

Phosphated fertilization with organic and inorganic amendments in corn crops (*Zea mays* L.)

Fertilización fosfatada con enmiendas orgánica e inorgánica en maíz (*Zea mays* L.)

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ARTICLE DATA	ABSTRACT
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RESUMEN

La limitada disponibilidad de fósforo en la mayoría de los suelos de la Región Oriental del Paraguay restringe la productividad del maíz chipa, en donde la fertilización con fosfatos solubles podría ser una de las alternativas para compensar ese déficit nutricional del cultivo, además de la combinación con enmiendas hace más eficiente el uso de fertilizantes inorgánicos en este sistema de producción. El trabajo se

realizó en la localidad de Ybyrarobana, Canindeyú, con el objetivo de evaluar los efectos de dosis de fósforo, en combinación con enmiendas orgánica e inorgánica sobre la producción del maíz. Los tratamientos se distribuyeron en un diseño de bloques completos al azar en parcelas divididas, en 4 bloques. Las enmiendas (estiércol bovino y ceniza) y el testigo ocuparon las parcelas principales y las dosis de P_2O_5 (0, 40, 80, 120 y 160kg ha^{-1}) las subparcelas. Se determinaron parámetros químicos del suelo posterior a la cosecha, parámetros de crecimiento y caracteres de rendimiento del cultivo. Los datos fueron sometidos a ANDEVA y comparación de medias mediante el test de Tukey al 5% de probabilidad. A excepción de la longitud de espiga, las variables evaluadas mostraron diferencias significativas entre las enmiendas utilizadas, sin embargo, no se encontró significancia estadística entre dosis de P_2O_5 . La aplicación de estiércol bovino y ceniza de expeller de soja aumentaron los valores de pH del suelo y potasio intercambiable y disminuyeron el aluminio intercambiable, en tanto los tenores de calcio, magnesio y fósforo no fueron influenciados.

Palabras clave: Ceniza; estiércol de bovino; fósforo; maíz harinoso.

INTRODUCTION

Corn (*Zea mays* L.) is one of the most important cereals worldwide; it is one of the traditional subsistence crops of peasant families. The corn variety chipá or starch is characterized by grains with endosperm soft, and smooth amylaceous (Acosta, 2009). In Paraguay, the Guaraní indigenous people growth chipá maize and since then it has been rooted in their customs, and inherited from them so far (Rodriguez and Raveri, 2003). In Paraguay, small corn farms (1 -20ha) represent the 88.4% of the total. It is sown alone or associated with other food crops such as beans (*Phaseolus vulgaris* L.), pumpkin (*Cucurbita maxima* ssp.) and cassava (*Manihot esculenta* Crantz). Corn is used for self-consumption and cash crop. The average yield of chipa is low with just $1,500\text{kg ha}^{-1}$, growth on soils with low fertility and without fertilization, however, applying technologies, yields can be raised up to $5,000\text{kg ha}^{-1}$ (MAG and DCEA, 2017).

The areas planted with grain crops in soils of the Eastern Region of Paraguay present acidity levels with low phosphorus (P) content available to plants (Bataglia, 2011; Jorge, 2012). In this context, Zambrosi *et al.* (2012), highlight that the extractions of P and other nutrients are slowly but progressively impoverishing the soils, which is why it is essential to carry

out a good management in order to reduce its loss. Camas *et al.* (2012) and Almendro *et al.* (2003), argue that erosion, runoff, washing and extraction by harvest are the main causes of the loss of this element, while other factors such as the fixation and precipitation processes that occur in the soil are not considered losses, but they do reduce its bioavailability.

