

# Residual Effects of the Organic Amendments Poultry Litter, Farmyard Manure and Biochar on Soybean Crop

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## Abstract

The use of organic wastes, as an alternative to inorganic fertilizer, can be an important strategy for Brazilian and tropical agriculture. Despite the importance, few field studies have been done for evaluating organic amendments on soybean crops in Brazil. The study aimed to evaluate the residual effects of the organic amendments poultry litter, farmyard manure and biochar combined with mineral fertilizer on some agronomic attributes of a soybean crop. A field experiment was carried out in a split-split-plot scheme, with three replicates in a randomized block experimental design. The organic sources (plots) at rates of 0, 3, 6 and 9 Mg·ha<sup>-1</sup> (subplots) combined with 0, 100, 200, 300 and 400 kg·ha<sup>-1</sup> (sub subplots) of a mineral fertilizer were applied in 2008. In 2009, only the mineral fertilizer was used on the soybean crop. As a result, all evaluated attributes were influenced by the treatments, except for the number of grains per pod. The application of poultry litter provided the highest yield (3715 kg·ha<sup>-1</sup> using 9 Mg·ha<sup>-1</sup> of the source). A synergistic effect between organic amendments and mineral fertilizer was observed. It was found the possibility of decrease doses of mineral fertilizers by prior use of organic amendments. The most effective dose combination application is 5.5 Mg·ha<sup>-1</sup> of organic amendments associated with 200 kg·ha<sup>-1</sup> of mineral fertilizer to provide optimum yield. The use of organic amendments, rich in nutrients, is a technology to sustainably increase the soybean grain yield.

## Keywords

*Glycine max*, Integrated Production, Organic Wastes, Sustainability, Yield

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## 1. Introduction

Brazil is an important food producer in the world, standing as the biggest exporter and second producer of soybean [1]. Participation of the Brazilian soybean in world trade is highly significant. The importance of soybeans to Brazil's economy and social status is unmatched amongst others cash crops.

The country is the fourth largest fertilizers consumer market; however, it is only the sixth largest producer in the world. More than half of fertilizers used in the country are imported [2]. In Brazil, the soybean crops are responsible for more than a third of the national demand of mineral fertilizer [2]. Mineral fertilizers represent the major part of the production costs in the soybean crop in Brazil [3].

Considering this, several researchers have focused to create and develop technologies in order to increase fertilizer efficiency and identify alternative sources of nutrients, such as the organic wastes in Brazil and other countries [4]-[7].

Several organic sources have shown potential to provide satisfactory amounts of nutrients to plants [8]. As a rule, this practice is both more profitable and sustainable compared to the application of mineral fertilizers [9]. Some organic wastes have been tested on soybean crops. The use of biosolid as a fertilizer can be feasible, once that is more agronomically efficient than mineral fertilizers [10]. In this sense, soybean yield can be boosted by amendments like flue dust, aqueous lime, sewage sludge and lime use. In addition, the dynamics of nutrients in a soybeans/sorghum intercropping system observed that the application of 75% mineral NPK combined with chicken manure/farmyard manure/phosphocompost compound is an option of plant nutrition management [11]. In Brazil, poultry litter can be a viable and alternative input to enhance the soybean production and to reduce the production costs [12].

Organic amendments combined with inorganic fertilizer are a promising sustainable technology. Nevertheless, few studies have evaluated the residual effects, over the years, of the organic amendments associated to mineral fertilizer on cash crops. The aim of this study was to evaluate the residual effects of poultry litter, farmyard manure and biochar previous use, with or without mineral fertilizer, on grain yield and others agronomic attributes of soybean plants.

## 2. Materials and Methods

The experiment was carried out in Itutinga, located in Minas Gerais Province (21°23'S, 44°39'W; 958 m.a.s.l.), in Brazil, over a two-year period. According to the climatic classification of Köppen, the climate is classified as Cwa type with humid summers and dry winters [13]. The temperatures and precipitation during the experiment are shown in **Figure 1**.

