Interactions between green manure and rock phosphate on corn production in family farms[1]

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ABSTRACT

The aim of this study was to analyze whether the use of green manures in association with rock phosphate rates can guarantee corn yields to family farmers. An experiment was conducted with six types of green manures: *Mucuna cinereum*, *Crotalaria juncea*, *Crotalaria ochroleuca*, *Cajanus cajan*, *Pennisetum glaucum* and a weedy fallow control treatment; and three rates of phosphorus (0, 50 and 100 kg P_2O_5 ha^{-1}) in a complete randomized block design. The management with *Crotalaria juncea* achieved the highest dry mass yield (39.3 Mg ha^{-1}) and in year 2 (2016), with the water deficit during the corn cultivation, led to an increase of the root/shoot mass ratio, as well as presented the lowest water deficit sensitivity index (Ky), indicating that it can be an alternative for managing climate change. The highest corn yield (7510 kg ha^{-1}) was obtained in the management with the *Crotalaria ochroleuca*, which defines it as a technically and economically viable alternative for family farming, with corn yield exceeding the average yield of the State of Mato Grosso and production cost lower than the average production cost of corn in the State of Mato Grosso.

Keywords: dry mass; food production; legumes; sustainability.

INTRODUCTION

Family farms are important for both the basic production of food for human consumption and food security (Guillen *et al.*, 2020). Family farmers in Brazil account for 87% of the national production of cassava, 70% of beans, 34% of rice, and 46% of corn (IBGE, 2017). Despite the importance of family farming for food production, it is still not the holder of the largest sources of financing or benefits from its production and participation in the Brazilian economy (Abraham *et al.*, 2014).

Family farmers still face climatic fluctuations and rainfall seasonality, which in years of drought can reduce their production (Langner *et al.*, 2019). Studies conducted by Altieri & Nicholls (2017) and Altieri *et al.* (2012) showed that farmers who adopted practices such as the use of local seeds, green manure, rock phosphate dust, and minimum tillage had lower losses, around 20%, confirming the great resilience of these systems.

Corn is an important crop for Brazil and its use by family farmers is intertwined with its own identity within family farming, as it is the most cultivated cereal in the segment, guaranteeing the supply of energy for human and animal food and the family's food security (Spagnolo *et al.*, 2017). Corn is a demanding crop in terms of fertility, mainly nitrogen, which is generally necessary to be added. Studies on the use of green manures in corn production systems are important for the understanding and maintenance of crop residues on the soil surface with an adequate supply of nutrients to the commercial crop (corn) (Correa *et al.*, 2014; Maluf *et al.*, 2015), in order to guarantee food security, soil security (McBratney *et al.*, 2013) and environmental sustainability (Finney *et al.*, 2016; Borges *et al.*, 2020).

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Green manure promotes protection, improvement and maintenance of soil quality, increases the content of organic matter and nutrients, and produces large amounts of dry matter in short time, especially in the case of leguminous species. These species perform biological nitrogen fixation (BNF), providing a source of organic nitrogen for agricultural systems (Hernani & Padovan, 2014; Aytemirov *et al.*, 2018; Sarmento *et al.*, 2019). Legumes can also be a carbon source for agroecosystems, which increases the ecological processes of decomposition and mineralization and consequently provides nutrients to plants intended for production, reducing the use of synthetic fertilizers.

The hypothesis of this study is that soil management with green manure and rock phosphate, in addition to being a viable option for family farms, will promote, through ecological processes, greater services to the ecosystem, so that in years of drought, the corn yield is ensured, minimizing shortfalls. The objectives of this work were i) to analyze the management potential in the climate change scenario, regarding water deficit, in order to avoid decreases in corn yield and ii) be able to recommend one or more species for soil management to maintain satisfactory corn yields, at low cost, reducing the use of external inputs and conserving natural resources.

MATERIAL AND METHODS

Study Region

The experiment was conducted in the Florestan Fernandes Settlement Project (PA), at UTM Coordinates 8 282 294 m N and 355 051 m E (21S Zone, MC 57Wgr, Datum Sirgas 2000), in the municipality of Araputanga, MT, Brazil.

Altitude in the region ranges from 200 to 300 m and total annual rainfall from 1400 to 1600 mm between November and April, characterizing as rainy season. The dry season occurs from May to October, with a drastic reduction in the rainfall. The annual average temperature is above 24.9 °C, with maximum varying between 32.3 and 32.7 °C.

During the experimental periods (November 2014 to July 2016), the rainfall and temperature data (Figure 1) were obtained from the Automatic Station (MT-A-936) of the National Institute of Meteorology (INMET). The first experimental period (year 1) was from November 2014 to July 2015, and the second (year 2) was from November 2015 to July 2016.

History and Characterization of the Study Area

The experimental area was kept fallow for the last five years after the cultivation of vegetables by family farmers. Initially, the area was prepared by one pass of a heavy disc harrow and two passes of leveling disc harrow to clean and level the area for the installation of the experiment.

The soil was classified as Eutrophic Red Yellow Ultisol, deep A moderate, medium-sandy texture, subdeciduous tropical forest phase, smooth and wavy, according to EMBRAPA (2018).

The chemical and physical characteristics of the soil at the installation of the experiment, at depths of 0–0.2 and 0.2–0.4 m are shown in Table 1.

Installing green manure and rock phosphate experiments

The experiment (years 1 and 2) was arranged in a 6 x 3 factorial, randomized block design (RBD), with 4 replications. The plot size was 3 x 3 m, spaced 1 m apart, and net plot-size was 4 m² (central), according to Teodoro *et al.* (2011). The green manure species factor consisted of four legumes (family Fabaceae), one grass (family Poaceae), and a weedy fallow treatment.