P is found in the soil in three fractions, a part in the soil solution, a labile fraction and a non-labile fraction (Rheinheimer and Anghinoni, 2001). The absorption of P by plants is directly related to its availability, which in turn is influenced by texture, fertilizer dose and by the time of contact with the soil (Vieira *et al.*, 2015). For their part, Oliveira *et al.* (2014) and Barbieri *et al.* (2013) highlights that the higher the clay content in the soil, the higher the adsorption of the P and lower availability. Contact of the P in the solution of the soil with the root is performed almost exclusively by diffusion process in which the element translocate short distances in a stationary aqueous phase, called solution soil, for the concentration gradient. Plants only absorb the P that is in the soil solution in the form of $H_2PO_4^{-2}$ (diacid phosphate ion) and HPO_4^{-2} (monoacid phosphate ion), (Malavolta, 2004).

With the intensification of agriculture to meet the growing demand for food, the production

and use of chemical fertilizers have increased, as well as the economic costs that this entails, which in many cases are difficult to achieve for most family producers, for such with organic fertilizer from animal waste, such as bovine manure stool it represents a valid alternative to reduce or make use of inorganic fertilizers more efficiently, which are added to the soil to improve their properties, both chemical, physical and biological, promoting plant nutrition, stimulate the microflora of the soil and increasing yields of crops (Sosa, 2005). Bovine manure in its dry form has relative contents of N (2%), P_2O_5 (1.5%), K_2O (2.2%), Ca (2.9%) and Mg (0.7%) (Osorio *et al.*, 2013).

Paraguay produces between 8 to 10 million tons of soybeans per annual harvest, where more than 30% are destined for industrialization (CAPECO, 2020), generating significant volumes of waste in the form of expeller and ash, it can be used as soil amendments. The ashes coming from the expeller soybean have an important alkaline character, by the presence of oxides, mainly Ca (0.25%) and Mg (0.35%) so it would be possible to use the correction of acidic soil and increasing the pH value of the soil (Solla *et al.*, 2001), in addition to contributing and increasing its availability of primary elements

such as P (0.65%) and K (2.5%), and increasing the activities of decomposing microorganisms of organic matter (Omil, 2007).

Therefore, the objective of the research is to evaluate the effects of the application of bovine manure and soybean expeller ash with phosphorus doses on the production of chipá corn and soil chemical parameters.

MATERIALS AND METHODS

The study was conducted in the period is september 2015 to february 2016, in the district of Ybyrarobana, Canindeyú Department, Paraguay, located between the geographical coordinates 24°20'20,45"S - 55°06'51,9"W. The experiment area has a climate subtropical, with average annual temperature of 21°C and rainfall reaching 1,600mm per year. The predominant soil in the area is classified as Arenic Rhodic Paleudult (Soil Taxonomy, USDA) with sandy texture, low fertility class, good drainage and zero rockiness (Lopez *et al.*, 1995).

Before the installation of the experiment, a physical-chemical analysis of the soil of the 0-20 cm deep layer was carried out (Table 1), verifying acidic pH, harmful exchangeable Al^{+3} , low MO percentage, low available P content and low exchangeable cations (Ca, Mg and K).

Table 1. Physical-chemical characteristics of the soil used in the experiment.

Prof.	pH	MO	Ca ⁺²	Mg ⁺²	K ⁺	Al ⁺³	P	Text
cm.	H ₂ O	%	----- cmol _c kg ⁻¹ -----				mg kg ⁻¹	
0-20	5.1	0.9	1.13	0.29	0.11	0.63	9	s

Extractors: pH = H₂O; P and K⁺ = Mehlich-1; Ca⁺² + Mg⁺² and Al⁺³ = KCl 1Mol L⁻¹; s = sandy

The study was performed on a complete block design to the randomly arranged in plots divided, and in four blocks, where amendments occupied the main plot and the dose of the phosphorus secondary. The amendments used were bovine manure (30Mg ha^{-1}), soybean expeller ash (0.87Mg ha^{-1}) and control (without application of amendment). The phosphorus doses applied were 0, 40, 80, 120 and 160kg ha^{-1} of P_2O_5 , totaling 60 experimental units. The experimental units had a dimension of 5.0m long by 3.5m wide (17.5m^2), with five rows of corn chipá, with spacing of 0.70 m between rows and 0.25m between plants, thus obtaining a density of $57.143\text{ plants ha}^{-1}$.