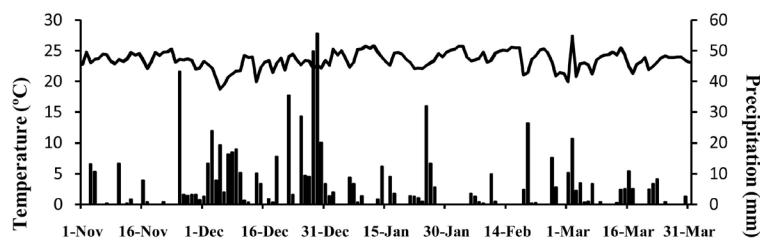
A randomized complete block design, with three replicates in split-split-plot scheme was used. The treatments applied to whole plots were the organic sources: poultry litter (PL), farmyard cattle manure (FM) and biochar (BC). The organic sources were manually spreaded and incorporated into the soil with a harrow, in the previous growing season (2008) at rates of 0, 3, 6 and 9 Mg·ha<sup>-1</sup> in the total area of the split-plot. Mineral fertilizer, at rates of 0, 100, 200, 300 and 400 kg·ha<sup>-1</sup>, had been used and manually applied to the sub-subplot furrow at sowing time, in both seasons (2008 and 2009). The standard sowing fertilization was based on soil analysis and interpretations according to [14], by use of 400 kg·ha<sup>-1</sup> of 04-30-10 NPK mineral fertilizer with 6.10 of Ca, 2.97 of S, 0.06 of B, 0.97 of Mn and 0.31% of Zn.

The soybean seeds, of cultivar "BRS Favorite", have been previously inoculated with *Bradyrhizobium japonica*, using the ratio of 1,200,000 bacteria per seeds. The sub subplots consisted of four rows, five meters long, with fifty cm between-row spacing. The physicochemical properties of the organic amendments are given in **Table 1**.

The experiment was carried out in a Dystrophic Cambisol (Inceptisol) [15], with a clay texture (53% clay); a low fertility soil: pH in water 5.4; P (Mehlich 1) 2.0 mg·dm<sup>-3</sup>; K 98.0 mg·dm<sup>-3</sup>; Ca<sup>2+</sup> 1.5 cmolc·dm<sup>-3</sup>; Mg<sup>2+</sup> 0.4 cmolc·dm<sup>-3</sup>; Al<sup>3+</sup> 0.2 cmolc·dm<sup>-3</sup>; sum of bases 2.2 cmolc·dm<sup>-3</sup>; cation exchange capacity (effective) 2.4 cmolc·dm<sup>-3</sup>; base saturation 35.0%; organic matter 40.0 g·kg<sup>-1</sup>; sand 310 g·kg<sup>-1</sup> and clay 400 g·kg<sup>-1</sup>.

At harvest, R8 phase [16], the attributes: number of pods per plant, number of grains per pod (10 plants sampled in the sub subplots), weight of 100 grains, grain yield (13% moisture), plant height and first pod height (10 randomly selected plants were sampled) were evaluated.

The data were analyzed using the Sisvar<sup>®</sup> software [17]. The significant effects were submitted to regression analysis for the doses of organic amendments and NPK fertilizer. The response surfaces were obtained and in-



**Figure 1.** Mean temperature (°C) and precipitation (mm) between November 2009 and April 2010. Engineering Department, Federal University of Lavras, Brazil.

