> or 17.7 plants.m<sup>-2</sup>, justified by coefficients of variation below 10%.

No significant effects were observed on plant height, stem diameter, panicle length and dry matter of the panicle as a function of the application of different doses of P in 'BRS Alegria' amaranth (Table 1). There was, however, a tendency to increase plant height and stem diameter from the 30 kg ha<sup>-1</sup> dose of P relative to the control. The effects on these parameters can also be explained by the decomposition of the soybean residues and the fertilizations used in previous years, resulting in the P content in soil of 12.1 mg dm<sup>-3</sup>, which is considered as a compliant medium [23].



Fig. 3. Leaf sampling in *Amaranthus cruentus* cv. 'BRS Alegria' in Lucas do Rio Verde, Mato Grosso, Brazil



47 DAE





**Fig. 4. Plants of *A. cruentus* cv. BRS Alegria in the test with different doses of P at different stages in Lucas do Rio Verde, Mato Grosso, Brazil**

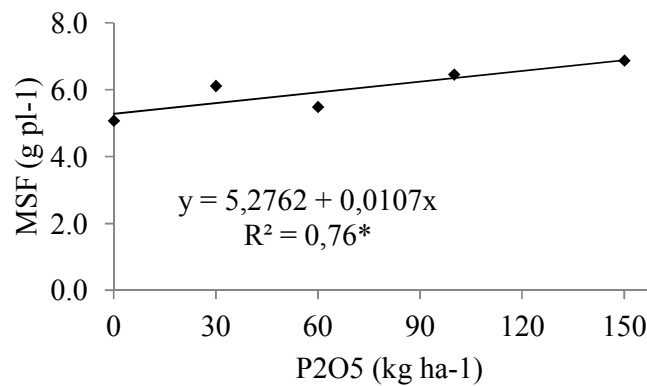
**Table 1. Effect of different doses of phosphorus ( $P_2O_5$ ) on the agronomic characteristics of *A. cruentus* cv. 'BRS Alegria'. Lucas do Rio Verde, Mato Grosso, Brazil**

Doses of $P_2O_5$ ( $kg\ ha^{-1}$ )	AP	DC	CP	MSP
	--- m ---		----- mm -----	-- $g\ pl^{-1}$ --
0	1.26	10.8	318.7	4.46
30	1.34	11.4	337.7	4.77
60	1.39	12.0	329.2	4.80
100	1.41	12.3	322.0	5.47
150	1.34	12.3	348.5	5.28
Média	1.35	11.7	331.2	5.15
C.V. (%)	5.7	7.6	7.7	21.6

AP - Plant height; DC - Stem diameter; CP - Panicle length; MSP - Panicle dry matter mass. C.V.(%) coefficient of variation

A linear increase of leaf dry mass was observed as the P doses, with a maximum value of  $6.88\ g\ pl^{-1}$  for  $150\ kg\ ha^{-1}$  of P (Fig. 5), were increased. This value did not result in higher plant height

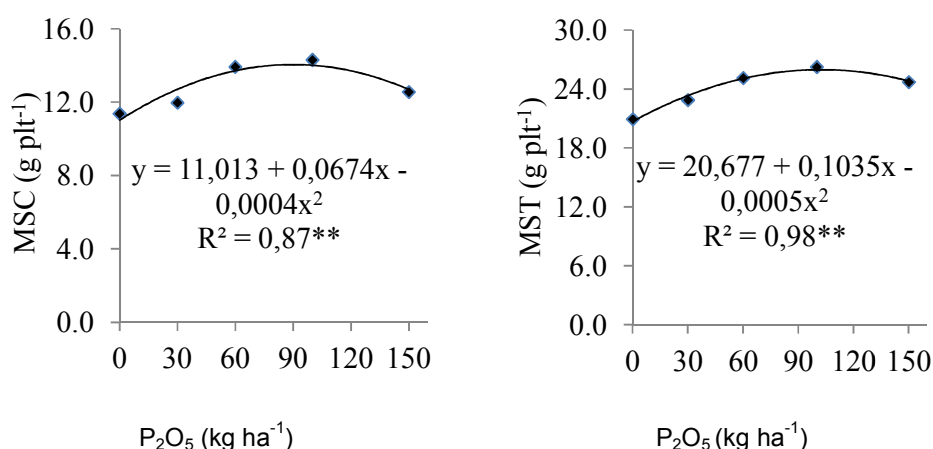
and amaranth stem diameter as a function of the P doses. This fact may be associated with the initial nutrient contents in the soil, supplying the need for the initial development of the plant.