The second factor consisted of three phosphorus rates: 0, 50, 100 kg P_2O_5 ha^{-1} rock phosphate (i.e., reactive natural phosphate), with available P content (P_2O_5) of 15.50% (citric acid 2%), sedimentary and organic origin, from Morocco (Table 2).

The leguminous plants tested were velvet bean – MUC (*Mucuna cinereum*), two species of sunnhemp – CJ (*Crotalaria juncea*) and CO (*Crotalaria ochroleuca*), and dwarf pigeonpea – G (*Cajanus cajan*). The other plots were planted with the non-legume cover crop, pearl millet – MI (*Pennisetum glaucum*) or were under the weedy fallow control (VE). In the latter, the predominant species were *Xanthium strumarium*, *Commelina benghalensis*, *Acanthospermum hispidum*, *Panicum maximum*, *Senna occidentalis*, and *Sida* spp.

The spacing between planting furrows was 0.5 m with a density of nine plants per meter for velvet bean and 20 plants per meter for the sunnhemp species CJ and CO and dwarf pigeonpea. The population obtained for velvet bean was approximately 180 000 plants per hectare, for the sunnhemp species CJ and CO and dwarf pigeonpea approximately 400 000 plants per hectare, and for pearl millet approximately 6 000 000 plants per hectare. The planting depth of the legume seeds varied from 0.02 to 0.04 m, by hand sowing. Pearl millet was hand broadcast, at a seed rate of 50 g $plot^{-1}$ to a depth of approximately 0.01 m, using a rake for surface incorporation.

The main cultural practices for the legumes included weeding between the lines, hand weeding on the lines, and replanting in the places where germination or emergence failed. The cultural practives for pearl millet, since it was broadcast, were only hand weeding and replanting. There was no occurrence of pests and diseases that would harm the plants grown for green manure.

The plants were sampled in the net plots, at full bloom stage, by cutting the shoots close to the ground, with stems, leaves and flowers, using a 0.25 m² frame. Then, they were labled, packed in paper bags, and dried in an oven with forced-air circulation at 65 ºC for 72 hours to constant weight (dry mass). The agronomic characteristics evaluated in the legumes, pearl millet, and weedy fallow were i) cycle duration until full bloom and ii) dry mass yield (DM).

The plants used as green manure, but not sampled, were also cut when the plots had more than 50% of the plants in full bloom. After cutting, their respective masses were evenly distributed over the area of each plot, without soil incorporation for decomposition and mineralization. This procedure for the green manure plants (sowing, growing, sampling, and cutting) was repeated in year 2.

Corn Cultivation

After cutting the plants used as green fertilizers, corn (variety BRS 4103) was planted in succession in all plots in March 2015 (year 1) and March 2016 (year 2). The spacing between corn rows was 0.6 m, planting density of four plants per linear meter, and planting depth of approximately 0.05 m, forming a population of 66 000 plants per hectare. The main cultural practices for the corn included weeding, replanting, and biological control of fall armyworm (FAW) (*Spodoptera frugiperda)* by spraying of *Bacillus thuringiensis*. The corn cycle from sowing to harvest was approximately 120 days.

Corn was harvested by hand in July 2015 (year 1) and in July 2016 (year 2). The ears of 3 plants per plot were sampled for yield evaluation; and 3 plants with aerial part (AP) and root, to evaluate the root/AP ratio. The roots were collected from trenches dug between the lines and carefully separated from the soil in order to minimize losses and allow that they remained in the plot.

After the corn harvest, the wet grains were separated and dried at 65 °C for 72 hours or until constant weight to obtain the dry mass of the grains. For yield purposes, the grain moisture was standardized at 13% (desired commercial moisture content), according to Eq. (1) proposed by Cromarty *et al.* (1985).

$$\text{Mf} = \text{Mi x } \frac{(100 - \text{TAi})}{(100 - \text{TAd})} \qquad (1)$$

where:

Mf – final mass of grains (g);

Mi – initial mass of grains (g);

TAi – initial moisture content (%);

TAd – desired moisture content (13%).