**Table 1.** Physiochemical analysis of the poultry litter (PL), farmyard manure (FM) and biochar (BC).

Parameters	Units	Results		
		PL	FM	BC
pH in water	-	7.40	7.60	7.30
Electrical conductivity (EC)	dS·m <sup>-1</sup>	26.40	19.00	2.90
Water retention capacity	ml·g <sup>-1</sup>	2.10	1.80	0.80
Apparent density	g·cm <sup>-3</sup>	0.40	0.40	0.80
Total carbon	g·kg <sup>-1</sup>	411.00	285.00	191.00
Organic matter (OM)	g·kg <sup>-1</sup>	820.00	570.00	380.00
Total nitrogen (N)	g·kg <sup>-1</sup>	44.00	24.00	5.00
N-ammonium	mg·kg <sup>-1</sup>	362.00	70.00	26.00
N-nitrate	mg·kg <sup>-1</sup>	82.00	624.00	178.00
Total phosphorus (P)	g·kg <sup>-1</sup>	8.50	1.10	0.40
Total potassium (K)	g·kg <sup>-1</sup>	37.00	19.60	2.60
Sodium (Na)	g·kg <sup>-1</sup>	4.50	0.90	0.40
Calcium (Ca)	g·kg <sup>-1</sup>	31.00	9.50	13.00
Magnesium (Mg)	g·kg <sup>-1</sup>	11.50	5.40	2.30
Sulfur (S)	mg·kg <sup>-1</sup>	6.20	2.70	0.00
Boron (B)	mg·kg <sup>-1</sup>	46.70	13.00	0.00
Copper (Cu)	mg·kg <sup>-1</sup>	119.00	30.00	19.00
Iron (Fe)	mg·kg <sup>-1</sup>	2324.00	14.56	354.60
Manganese (Mn)	mg·kg <sup>-1</sup>	691.00	232.00	1107.00
Zinc (Zn)	mg·kg <sup>-1</sup>	624.00	82.00	371.00

\*Analyses performed at the Soil Science Department of Federal University of Lavras.

terpreted using the statistical package software Statistica<sup>®</sup> 6.0 for Windows.

### 3. Results and Discussion

All evaluated attributes were influenced by the treatments, except the number of grains per pod (**Table 2**). This attribute has a high genetic control being weakly responsive to environmental variation [18].

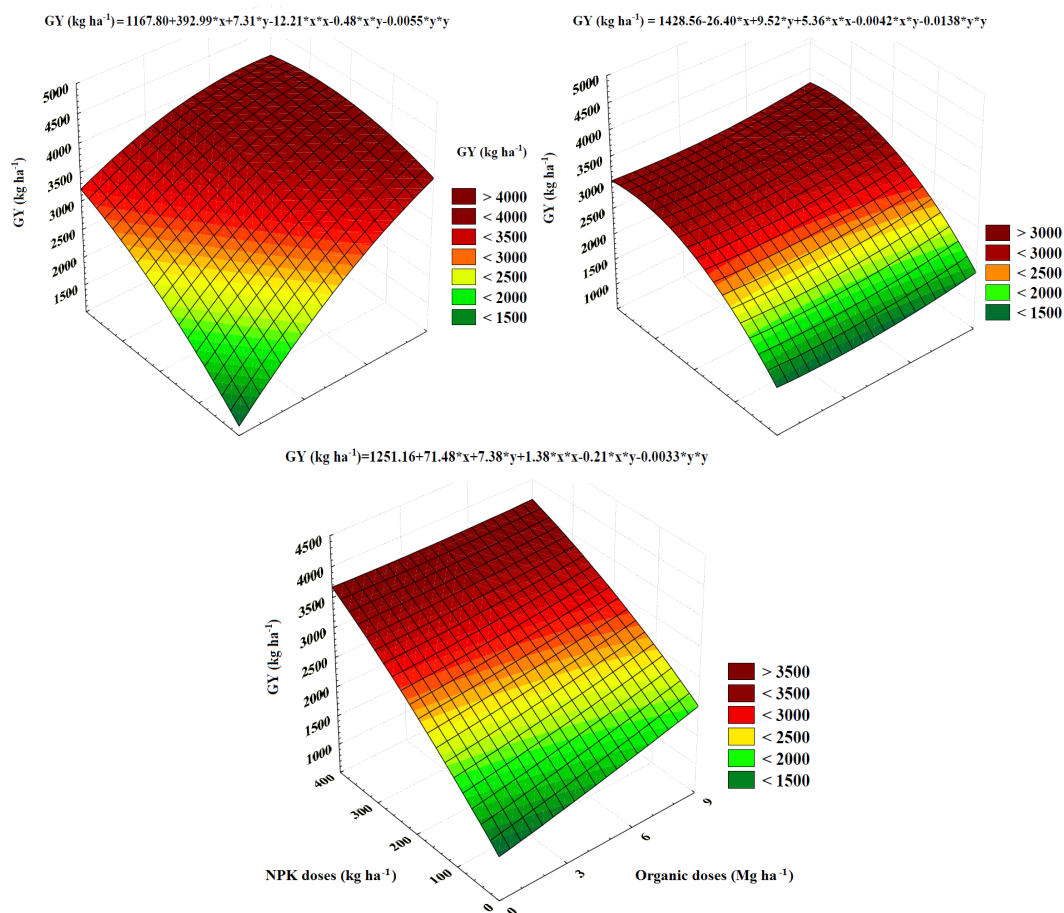
A triple interaction among the organic sources, their doses and mineral fertilizer doses was observed on the grain yield (**Table 2**). The effects of the organic amendments doses for each source were evaluated through the response surface methodology [19].