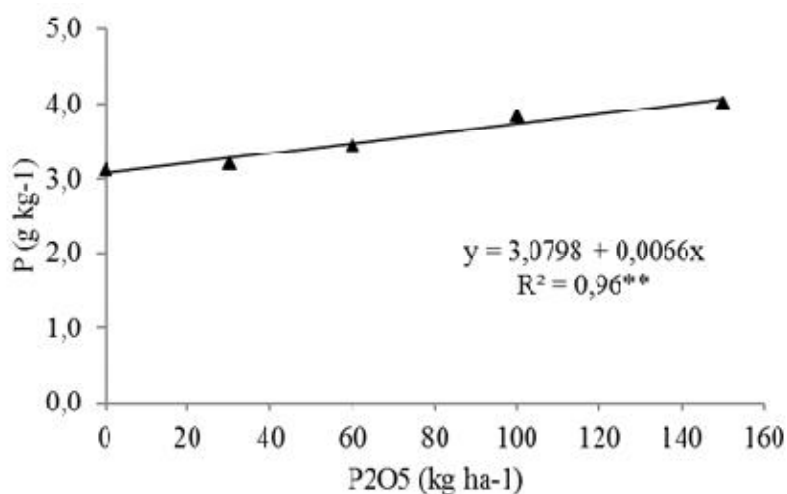
**Fig. 5. Plants of *A. cruentus* cv. BRS Alegria in the test with different doses of P at different stages in Lucas do Rio Verde, Mato Grosso, Brazil**

The mass yields of the dry matter of the stem and total dry matter adjusted to the quadratic model of response to the increase of P, where the dose of 84.2 and 103.5 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> presented the maximum estimated yields of 13, 8 and 26.0 g plt<sup>-1</sup> of amaranth cv. 'BRS Alegria', respectively (Fig. 6). According to Pereira et al. [24] in areas under no-tillage with the use of soil cover plants in succession, the increase in organic matter contents can reduce the adsorption of phosphorus to the soil, which is one of the major problems with phosphate fertilization in soils of the Cerrado.

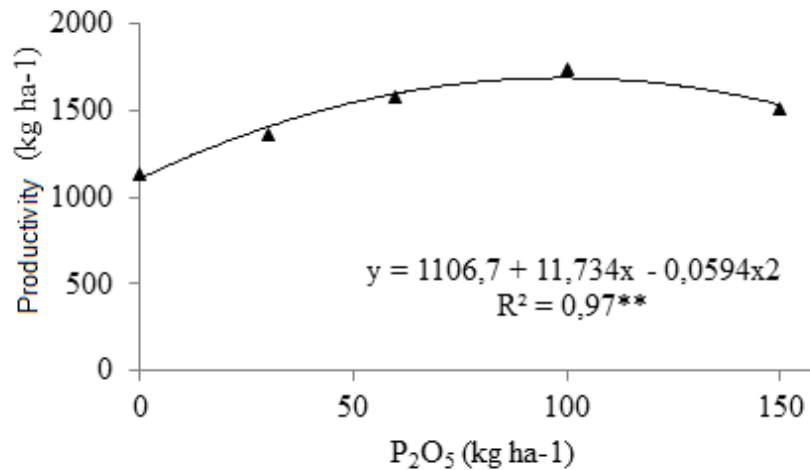
P content in leaf tissue increased linearly as P doses increased, reaching 4.06 mg kg<sup>-1</sup> for application of 150 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> (Fig. 7). However, this dose was not enough to reach the highest level of phosphorus in the leaf tissue of this study. According to Batistella et al. [25], phosphate fertilization increased linearly the P concentrations in the leaf tissue and the yield of the soybean crop in two consecutive harvests up to the dose of 160 kg ha<sup>-1</sup> reaching a content of 6.0 mg dm<sup>-3</sup>. In legumes, P deficiency decreased the yield potential by lower flower production and seed pods with lower mass [26,27,28].