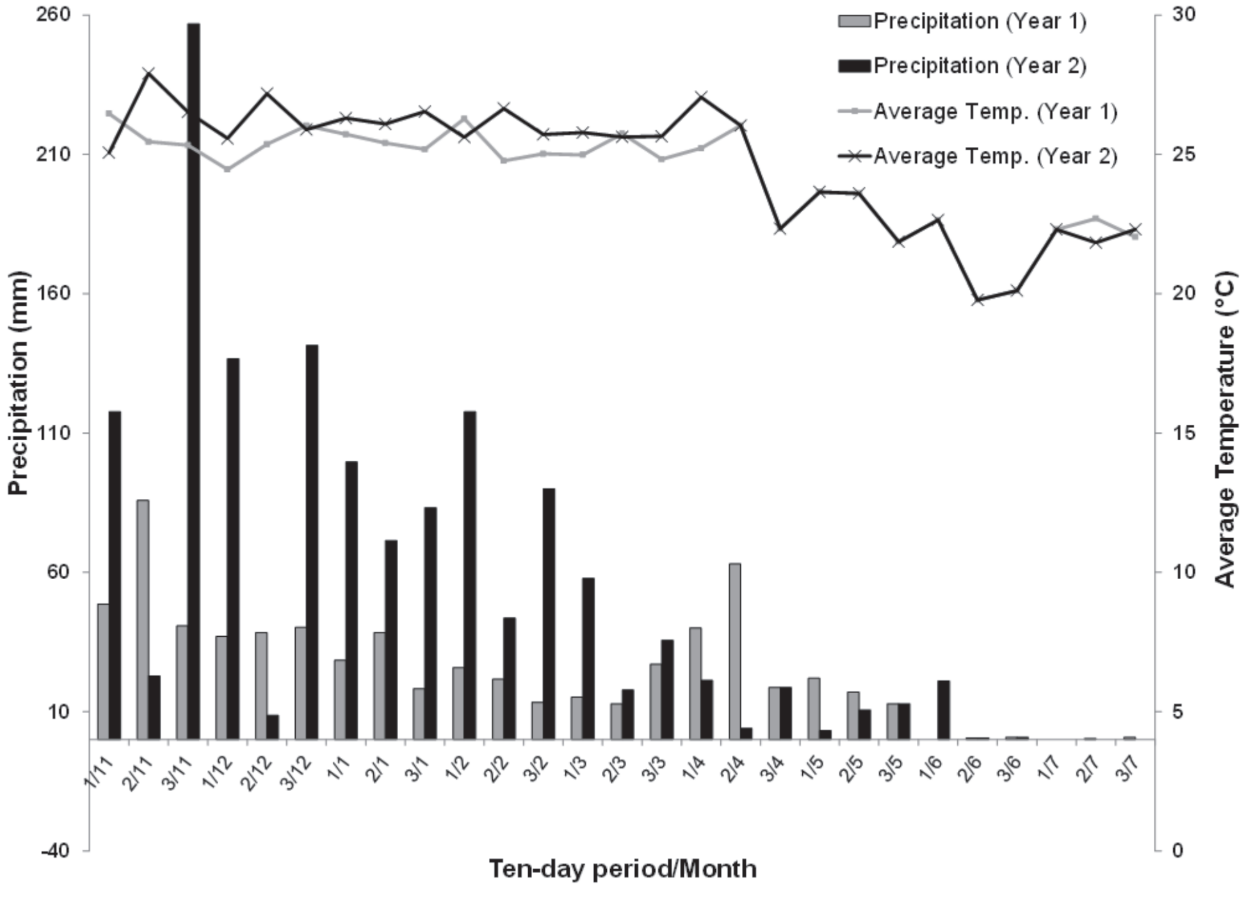

Figure 1: Rainfall and average air temperature in years 1 and 2 at the Automatic Station (MT-A-936). Source: INMET (National Institute of Meteorology).

Table 1: Initial chemical and physical characteristics of the soil in the experimental area

Depth	pHH$_2$O	Ca^{2+}	Mg^{2+}	K$^+$	Al^{3+}	H$^+$	T	Org. M.	V	m	P	S	Zn	Cu	Mn	B	Sand	Silt	Clay
(m)		(cmol$_c$ dm^{-3})						(g kg^{-1})	(%)		(mg dm^{-3})						(g kg^{-1})		
0–0.2	6.1	2.0	0.6	0.2	0.1	3.5	6.4	15.01	56.8	2.1	37.9	7.3	17.5	2.5	130.3	0.43	797	107	96
0.2–0.4	6.5	2.6	0.8	0.1	0.2	2.1	5.8	7.72	60.1	5.4	26.2	9.3	5.2	2.2	114.6	0.25	809	106	85

T: total CTC at pH 7.0; M. Org.: organic matter; V: base saturation; m: saturation of aluminum.

The water deficit sensitivity index (Ky) was used to estimate the decrease in yield, due to lack of rain, of corn cultivated in succession to green manures at different rates of phosphorus (P), according to Eq. (2) proposed by FAO (1979).

$$ky = \frac{(1 - Yr/Ym)}{(1 - ETr/ETm)} \quad (2)$$

where:

Ky –water deficit index of sensitivity;

Yr – actual yield (kg ha^{-1}) obtained in the treatments with green manures and P rates;

Ym – maximum corn crop yield (production potential of variety BRS 4103);

ETr – actual evapotranspiration (mm ten-day^{-1}) obtained with the maximum evapotranspiration multiplied by the crop coefficient (Kc) for each phenological phase of the corn crop (water balance method, Thornthwaite & Mather, 1955). Kc, as suggested by FAO (1979) and Fancelli & Dourado Neto (2004);

ETm – maximum evapotranspiration (mm ten-day^{-1}), obtained with the Penman–Monteith equation (FAO, 1998).

The water deficit index of sensitivity (Ky) expresses the effect of water shortage on the production, therefore values of Ky < 1 denote that crop yield will not be limited by the water deficit. On the other hand, Ky values > 1 reveal greater sensitivity to shortage of water, resulting in lower crop yield (FAO, 1979). The sensitivity of crops to water deficit are classified as low (Ky < 0.85), low–medium (0.85 < Ky < 1), medium–high (1 < Ky < 1.15), and high (Ky > 1.15).

Table 2: Analytical results of rock phosphate (i.e., reactive natural phosphate)

Determinations	Units	Results
pH in 0.01 M CaCl$_2$ (1:5)		7.30
Ratio C/N (total C/total N)		56/1
Total Organic Matter (combustion)	% (w/w)	5.44
Total Carbon (organic and mineral)		3.16
Organic Carbon		2.96
Total Nitrogen		0.06
Total Phosphorus (P$_2$O$_5$)		25.54
Phosphorus – P$_2$O$_5$ (citric acid 2%)		15.50
Total Potassium (K$_2$O)		0.30
Total Calcium (Ca)		37.20
Total Magnesium (Mg)		0.38
Total Sulfur (S)		2.60
Total Zinc (Zn)	(mg kg^{-1})	110.40
Total Copper (Cu)		14.40
Total Manganese (Mn)		48.20
Total Boron (B)		86.80
Total Iron (Fe)		5640
CEC (cation exchange capacity)	(cmol$_c$ kg^{-1})	48

Table 3 presents the meteorological data of precipitation and temperatures during the phenological phases of corn managed with green manures and phosphorus rates. Data were also obtained from the automatic station (MT-A-936) of the National Institute of Meteorology (INMET).