The biochar and the farmyard manure provided similar effect on the yield. The effects of mineral fertilizer doses were more expressive than the organic doses on the grain yield (**Figure 2**). On the other hand, a larger synergistic effect between the poultry litter doses and mineral fertilizer doses were detected. In this organic source, it was possible to achieve the highest yield levels (>4000 kg·ha<sup>-1</sup>) using only 9 Mg·ha<sup>-1</sup>; while for the biochar and farmyard manure, the increments were significantly lower than that (2000 and 1500 kg·ha<sup>-1</sup>, respectively). In both residues (FM and BC), the lower grain yield may be explained due the lower supply of nutrients

**Table 2.** Summary of the analysis of variance for grain yield (GY), number of pods per plant (PP), number of grains per pod (GP), weight of 100 grains (WG), plant height (PH) and first pod height (FP) obtained in the experiment organic amendments and mineral fertilizer on soybean crop.

Source	DF	Mean Square					
		GY	PP	GP	WG	PH	FP
Sources (S)	2	8185322.46 <sup>*</sup>	123.7905	0.0436	3.0209 <sup>§</sup>	1626.5389 <sup>*</sup>	18.4389
Error 1	4	784697.12	81.1228	0.0189	0.4482	216.5722	33.1556
Organic (D1)	3	4849677.82 <sup>**</sup>	655.2085 <sup>**</sup>	0.0339	30.3862 <sup>**</sup>	546.9704 <sup>§</sup>	3.3537
S × D1	6	2238745.74 <sup>**</sup>	74.9683	0.0187	1.0769 <sup>§</sup>	280.6426	18.1649
Error 2	18	394455.60	94.0005	0.0166	0.4091	215.3074	31.2500
NPK (D2)	4	15385770.98 <sup>**</sup>	839.5845 <sup>**</sup>	0.0154	12.2767 <sup>**</sup>	1597.9111 <sup>**</sup>	38.5083 <sup>*</sup>
S × D2	8	634253.48 <sup>**</sup>	71.7727	0.0131	1.3439 <sup>**</sup>	75.4694 <sup>§</sup>	10.9250
D1 × D2	12	347592.12 <sup>§</sup>	61.8711	0.0335	2.4604 <sup>§</sup>	30.1000	8.9972
S × D1 × D2	24	342170.26 <sup>*</sup>	73.2197	0.0293	1.1400 <sup>*</sup>	60.5917 <sup>§</sup>	15.6972
Error 3	96	192403.86	52.8298	0.0241	0.6828	39.1667	13.9236
Coefficient of Variation (CV)							
CV 1 (%)		31.23	32.23	6.71	4.67	21.29	22.81
CV 2 (%)		22.14	34.69	6.28	4.46	21.23	22.15
CV 3 (%)		15.47	26.01	7.57	5.76	9.05	14.78

<sup>\*\*</sup>, <sup>\*</sup>, <sup>§</sup> Significant at the 5%, 1% and 10% levels, respectively, by the F test.

**Figure 2.** Response surface for residual effects of the organic amendments sources and doses and the mineral fertilizer doses uses on the soybean grain yield.

to the soil, allocated by these wastes, in the studied doses. This fact justifies the need for further works considering the use of higher doses. When in suitable amount, biochar use can enhance agro ecosystems. Converting agricultural wastes into a useful soil amendment that holds carbon and makes soils more fertile, avoiding the deforestation and improving the food security [20] [21].