The source of P_2O_5 used was triple superphosphate (0-46-0). In all the treatments, 80kg ha^{-1} of N and 70kg ha^{-1} of K_2O were applied, using urea (45-0-0) and potassium chloride (0-0-60) as nitrogen and potassium sources, respectively. Soil preparation was in the conventional system, which was performed one plowing tracks and two days. The application of the organic amendments and inorganic fertilizers were carried out manually, fifteen days before the crops were sown.

Sowing was done using seeds without chemical treatment, using the variety Guaraní V 252 (avati moroti), it was done manually by using a ratchet, depositing 2 seeds per hole, approximately 15 days after emergence, thinning was carried out, leaving one plant per hole.

To control *Spodoptera frugiperda* was applied insecticide active ingredient Profenofos + Lufen Uron, with doses of 30mL in 20L^{-1} of water, three times during the cycle, the first 15 days after planting, second at 45 days and the third at 75 days. Weed control was carried out manually, through weekly carpidis.

The corn harvest was carried out manually, once the grains reached their physiological maturity. The surface harvested was 2.10m^2 , with targeted

samples or intentional is considering the central portion of each experimental unit. The variables analyzed were:

Soil chemical parameters. After the crop harvest, five simple samples were extracted to compose a composite sample at a depth of 0-0.10m from each experimental unit where the organic amendments with the doses of P were applied. Once dried and sieved to 2 mm samples the soil were determined: pH in water; available K^+ and P levels, extracted by Mehlich-1, K^+ being determined by atomic absorption spectrometry and P by the colorimetry method; tenors of Ca^{+2} , Mg^{+2} and Al^{+3} interchangeable, extracted with $\text{KCl } 1.0\text{mol L}^{-1}$. Al^{+3} being determined by titration with NaOH solution 0.015mol L^{-1} and the Ca^{+2} and Mg^{+2} by atomic absorption spectrometry, the OM was determined by the Walkley and Black method.

Stem diameter. They were selected 10 plants randomly from each experimental unit within the area useful, and using a digital caliper was determined the diameter of the stem above the second internode of each plant from the surface of the ground. The measurement was made at the time of physiological maturity of the crop (hard grain), the results were averaged and recorded in millimeters.

Plant height. Of the same 10 plants selected in the used area, the height measurement was done by using measuring tape, measuring from the base of the stem to the tip of the inflorescence male (panicle). The measurement was made when the plant was in physiological maturity, the results of which were averaged and expressed in centimeters.

Number of leaves per plant. They were selected randomly 10 plants of each experimental unit, which were quantified number of leaves, subsequently averaged.

Spike length. From the selected plants, the spikes were harvested and measured with a ruler graduated in centimeters, from the base to the upper end, discarding the husks, averaged, whose results were expressed in centimeters.

Spike diameter. The same pins chosen for length measurement, were used to determine the diameter, using one digital caliper, and then the data were averaged and recorded in millimeters.

Dry mass of aerial part. Is used five whole plants from the central part of each experimental unit, considering stem, leaves, husks and tassel ears with which were weighed, crushed and mixed. From this mixture, a sample was extracted that was subsequently dried and subjected to an oven at 60°C for 72 hours, which was weighed again, whose results were expressed in kg ha⁻¹.

Performance grain. In the harvested dowels the useful area of each experimental unit (2.10m²) manually. Subsequently, the shelling was carried out to bag and weigh them with a precision balance, where the results were expressed in kg ha⁻¹.

Thousand grain weight. In randomly selected from each unit experimental ad 100 grains with eight repetitions, which were weighed using precision scales and averaged by calculating the weight of a thousand grains by simple rule of threes.

The data obtained were subjected to analysis of variance according to the model of divided plots, in the treatments that yielded statistical significance, the comparison of means was carried out with the Tukey test at 95% probability and regression analysis, using the statistical program InfoStat (Di Rienzo *et al.*, 2008).