Statistical Analysis

The data were analyzed by the tests of normality (Kolmogorov–Smirnov) and homogeneity of variance (Levene's test), both at 5% probability. Analysis of variance (ANOVA) and Tukey's test ($p < 0.05$) were performed for comparisons between the treatments of green manures and phosphorus rates, with unfolding of the significant interactions ($p < 0.05$).

RESULTS

The life cycle of the green manures, from sowing to full bloom in year 1 varied according to the species; the first to bloom, at 60 days after sowing (DAS), was the pearl millet - MI followed by the dwarf pigeonpea - G at 83 DAS, then sunnhemp - CJ at 92 DAS, sunnhemp - CO at 110 DAS, and finally, the velvet bean – MUC at 117 DAS. In year 2, the first species to flower was G at 88 DAS followed by CJ and MI at 118 DAS, and in the end, the two most delayed species were CO and MUC, entering the reproductive phase at 129 DAS.

Figure 2 shows the dry mass yield (DM) means of green manures at P rates. In year 1, the DM production of the green manures ranged from 5.9 to 23.2 Mg ha^{-1}, with significant differences (Tukey, $p < 0.05$) between the means.

The highest dry mass means were found for the species CJ, intermediate means for MI and CO, and the lowest means for the green manures MUC and G. In year 2, the DM means ranged from 9.7 to 39.3 Mg ha^{-1}, with significant differences (Tukey, $p < 0.05$) between them, being higher for the CJ species, intermediate for CO and lower for MUC, G, VE and MI species. There was no significant interaction ($p > 0.05$).

Figure 3 illustrates the root/shoot mass ratio of corn cultivated in succession to the green manures and P rates. In year 1, the ratio varied from 0.18 to 0.25, without significant differences ($p > 0.05$) between the green manure treatments and without interactions.

In year 2, the root/shoot mass ratio of the corn varied from 0.34 to 0.82, with significant differences ($p < 0.05$) between treatments using different green manures. The highest ratio was obtained with CJ, intermediate ratio with MI, and the lowest ratio with treatments using the green manures CO, G, MUC, and VE. There was no significant interaction between P rates and management with green manure plants.

Figure 4 shows the the water deficit index (Ky) for the corn crop. In year 1, the Ky varied from 0.15 to 1.89, with significant differences ($p < 0.05$) between treatments with different green manure plants.

The highest Ky means were found in the treatments with CJ, G, MI, MUC, and VE, and the lowest Ky means with CO. In year 2, Ky ranged from 1.19 to 2.10, with significant differences between managements in the following decreasing order: G e" CO = MI = MUC = VE e" CJ. No significant interaction was found between P rates and management with green manures in the two years studied.

Finally, Figure 5 shows the mean yields of corn cultivated in succession to green manures and P rates in the years 1 and 2. In the first year, yields ranged from 2115 to 7510 kg ha^{-1}, with significant differences ($p < 0.05$) between the treatments with different green manure plants.

Table 3: Rainfall at different stages of development of the corn crop

Month	Stages of development of the corn*	Rainfall (mm) Year 1 (2015)	Rainfall (mm) Year 2 (2016)
March	0 (emergence seeding)	12.8	0.2
March	1 (plant with 4 leaves fully grown)	27.0	32.6
April	2 (plant with 8 leaves)	40.0	24.0
April	3 (plant with 12 leaves)	81.6	4.2
May	4 (emission of the tassel)	22.0	18.8
May	5 (flowering and pollination)	17.0	3.0
May	6 (milky grains)	12.8	15.8
June	7 (pasty grains)	0.0	28.4
June	8 (beginning of tooth formation)	0.0	0.8
July	9 (hard grains)	0.4	0.6
July	10 (physiologically mature grains)	0.8	0.0
	Total Rainfall	214.4	128.4

Source: INMET (National Institute of Meteorology)
*Fancelli, 1986, adapted from Nel & Smit, 1978

The highest yield was recorded for the treatment with the green manure CO, while the other treatments had lower yields. Significant interaction for corn yield was found between the P rates and CO in descending order: 100 kg P_2O_5 ha^{-1} $\geq$ 50 kg P_2O_5 ha^{-1} $\geq$ 0 kg P_2O_5 ha^{-1}.

In year 2, the corn yield means (Figure 5) ranged from 1546 to 4076 kg ha^{-1}, showing significant differences in the following descending order: CJ = CO = MUC = VE $\geq$ MI $\geq$ G. A significant interaction was found between the P rates and G in the following descending order: 50 kg P_2O_5 ha^{-1} $\geq$ 0 kg P_2O_5 ha^{-1} $\geq$ 100 kg P_2O_5 ha^{-1}.

DISCUSSION

The life cycle duration, from sowing to flowering, of plants used as green manure is important for the rotation–succession crop system, since the early-flowering species have a great potential for this production system (Teodoro *et al.*, 2011). In this region and climate conditions, the late-flowering species (CO and MUC) should be sown until the first half of November, and the early-flowering species (CJ, G and MI) can be sown until the first half of December, so that they reach full bloom no later than the first ten days of March, and thus there will be favorable meteorological conditions for the successor crop (corn) to develop and produce.

The times from sowing to the full blooming in this experiment (years 1 and 2) were shorter than those reported by Teodoro *et al.*, 2011. In addition to the photoperiod, for plants sensitive to it (legumes), it is believed that higher average temperatures, such as those observed in the experimental area (Figure 2), may have contributed to the early flowering of the plants.