**Fig. 6. Mass of the dry matter of stalk (MSC) and mass of the total dry matter (MST) as a function of different doses of P<sub>2</sub>O<sub>5</sub> in the culture of *A. cruentus* cv. BRS Alegria in Lucas do Rio Verde, Mato Grosso, Brazil. \*Coefficient of Variation of 7.5 and 7.7% for MSC and MST, respectively**



**Fig. 7. Phosphorus content in the leaf tissue of *A. cruentus* cv. BRS Alegria due to different doses of P<sub>2</sub>O<sub>5</sub> in Lucas do Rio Verde, Mato Grosso, Brazil**



**Fig. 8. Productivity of *A. cruentus* cv. BRS Alegria due to increasing doses of P<sub>2</sub>O<sub>5</sub> in Lucas do Rio Verde, Mato Grosso, Brazil**

The grain yield averages were adjusted to the quadratic model of regression (Fig. 8), where the derivative of the equation calculated the dose of 98.7 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>, for a maximum estimated productivity of 1690.14 kg ha<sup>-1</sup> of amaranth grains 'BRS Alegria'. The productivity drop beyond this value may have occurred due to a zinc deficiency, induced by the high concentration of phosphorus in the sowing furrow as observed [29] in soybean. In addition, the nutritional imbalance in the crop can reduce the initial growth of the roots [30].

The formula obtained for the dose of maximum economic efficiency was:

$$\text{Dose } P_2O_5 = \frac{11,734 - Y}{0,1188}$$

where Y is the relationship between input and output prices. Thus, the most economical dose of P<sub>2</sub>O<sub>5</sub> was 94.8 kg ha<sup>-1</sup>, for Y = 0.46, with yield of 1,686.1 kg ha<sup>-1</sup> of amaranth grains, representing an increase of 579.4 kg ha<sup>-1</sup> in relation to the absence of the input. This dose represented 96% of that responsible for maximum productivity, indicating that amaranth responds economically to the use of P<sub>2</sub>O<sub>5</sub>, even in areas where the level of P is high.

In a study carried out in Sorriso, MT, with the BRS Alegria sour amaranth seeded in succession to the soybean crop without the use of phosphate fertilization in different soil

management systems, the average yield was 923.0 kg ha<sup>-1</sup> [31]. According to Spehar et al. [3] in work performed with amaranth cv. BRS Alegria seeded in succession to soybean in Goiás, obtained 2,000 kg ha<sup>-1</sup> of grain yield with application of 60 and 80 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O, respectively. In a study conducted in Malaysia, [17] in Malaysia, they concluded, for the purpose of fertilizer recommendation, that 50 kg of P ha<sup>-1</sup> (114.57 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>) was the most adequate for the production of leaves and grains of amaranth. In another experiment, with phosphorus doses, conducted in hot and humid Nigerian regions, similar to the Brazilian Cerrado, [18] obtained the best grain yield using 100 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>. According to the results obtained in other studies, it can be verified that the doses of maximum productivity, as a function of phosphorus content, are close to those found in this study, regardless of the location and pre-existing phosphorus levels.

The search for new species of cover crops in the Cerrado region and the correct technical positioning, aiming at high production of dry biomass and high grain yield in the second crop should be constant. Thus, greater diversification of grain yield and nutrient intake by plants of different species in the soil-plant system over the agricultural years is expected.

#### 4. CONCLUSION

The phosphorus applied in the sowing furrow increased yield and P content in leaf tissue in

amaranth cv. BRS Alegria, in succession the soybean crop, even with medium to high levels of soil phosphorus.