Through the response surfaces is observed that the best dose combination was the application of  $5.49 \text{ Mg}\cdot\text{ha}^{-1}$  of either organic amendments combined with  $200 \text{ kg}\cdot\text{ha}^{-1}$  of the mineral fertilizer; in order to obtain 2792; 2796 and  $3672 \text{ kg}\cdot\text{ha}^{-1}$  of soybean grains obtained by the farmyard manure, biochar and poultry litter use, respectively. The best yield obtained through poultry litter use might be due to higher concentration of nutrients in this input, providing higher residual effect on soybean crop. Once soybean plants are highly responsive to nutrient supply [22], mainly in dystrophic tropical soils and in agro ecosystems which have high levels of productivity, given the high nutrient demand for biomass production [23] [24].

These results are consistent with other studies that, by poultry litter use on soybean, also reported increases on grain yield [12] [25]. This fact demonstrates the high potential of the combined use of mineral fertilizers with organic amendments, as a synergistic way to increase the soybean grain productivity [9] [26].

In this study, the number of pods increased as a result of increases in organic rates of the amendments applied in the previous growth season and mineral fertilizer, in 2009 (Figure 3).

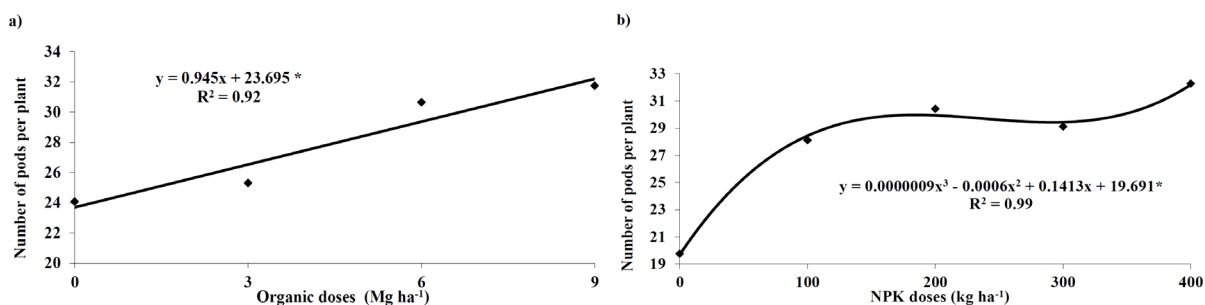
In the grain yield, one of the most important factors is the number of pods per plant. In soybean, the adequate plant nutrition is essential for enhance the pod set, which requires adequate availability of nutrients and assimilates in soybean plants [22]. These results are consistent with other studies, which it was observed a positive and high correlation between organic and mineral fertilizer use on number of pods per plants [21] [26].

The application of the organic amendments and mineral fertilizer influenced the grain weight (Figure 4(a)). It is observed that highest weights were obtained by increasing the doses in both inputs. This result is consistent with the findings by other authors evaluating the effect of organic and mineral fertilizers on soybean plants; hence, demonstrating that for tropical soils, generally low fertility, the major factor in the intensification of agricultural production is the adequate soil fertilization and consequent plant nutrition [8] [26]. The best combination of doses in each organic amendments was the same previously observed for the grain yield ( $200 \text{ kg}\cdot\text{ha}^{-1}$  of the mineral fertilizer associated with  $5.5 \text{ Mg}$  of the organic amendments) in order to obtain the weight of 100 grains of 14.2; 14.3 and 14.9 g, by the farmyard manure, biochar and the poultry litter addition, respectively. The poultry litter provided greater weight of 100 grains than the farmyard manure and the biochar, rendering the maximum weighs of 16 g per 100 grains when were combined  $100 \text{ kg}\cdot\text{ha}^{-1}$  of mineral fertilizer with  $9 \text{ Mg}$  of the organic input. Adequate plant nutrition is important for grains and seeds filling and, consequently, weight of them. According [27], seed size positively affects the productivity of soybean due to better plant stand and consequent establishment of the crop in the field, especially if sowing is done under water stress conditions [28].