No significant interaction ($p > 0.05$) was found between the green manures and the P rates tested for dry mass production (Figure 2). The P content in the soil, at the beginning of the experiment, was high (P: 37.9 mg dm^{-3}, clay: 9.6%) (Table 1), meaning that it contained adequate amounts for the growth of the green manures, which contributed to the absence of a significant interaction between the production of DM by the green fertilizers and the P rates. Another attribute of the soil that explains the non-significant interaction is the pH in the layers 0–0.2 m and 0.2–0.4 m of 6.1 and 6.5, respectively. These pH values did not favor the dissolution of rock phosphate, which solubilizes faster under acidic soil conditions.

In year 2, the CJ species produced 39.3 Mg ha^{-1} of DM in the absence of P (Figure 2). This yield was achieved because of the introduction of management with that species in year 1, which increased the input of nutrients and created optimal conditions for DM production in year 2.

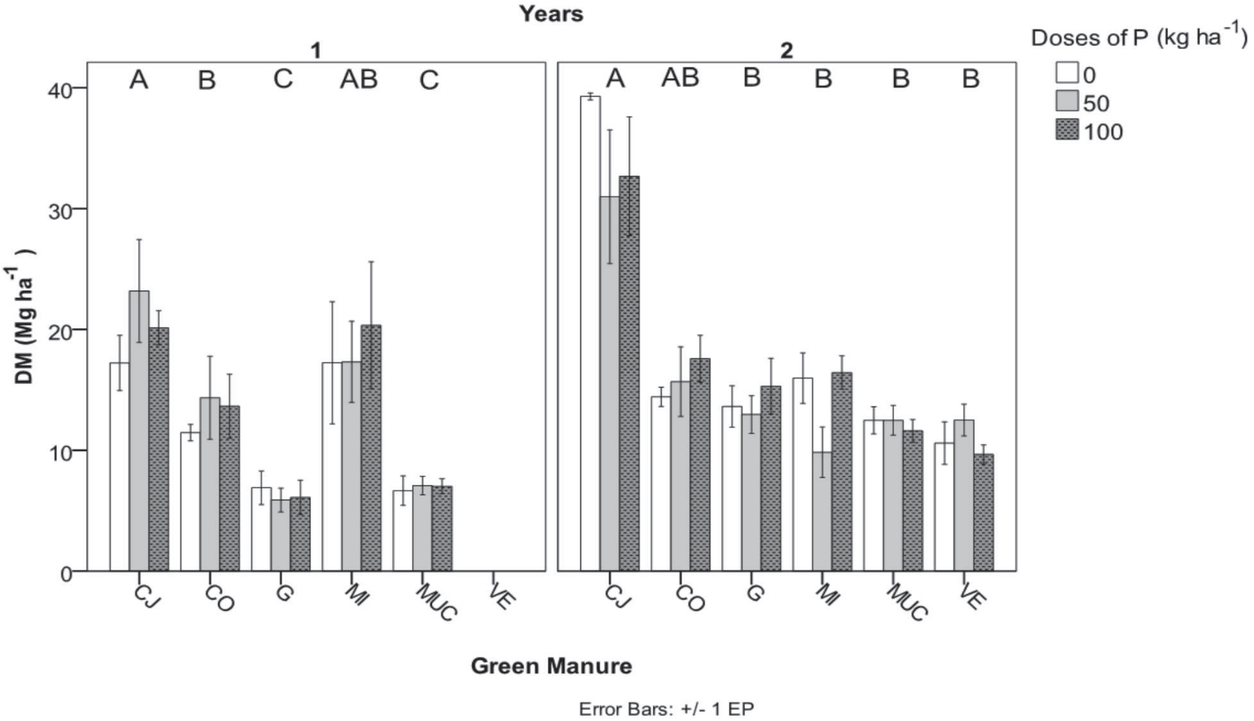

Figure 2: Dry mass (DM) of plants used as green manure at three rates of phosphorus (P). CJ: sunnhemp *Crotalaria juncea*; CO: sunnhemp C*rotalaria ochroleuca*; G: dwarf pigeonpea; MI: pearl millet, MUC: velvet bean and VE: weedy fallow control. SE: standard error of the mean. Data were transformed into log (x) for statistical analysis. Different capital letters indicate a significant difference between green manure species (ANOVA and Tukey's test $p < 0.05$).

Another factor that favored the production of DM by CJ was the greater and more evenly distributed rainfall recorded in year 2, between November and March (Figure 1), in association with the rapid growth of this species in the first 40 DAS (Teodoro *et al.*, 2011). However, with regard to cultural practices, this high DM production (39.3 Mg ha^{-1}) made it difficult to manage straw by hand for the planting of corn, which may restrict the recommendation of this management for use in family farms, since they lack farm labor and resources for investments in tractors and farm machinery.

In year 2, the legume species increased dry mass production when compared to year 1 (Figure 2). Variations in DM production reached values close to 150% increase for the species G and MUC. These results occurred for the same reasons already described for CJ, as well as the rates of reactive rock phosphate also applied to the plots in year 2.

MI showed the smallest variations in dry mass from year 1 to 2, including a negative variation at the rate of 50 kg P_2O_5 ha^{-1}. This result was due to the replacement of cultivar ADR 300 planted in year 1 by the cultivar BRS 1501 in year 2, which was necessary because of the unavailability of ADR 300 seeds for planting in year 2.