RESULTS AND DISCUSSION

Soil chemical parameters. Soil pH values both in the control and where the organic amendments

were applied showed an acid level (<5.5). However, the application of ash expeller soybean caused increase of the pH, reaching 5.38, differed or statistically obtained from the witness 4.73. While the pH of the soil where the application of bovine manure occurred presented a value of 5.23, without presenting a significant difference compared to the other treatments (Table 2). These results match those obtained by González (2016), in a similar experiment observed change in the pH of the soil with the application of 0.87Mg ha⁻¹ ash expeller soybean. The pH of the soil was not influenced by applying 25Mg ha⁻¹ of bovine manure, possibly for the little, considering that the ash is an alkaline material, the increase in pH in the short term was to be expected.

To amendment organic employed caused decrease in the values of a the Al⁺³ interchangeable, initially with high toxicity (1.1cmol_c kg⁻¹) to values low toxicity (0.47cmol_c kg⁻¹) but no statistical differences between treatments. The application of bovine manure increased the concentration of exchangeable K⁺ initially of low level (0.09cmol_c kg⁻¹) to a maximum value of 0.15cmol_c kg⁻¹, statistically equal to the treatment with application of ash from soybean expeller, but both superior to the control (Table 2). Likewise, these results were similar to those obtained by González (2016), who, incorporating the same sources and doses of organic amendments, observed an increase in the contribution of K⁺ with values of 0.16cmol_c kg⁻¹ (bovine manure) and 0.14cmol_c kg⁻¹ (soy expeller ash). According to the analysis of variance and the value of p> 0.05, the contents of MO, P, Ca and Mg in the soil, all with initially low levels, were not significantly influenced by the application of the amendments, also without interaction between factors (Table 2). Possibly doses applied amendments seven were low to alter fertility of the soil, mainly short time in the case of the organic amendment.

Table 2. Soil analysis of the 0-10 cm litter at the end of the experiment according to sources of amendments. Ybyrarobana, Canindeyú, Paraguay, 2016.

Sources of amendments	pH	MO	P	Ca ⁺²	Mg ⁺²	K ⁺	Al ⁺³
		-% -	--mg kg ⁻¹ -	-----	-----	cmol _c kg ⁻¹ -----	
Ash	5.38 a	0.78 ^{ns}	8.13 ^{ns}	0.63 ^{ns}	0.22 ^{ns}	0.11 ab	0.47 ^{ns}
Manure	5.23 ab	0.82	6.31	0.58	0.21	0.15 to	0.47
No amendment	4.73 b	0.81	7.00	0.53	0.13	0.09 b	1.17

CV, coefficient of variation; ns, not significant. Means followed by different letters differ from each other by Tukey's test at 5% probability of error.

Growth parameters of culture corn.

According to the analysis of variance, as variables height of plant, number of leaves per plant, air dry mass and diameter of the stem had significant effect by applying the amendments organic, whose averages were above is to the control, but no differences between both and without interaction between factors. These results are similar to those obtained by Lopez *et al.* (2015), who, when applying the same treatments in relation to amendment in the same crop, obtained increases of 0.35m in plant height and 5850kg ha⁻¹ in aerial dry mass. Similarly, Rivas (2018) applying 0 to 15Mg ha⁻¹ of bovine manure with doses of 0 to 140kg ha⁻¹ of P₂O₅ observed an increase in plant height, stem diameter and dry mass area of up to 0.66 m, 0.55mm and 2.882kg ha⁻¹ respectively compared to the control. However, Longoria (2000) found no statistical significance manure bovine incorporate plant height corn diameter of the stem and dry air

mass, with mean values of 2m; 2.28cm and 108g pl⁻¹ respectively.

The use of organic amendments in this experiment, caused a greater availability of nutrients, satisfying to a great extent the demand from the chipá corn, promoting an increase in its growth parameters. Bovine manure is made up of liquid droppings, as well as solid droppings, the latter constituting the main source of N, an essential element that favors greater vegetative development (Van Raij, 2011).