Plant height was also influenced by the levels of organic amendments and mineral fertilizer (Figure 4(b)).

It was found greater plants growth with increasing doses. The maximum plants height, of 77.9, 76.8 and 65.1 cm, were obtained by the doses of 5.50, 3.51 and  $7.23 \text{ Mg}\cdot\text{ha}^{-1}$  of poultry litter, biochar and farmyard manure associated with 200, 200 and  $346.8 \text{ kg}\cdot\text{ha}^{-1}$  of mineral fertilizer (Figure 4(b)). Without mineral fertilizer, it was observed little influence of the farmyard manure and biochar doses on this attribute (green area on the response surface).

The doses of mineral fertilizer influenced the height of first pod (Figure 5).

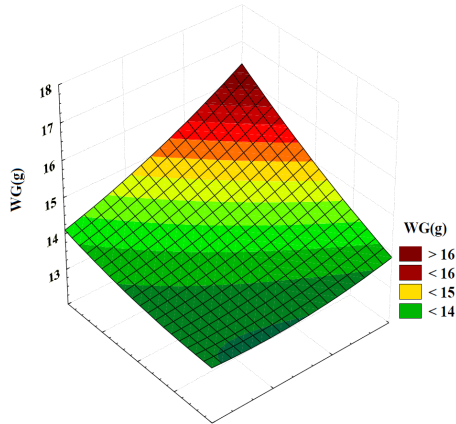


**Figure 3.** Regression analysis for the number of pods per plants due to the organic amendments doses a) and the mineral fertilizer doses b) on soybean plants. \*Significant at the 1% level, by the F test ( $p \leq 0.01$ ).

**BIOCHAR**

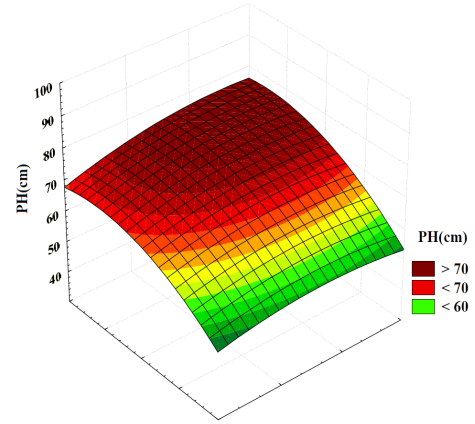
a)

$$WG(g) = 13.52 - 0.048x - 3.35E-5y + 0.0094x^2 + 0.0005x^2y + 3.72E-6y^2$$



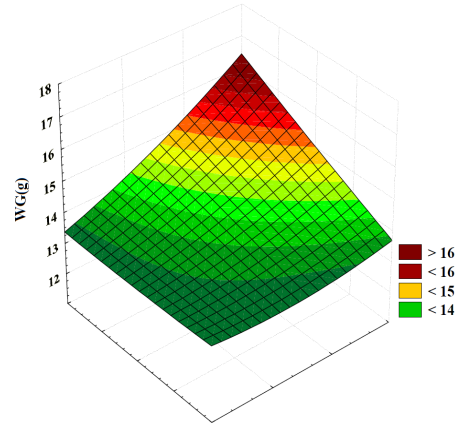
b)