Alvarenga *et al.* (2001) argued that an adequate production of dry mass, in order to obtain the benefits of green manure, requires a minimum yield of 6 Mg ha^{-1}. In this study, the DM yield in all treatments was greater than 5.9 Mg ha^{-1}, which provides family farmers with alternatives for managing corn production, in order to maintain or increase the yield of this crop.

The increase in the root/shoot mass ratio (Figure 3) is due to the greater allocation of carbon, as a strategy to increase the efficiency of absorption, guarantee the exploration of more interstitial spaces and greater occupation of soil volume (Aziz *et al.*, 2011). Figure 3 shows that root/shoot mass ratios were higher in all treatments in year 2 than in year 1, which is related to the water deficit that occurred in year 2, between April and May, when corn plants invested in the development of the root system for greater exploration of soil in search of water.

The management of corn with the leguminous species CO (year 1) and CJ (year 2) was less affected by the water deficit (Figure 4), providing a resilient management in the climate change scenario related to the lack of rainfall for the production of the second corn crop.

Although the Ky values for year 2 are greater than 1.19, which is considered high for most crops, it is a second crop of corn, susceptible to water deficit, with a higher

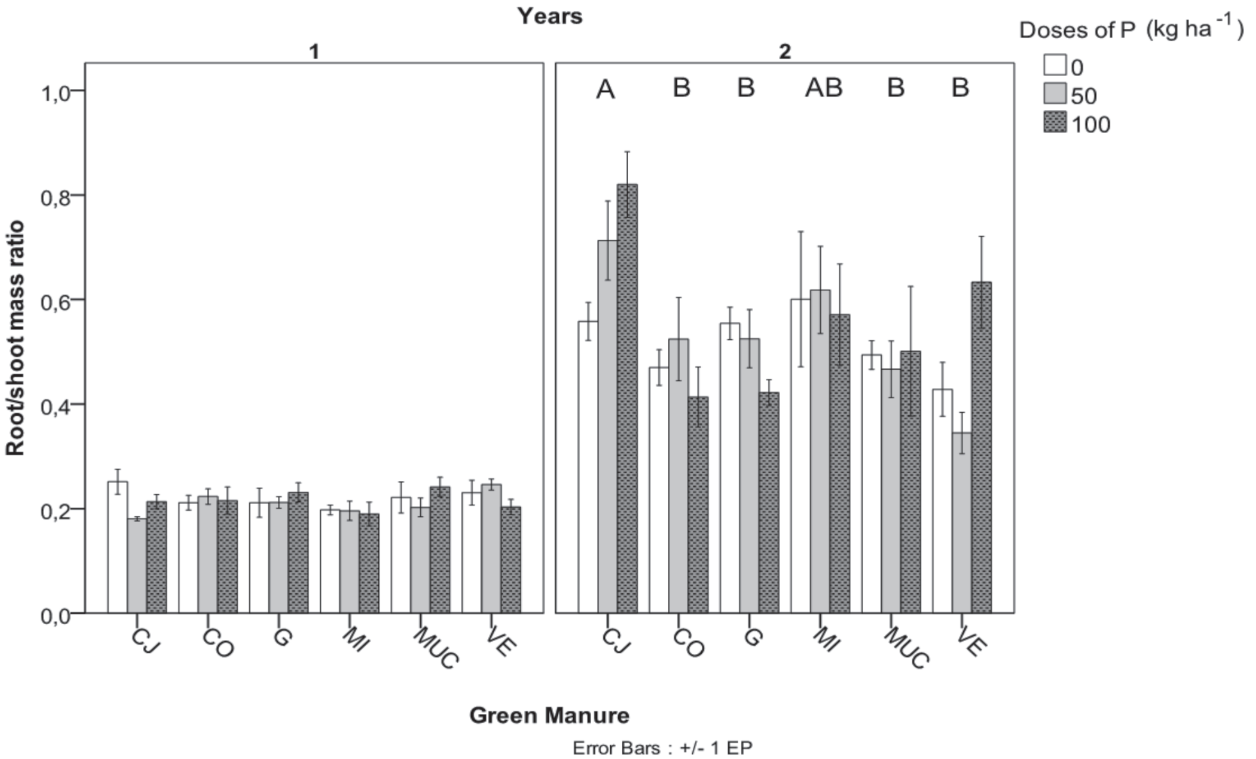

Figure 3: Root/shoot mass ratio of corn managed in succession to plants used as green manure, at three rates of phosphorus (P). CJ: sunnhemp *Crotalaria juncea*; CO: sunnhemp C*rotalaria ochroleuca*; G: dwarf pigeonpea; MI: pearl millet, MUC: velvet bean and VE: weedy fallow control. SE: standard error of the mean. Data transformed into square root (x) for statistical analysis. Different capital letters indicate a significant difference between green manure (ANOVA and Tukey's test $p < 0.05$). The absence of lowercase letters indicates no significant difference ($p > 0.05$).

risk of yield decline, and thus may present higher Ky values. In year 2, the water shortage in the flowering and pollination stages of the corn (Table 3) caused a decrease in yield, which resulted in Ky > 1 indices.

In the first year, yields ranged from 2115 to 7510 kg ha^{-1}, with significant differences ($p < 0.05$) between the green manure species. The highest yield was obtained in crop succession with CO, and the lowest yields were obtained in the other treatments. A significant interaction was found between P rates and the CO species for corn yield, in the following descending order: 100 kg P_2O_5 ha^{-1} (a)^2, 50 kg P_2O_5 ha^{-1} (ab), 0 kg P_2O_5 ha^{-1} (b). According to CONAB (2016), the average corn yield (2nd harvest) in the State of Mato Grosso in the 2014/2015 harvest was 5716 kg ha^{-1}. This yield was surpassed by the green fertilization with the CO species, at the both rates of 50 and 100 kg P_2O_5 ha^{-1}.