The highest estimated total dry mass of the plant (26.2 g.plant<sup>-1</sup>) and grain (1,700 kg.ha<sup>-1</sup>) of amaranth was obtained with 98.7 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub>.

The higher estimated productivity of amaranth grains was obtained with values very close to the level of economic response to the application of the input.

## ACKNOWLEDGEMENTS

We are grateful to the Federal University of Mato Grosso (UFMT).

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Erasmo EAL, Domingos VD, Spehar CR, Didonet J, Sarmento RA, Cunha AM. Evaluation of amaranth cultivars (*Amaranthus spp.*) in no-tillage system in the south of Tocantins. *Bioscience Journal*. 2004;20(1):171-176.
2. Brenner D, Williams JT. Grain amaranth (*Amaranthus species*). In: Williams JT. (Ed.). *Underutilized Crops: Cereals and pseudocereals*. London: Chapman & Hall. 1995;128-186.
3. Spehar CR, Teixeira DL, Lara Cabezas WAR, Erasmo EAL. Amaranth BRS. Alegria: An alternative to diversify production systems. *Pesquisa Agropecuária Brasileira*. 2003;38(5):659-663.
4. Spehar CR, Brenner D, Mujica-Sanches A. Origin and importance of Amaranth In: Spehar CR (Ed.). *Amaranth: Option to diversify agriculture and food*, Embrapa Cerrados. 2007;23-42.
5. Spehar CR, Santos RLB, Souza PIM. New coverage plants for the grain production system. In: *International seminar on the direct plantio system*, Passo Fundo. Anais. Passo Fundo: Embrapa, CNPT. 1997;69-172.
6. Spehar CR, Cabezas WARL. Introduction and selection of species for the diversification of the productive system in the cerrado. In: Cabezas WARL. Freitas PL (Ed.). *Direct planting in the integration of livestock farming*. Uberlândia: Ed. of the Federal University of Uberlândia. 2001;179-189.
7. Spehar CR, Teixeira DL. Differences between amaranth pseudocereal and weed species, *Amaranthaceae*. *Planaltina: EMBRAPA Cerrados*. (Technical Communiqué, 69); 2002.
8. Pacheco LP, Leandro WM, Machado Ploa, Assis RL, Cobucci T, Madari BE, Petter FA. Phytomass production and accumulation and release of nutrients by cover crops in the safrinha. *Pesquisa Agropecuária Brasileira*. 2011;46(1):17-25.
9. Costa DMA. Impacts of saline stress and mulching on soil chemical characteristics and amaranth development. Thesis (PhD in Chemical Engineering) - Federal University of Rio Grande do Norte. Natal. 2007;124.
10. Costa DMA, Melo HNS, Ferreira SR, Dantas JA. Contents of N, P, K +, Ca<sup>2+</sup> + and Mg<sup>2+</sup> + in amaranth (*Amaranthus spp*) under saline stress and mulching. *Revista Agronômica*. 2008;39(2):209-216.
11. Amaya-Farfan J, Marcílio R, Spehar CR. Should Brazil invest in new grains for its food? The proposal of amaranth (*Amaranthus sp.*). *Food and Nutrition Security*. 2005;12(1):47-56.
12. Costa DMA, Borges AS. Evaluation of agricultural production of amaranth (*Amaranthus hypochondriacus*). *Holos*. 2005;21:97-111.
13. Domingos VD, Erasmo EAL, Silva JIC, Cavalcante GD, Spehar CR. Growth, grain yield and biomass of amaranth cultivars (*Amaranthus cruentus*) as a function of fertilization with NPK. *Bioscience Journal*. 2005;21(3):29-39.
14. Bianchini MGA, Beléia ADP, Bianchini A. Modification of the chemical composition of whole meal of amaranth grains after the application of different thermal treatments. *Rural Science*. 2014;44(1):167-173.
15. Corrêa JC, Mauad M, Rosolem CA. Phosphorus in soil and soybean development influenced by phosphate fertilization and vegetal cover. *Brazilian agricultural research, Brasília*. 2004; 39(12):1231-1237.
16. Aquino LA. Parcelamento of phosphorus in cotton culture irrigated in quartzarenic neosol. Thesis (Doctorate in Phytotechny) - Federal University of Viçosa, Viçosa. 2009;86.