As for the dose of P₂O₅ applied no difference found significant on the same variables analyzed, nor was interaction observed between both. However, a slight trend of increase is observed depending on the maximum dose of 80 kg ha⁻¹ of P₂O₅ (Table 3). These results coincide with Alvarado (2002), who did not find differences in the height of the corn plant due to the application of increasing doses of P.

Table 3. Plant height, number of leaves per plant, aerial dry mass and diameter of the corn stem as a function of P_2O_5 doses and sources of amendments. Ybyrarobana, Canindeyú, Paraguay, 2016.

Amendment Factor Sources ($Mg\ ha^{-1}$)	Dose	Plant height	Leaves plant ⁻¹	Aerial dry mass	Stem diameter
		---m---	-number-	kg ha ⁻¹	---mm---
Bovine manure	30	2,47 a	14,67 a	12.757 a	23,06 a
Ash	0,87	2,42 ab	14,32 ab	12.122 ab	22,75 a
No amendment	0	2,35 b	14,09 b	10.842 b	21,37 b
General average		2,41	14,36	11.907	22,39
Phosphorus Factor Dose ($kg\ ha^{-1}$)					
	0	2.38 ^{ns}	14.18 ^{ns}	11,30 ^{ns}	21.79 ^{ns}
	40	2.39	14.35	12,184	22.00
P_2O_5	80	2.48	14.59	12,322	22.94
	120	2.41	14.29	11,577	22.81
	160	2.40	14.38	12,151	22.42
CV%		4.20	4.18	14.21	6.46
General average		2.41	14.36	11,907	22.39

CV, coefficient of variation; ns, not significant. Means followed by different letters differ from each other by Tukey's test at 5% probability of error.

Characters of the cultivation of the corn.

The shank diameter and thousand seed weight showed significant increases by application of cattle manure and soybean expeller ash when compared to the control, and both shank lengths, not was influenced. Rivas (2018) applying 0 to 15 $Mg\ ha^{-1}$ of manure with increasing doses up to 140 $kg\ ha^{-1}$ of P_2O_5 , as in the evaluated growth parameters, observed a significant effect with maximum values of 3.59cm in diameter of spikes and 241g in the weight of a thousand seeds. Meanwhile Longoria (2000) using the same treatments with organic amendment, it did not find significant differences in the length and diameter shank of corn yield overall mean of 28 and 4.63cm respectively.

Furthermore, no statistical significances were detected between treatments at doses of P and with no interaction between factors, for the parameters of spike length, shank diameter and thousand kernel weight (Table 4) that obtained average values of 17.04cm; 37.61 μm and 223g, respectively. In the same way, Salvador (2016) and Romero (2017) to the fertilizer apply phosphating not observed influence to about the length and the diameter of pins corn coinciding with the results obtained in this investigation, showing that short term is difficult to obtain response to the application of deteriorated soils. The length and diameter shank in corn is a self-genotypic characteristic of each cultivar, influenced sometimes by external factors as the humidity of the soil and plant density.

Table 4. Spike length, spike diameter and weight of a thousand corn grains based on P_2O_5 doses and sources of amendments. Ybyrarobana, Canindeyú, Paraguay, 2016.

Amendment Factor				
Sources (Mg ha ⁻¹)	Dose	Spike length	Shank diameter	Thousand grain weight
		---- cm ----	---- mm ----	---- g ----
Bovine manure	30	17.13 ^{ns}	37.92 a	230 a
Ash	0.87	17.24	37.80 ab	224 ab
No amendment	0	16.76	37.10 b	215 b
General average		17.04	37.61	223
Phosphorus Factor				
Dose (kg ha ⁻¹)	Dose	Spike length	Shank diameter	Thousand grain weight
	0	16.82 ^{ns}	37.22 ^{ns}	219 ^{ns}
	40	16.60	37.81	220
	80	17.33	37.82	222
	120	17.39	37.75	231
	160	17.07	37.44	222
CV%		4.63	2.73	6.04
General average		17.04	37.61	223

CV, coefficient of variation; ns, not significant. Means followed by different letters differ from each other by Tukey's test at 5% probability of error.