Yield results in year 2 (2016) (Figure 5), except for those associated with the species G (rates 0 and 100 kg P_2O_5 ha^{-1}), remained close to that recorded for the State of Mato Grosso, Brazil, average of all corn production in the State (3904 kg ha^{-1}). According to CONAB (2016), the lower corn yield compared to that of the previous year (2015) was due to water shortages in the midwestern region, in April and May, during the reproductive stages of the corn crop, thus impairing yields in the region and reducing the corn yield averages in 2016.

Effects of these water shortages were also observed in this study (Table 3). Fancelli & Dourado Neto (2004) investigated the effect of water shortage from stage 3 (plant with 12 leaves) to stage 5 (flowering and pollination) of the corn crop and found that the distribution of rainfall is a decisive factor in the definition of production and yield. Thus, analyzing the rainfall in this time interval, it was found a reduction in the volume of precipitation from year 1 to 2, causing the generalized decrease in corn yield under the managements, but as already described, keeping them close to the average corn yield of the State of Mato Grosso in the 2016 harvest.

In the weedy fallow treatment (VE), corn yields were statistically equal to those under some leguminous plants and pearl millet. Weedy fallow, given its evolution, competition, rusticity, adaptability and aggressiveness, has also developed over the years a great capacity for absorption and accumulation of nutrients compared to cultivated plants (Lorenzi, 2008). This may have contributed to the results of corn yield managed with VE, but unlike leguminous plants and pearl millet (annual crops), which do not regrow after the reproductive phase,

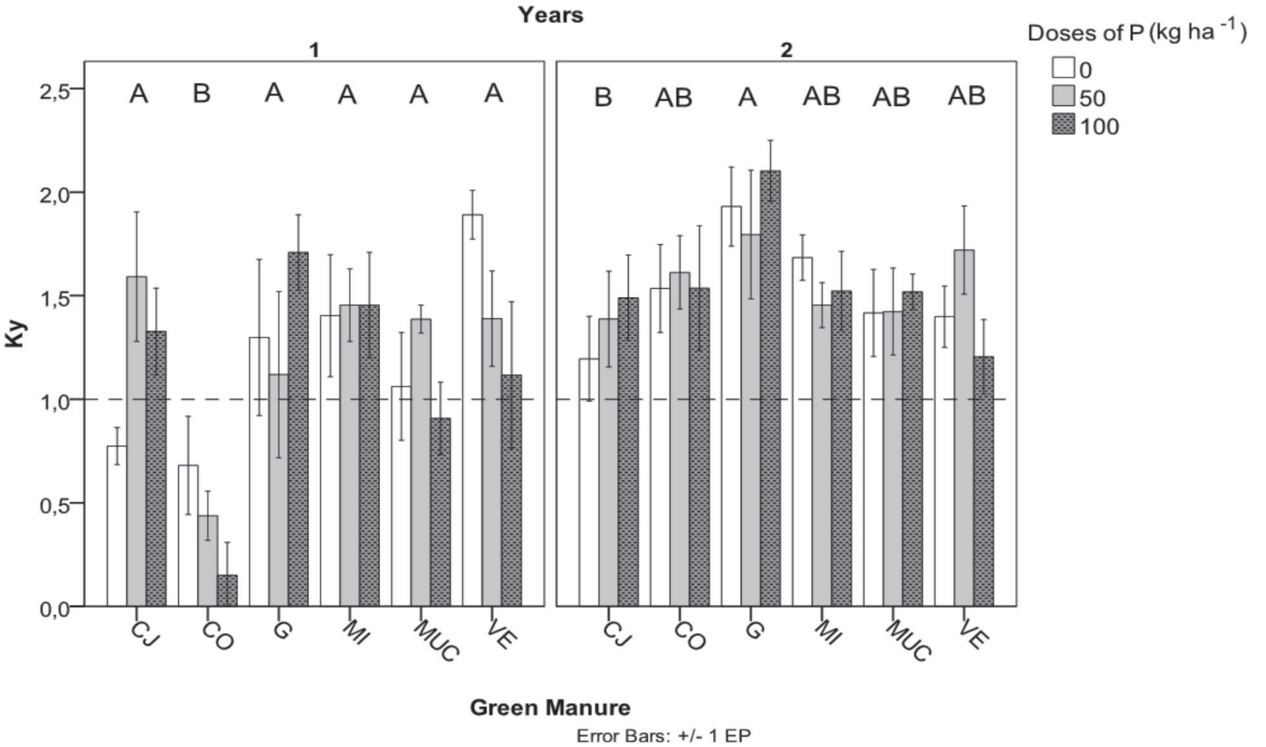

Figure 4: Water deficit index (Ky) of corn managed in succession to plants used as green manure, at three rates of phosphorus (P). CJ: sunnhemp *Crotalaria juncea*; CO: sunnhemp *Crotalaria ochroleuca*; G: dwarf pigeonpea; MI: pearl millet, MUC: velvet bean and VE: weedy fallow control. EP: standard error of the mean. Dashed line represents the limit of sensitivity to lack of water. Year 2 data was transformed into ln (x) for statistical analysis. Different capital letters indicate a significant difference between green manure species (ANOVA and Tukey's test $p < 0.05$).