17. Ojo OD, Kintomo AA, Akinrinde EA, Akoroda MO. Comparative effect of phosphorus sources for grain amaranth production. *Communications in Soil Science and Plant Analysis*. 2007;38(1-2): 35-55.
18. Olofintoye JAT, Adeniyi HA, Adetula OA. Effects of phosphorus fertilizer and intra row spacing on the growth and yield of grain amaranth (*Amaranthus cruentus*). *Agricultural Journal*. 2011;6(6): 366-368.
19. Brazilian Agricultural Research Corporation (Embrapa), National Soil Research Center. Brazilian system of soil classification. 2<sup>nd</sup> ed. Rio de Janeiro, Embrapa. 2006;306.
20. Malavolta E, Vitti GC, Oliveira SA. Evaluation of nutritional status of plants: Principles and applications. Piracicaba, Potafos. 1997;308.
21. Schlindwein JA, Gianello C. Doses of maximum economic efficiency of phosphorus and potassium for crops cultivated in the plantation direct system. *Journal of Plant Physiology*. 2005;85(1): 20-25.
22. Ferreira DF. Sisvar: A computer statistical analysis system. *Science and Agrotechnology (UFLA)*. 2011;35(6):1039-1042.
23. Alvares VVH, Novaes RF, Barros NF, Cantarutti RB, Lopes AS. Interpretation of soil analysis results. In: Ribeiro AC, Guimaraes PTG, Alvarez VVH (Ed.). Recommendation for the use of correctives and fertilizers in Minas Gerais: 5. Approximation. Viçosa: Soil Fertility Commission of the State of Minas Gerais. 1999;25-32.
24. Pereira MG, Loss A, Beutler SJ, Torres JLR. Carbon, light organic matter and phosphorus remaining in different soil management systems. *Pesquisa Agropecuária Brasileira*. 2010;45(5):508-514.
25. Batistella Filho F, Ferreira ME, Vieira RD, Cruz MCP, Centurion MAPC, Sylvestre TB, Ruiz JGCL. Phosphorus and potassium fertilization for the production and quality of soybean seeds. *Pesquisa Agropecuária Brasileira*. 2013;48(7):783-790.
26. Ventimiglia LA, Costa JA, Thomas AL, Pires JLF. Soil yield potential due to the availability of phosphorus in the soil and the spacing. *Pesquisa Agropecuária Brasileira*. 1999;34(2):195-199.
27. Zucareli C, Ramos Junior USA, Barreiro AP, Nakagawa J, Cavariani C. Phosphate fertilization, production components, productivity and physiological quality in bean seeds. *Brazilian Journal of Seeds*. 2006;28(1):9-15.
28. Oliveira Júnior A, Prochnow LI, Klepker D. Soybean yield in response to application of phosphate rock associated with triple superphosphate. *Scientia Agricola*. 2011; 68(3):376-385.
29. Seno S, Saliba GG, Paula FJ, Koga PS. Effect of phosphorus and earthworm humus on garlic (*Allium sativum* L.) cv. Purple Pearl of Hunter. *Horticultura Brasileira*. 1996;12(1):76-78.
30. Peryea FJ. Phosphate-fertilizer-induced salt toxicity of newly planted apple trees. *Soil Science Society American Journal* Madison. 1990;54(6):1778-1783.
31. Pittelkow FK, Scaramuzza JF, Weber OLS, Maraschin L, Valadão FCA, Oliveira ES. Biomass production and nutrient accumulation in cover crops under different tillage systems. *Revista Agrarian*. 2012; 5(17):212-222.

© 2019 Pittelkow et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*

The peer review history for this paper can be accessed here:  
<http://www.sdiarticle3.com/review-history/49828>