The yield of corn grains was significantly influenced by the application of bovine manure and soybean expeller ash, obtaining values of 4.692kg ha⁻¹ and 4.395kg ha⁻¹ exceeding the treatment without application of amendment in 761kg ha⁻¹ and 464kg ha⁻¹ respectively (Table 5).

Applying MO through manure bovine is widely used in most crop farming, in order to improve and maintain the conditions of the soil and increasing agricultural productivity, particularly their high concentration of N on dry matter (1.6%) that applied doses of 30Mg ha⁻¹, contributes approximately 13 0 kg ha⁻¹ of N available to the crop, assuming 45% mineralization of N and 60 % efficiency of use of mineralized N (Figuerola-Viramontes *et al.*, 2010). This can be corroborated in other experiments such as González (2016), who using the same variety of corn, with the same treatments of this experiment, observed that grain yield increased up to 15% in relation to the control.

Table 5. Yield of corn grains according to sources of amendments, Ybyrarobana, Canindeyú, Paraguay, 2016.

Amendment Factor		
Sources (Mg ha ⁻¹)	Dose	Grain yield
		---- kg ha ⁻¹ ----
Bovine manure	30	4.692 a
Ash	0.87	4.395 ab
No amendment	0	3.931 b
General average	0.61	4,339
Phosphorus Factor		
Dose (kg ha ⁻¹)	Dose	Grain yield
		---- kg ha-1 ----
	0	4099 ^{ns}
	40	4370
	80	4407
	120	4754
	160	4067
CV%	6.4	6.04
General average		4352

CV: coefficient of variation; Means followed by different letters differ from each other by Tukey's test at 5% probability of error. ns: not significant.

Likewise, Rivas (2018) applying 7 and 15Mg ha⁻¹ of bovine manure on deteriorated soil, found considerable increases in grain yield, initially from 779kg ha⁻¹ in the control to 2,952kg ha⁻¹ and 4,061kg ha⁻¹ respectively. No significant difference was found between the doses of P₂O₅ or interaction between factors. The results do not match Salvador (2016), who found increases in grain yield of the corn a fertilized or with P and compared to treatment without P, with a difference of 1503kg ha⁻¹. On the other hand, Alvarado (2002), obtained increases of 857kg ha⁻¹ in the yield of corn grains, applying 70kg ha⁻¹ of P₂O₅, compared to the control.

This s results in the parameters of performance of maize, it can be a result, that only the approximately 20% of phosphorus (P₂O₅) applied is used by cultivation in the first year, because the phosphorus released can be adsorbed by soil colloids or form insoluble iron and aluminum compounds (Silva, 2007).

It is estimated that another factor that could influence the non-response of corn to the doses of P₂O₅ was the non-application of agricultural lime, since the soil where the experiment was implanted initially presented strongly acidic pH (Table 1), decreasing the availability of P, therefore its absorption by the corn crop. The not applying agricultural lime obeys to determine the effect of amendments organic acid on the levels of the ground, determined by the values of pH and Al⁺³ the interchangeable.

Also can highlight, is that the ground is in a state of extreme deterioration in their fertility levels and the dose of organic amendments with P applied via chemical fertilization, is rum in sufficient a period of one year for recovery, mainly when relate to the activity micro biological, increase in the content of organic matter and supply of nutrients, not meeting

even beneficiaries significates, that for more that provide high amounts in many situations, the former initial terms limitations of the soil, not only in its chemical properties but also in physics, by initially presenting high levels of compaction, significantly reduce the response of crops to applied fertilizers, whether chemical or organic.

CONCLUSION

Under the conditions of this study, the application of phosphorus doses in combination with bovine manure and soybean expeller ash increased corn production.

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