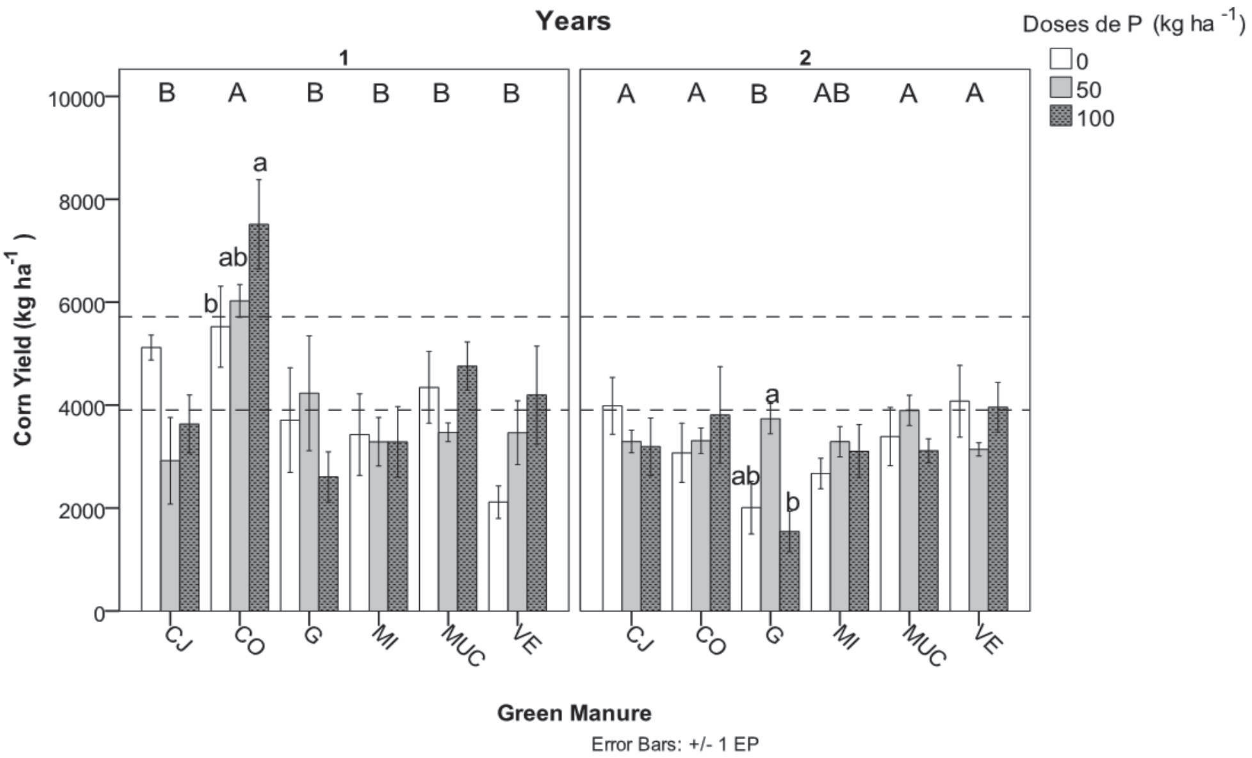

Figure 5: Corn yields managed in succession to plants used as green manures, at three rates of phosphorus (P). CJ: sunnhemp *Crotalaria juncea*; CO: sunnhemp *Crotalaria ochroleuca*; G: dwarf pigeonpea; MI: pearl millet, MUC: velvet bean and VE: weedy fallow control. SE: standard error of the mean. Dashed lines represent the corn yields of the State of Mato Grosso, Brazil, in years 1 and 2, 5716 and 3904 kg ha^{-1}, respectively (CONAB, 2016). Different capital letters indicate a significant difference between green manure species; different small letters indicate a significant difference between the P rates for each green manure species (ANOVA and Tukey's test $p < 0.05$). The absence of small letters indicates no significant difference ($p > 0.05$).

weedy fallow do not stop growing, making their management very difficult for family farming and requiring a great deal of manual labor, which is scarce in farms.

The production of corn using agroecological management of the soil with the species CO (year 1), in addition to surpassing the average yield of the State of Mato Grosso, with a predominance of high technology, also presented a lower production cost compared to the average corn production cost of the State of Mato Grosso (Leite, 2018). The reason for that is the lower use of inputs in the experiment, without the use of soil correction, micronutrients, fungicides, herbicides or adjuvants. Producing at a reduced cost while maintaining and/or increasing the yield of the corn crop is crucial today, especially in family farming, which lacks resources and technical assistance for production.

The production cost of the agribusiness, which uses high technology, tends to increase, because of the technology packages already imposed by the current production model, with the use of high quantities of external inputs. Conversely, the production cost to be recommended for family farming based on the findings of this study tends to decrease due to the ecosystem benefits that the proposed management provides from the ecological processes such as mineralization of nutrients from plants used as green manure, utilization of less external inputs, especially synthetic fertilizers, and the indication of a path towards sustainability and conservation of natural resources in climate change scenarios.

CONCLUSIONS

Our study shows what Agroecological management with green manure species produces large amounts of dry matter (DM), with the leguminous species sunnhemp - *Crotalaria juncea* - CJ producing the highest DM yield.

The water deficit observed in year 2 (2016), during corn cultivation increased the root/shoot mass ratio of corn for greater exploration of the soil in search of water, with the treatment managed with sunnhemp – CJ standing out, as well as for presenting the lowest water deficit sensitivity index (Ky), indicating that it can be an alternative for managing climate change.

In this region and soil characteristics, with high base saturation (V%), pH and availability of phosphorus, the highest corn yield was obtained for the management with the legume species sunnhemp - *Crotalaria ochroleuca* - CO, which defines it as a technically and economically viable alternative for family farming.

This study supports the conclusion that soils managed with green manure and rock phosphate can be indicated for the production of corn in family farming, guaranteeing food production even in years of low rainfall. In addition, such managements are low-cost and their benefits to the agroecosystem demonstrate a path towards sustainability.

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