$$PH(cm) = 51.73 + 1.52x + 0.11y - 0.15x^2 + 0.002x^2y - 0.0002y^2$$

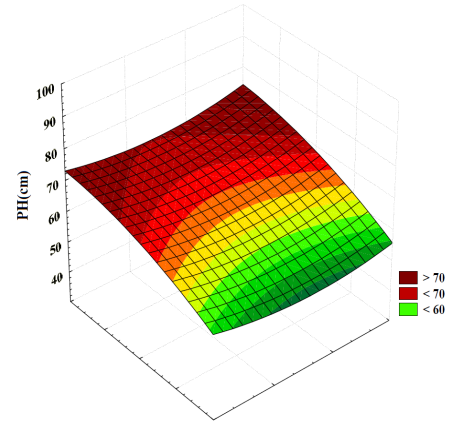


**FARMYARD MANURE**

$$WG(g) = 13.44 - 0.08x - 0.0006y + 0.0117x^2 + 0.0008x^2y + 1.0833E-6y^2$$

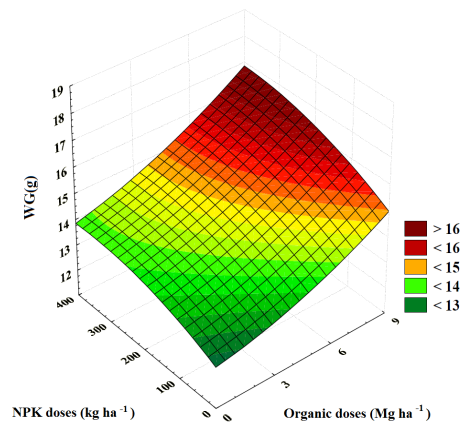


$$PH(cm) = 57.34 - 1.75x + 0.072y + 0.1733x^2 + 0.0008x^2y - 0.000008y^2$$

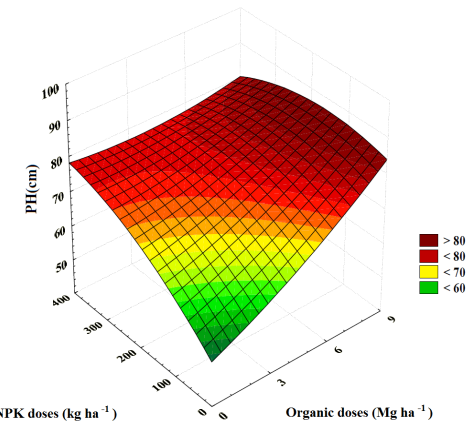


**POULTRY LITTER**

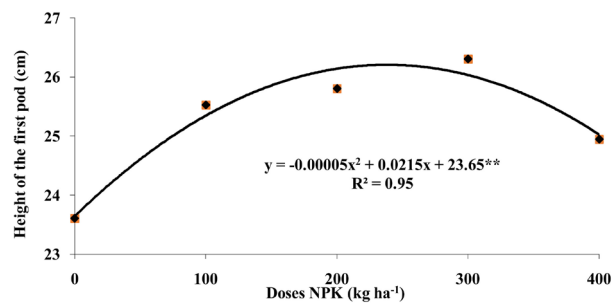
$$WG(g) = 12.59 + 0.1082x + 0.0072y + 0.0174x^2 + 0.0002x^2y - 1.0167E-5y^2$$



$$PH(cm) = 52.88 + 2.44x + 0.1075y + 0.1107x^2 - 0.008x^2y - 0.0001y^2$$



**Figure 4.** Response surface for residual effects of the organic amendments sources and doses and the mineral fertilizer doses on the weight of 100 grains (WG) a) and plant height (PH) b).



**Figure 5.** Regression analysis for the height of the first pod due to mineral fertilizer doses on soybean plants. \*\*Significant at the 5%, by the F test.

The maximum height of first pod (26 cm) was obtained using 215 kg·ha<sup>-1</sup> of the mineral fertilizer. The lowest observed height (23.6 cm) is appropriate to mechanical harvesting machines.

Several agronomic attributes of soybean, included grain productivity, can be expected to differ in response to organic and inorganic fertilization due the fertilizer sources, soil types, application rates and meteorological conditions [8] [20] [24]. Therefore, more studies should be done in order to determine the best and sustainable management practices of these inputs in the specific conditions and regions [29] [30].

#### 4. Conclusions

The best combination of the organic amendments and mineral fertilizer was the same for the grain yield and weight of 100 grains (200 kg·ha<sup>-1</sup> of the mineral fertilizer associated with 5.5 Mg of the organic amendments).

It is possible to decrease the dose of mineral fertilizers, by prior use of poultry litter, maintaining or boosting the levels of grain yield.

The previous use of organic amendments, rich in nutrients, is a promising technology to sustainably increase the soybean grain yield.

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