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Effect of organic N-sources on maize yield components

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Abstract

Maize is one of the main staple crops of the world but needs large amounts of nitrogen (N) to achieve a high yield. Mineral N fertilization is one of the main production costs to cultivation and organic N sources could be a cost-effective alternative to mineral sources. We hypothesized that organic N sources could replace mineral fertilizer whilst maintaining high yields. Therefore, our study examined the effect of N supplied through organic sources on the yield of maize and its components and evaluated the economic viability of using organic N sources in terms of cost savings of energy resources. A field experiment was carried out in the Southeastern region of Brazil (São Paulo state) on a Typical Acrudox soil with a clay texture. The experiment was set out in a complete randomized block design, with six treatments (five N sources + control) and four replicates. The treatments were: (A) mineral source (urea - Ur); (B) a by-product from the food industry (Fby); (C) biofertilizer from swine manure (Bs); (D) poultry bedding (Pb); (E) cattle manure (Cm); and (F) control (Co - without N). The maize yield components evaluated were plant height (V6 and R2 stages), root dry mass and morphoanatomy (R2 stage) and, at harvest, grains in ears, thousand kernel weight (TKW), productivity and crop residues dry mass. Economic viability was assessed by considering the cost of each N source in relation to gross economic revenues from the sale of corn. Overall, the results showed that only Fby produced better yield components and was more productive than urea. This source also provided the highest economic revenue and the lowest fertilizer cost for each unit produced. The Pb and Cm sources were less productive than the mineral source, but were better than Bs, which was slightly better than the control (without N application). The same pattern of results was found for economic revenue and fertilizer cost. Bs was the most expensive N source and consequently gave the lowest economic returns to farmers. In summary, the N efficiency of the organic sources as an alternative to mineral sources for high-yield maize was ranked as follows: Fby >Ur> Pb > Cm > Bs > Co.

Keywords: organic fertilizer, productivity, root system, crop residues, N-efficiency.
***Abbreviations*:** Bs_biofertilizer from swine manure; Cm_cattle manure; Co_control; Fby_food by-product; Pb_poultry bedding; Ur_urea.

Introduction

Maize (*Zea mays* L.) is the most frequently produced and consumed staple crop worldwide. Due to its high-yield potential and nutritional value, it provides several products used for human and animal feed and industrial applications (Okumura et al., 2011). During the 1960s the "Green Revolution" led to an increase in maize productivity through genetic selection, fertilizer use and agrochemicals, and, more recently, transgenic cultivars have further improved productivity and resistance to pests and diseases. Brazil plays an important role in the grain market, currently being the third largest producer in the world, with an estimated 84 million tons being produced on about 16 million hectares (CONAB, 2017).

Nitrogen (N) is one of the most limiting nutrients for maize productivity and is required in large amounts, mainly at the initial stage of plant development (Reichardt et al., 1979; Bredemeier and Mundstock, 2000; Costa et al., 2012). In plants, N content ranges from 1 to 4% in dry matter. In the soil, most N is complexed with carbon composts in the soil organic matter (SOM), the N content of which ranges between 0.05 and 0.5%. Generally, less than 5% of soil total N is in an inorganic form (ammonium and nitrate) available to plants (Whiethölter, 2000).

Non N-fixing crops, such as maize, require the supply of N in addition to the mineralized N in the SOM. However, more than 60% of the N fertilizer applied is not used by the plants, and thus, the annual cost of N can be very high (Raun and Johnson, 1999). For farmers with high-yield crops, the key to useful N fertilization is precise planning. They need to meet the crop's exact demands to provide the N available from fertilizer in an accurate 'window', thus avoiding the loss of reactive-N forms to the atmosphere by volatilization and denitrification and to deeper soil by leaching.

Animal wastes and industrial by-products have been highlighted as alternative sources of N for cultivated plants (Vanlauwe et al., 1997). Among the advantages of these N sources are: I) environmental - the need to find an appropriate destination for the large quantities of (animal or industrial) residues produced makes their reuse/recycling a useful practice; II) organic sources release N gradually, with low gaseous losses or leaching, therefore reducing environmental pollution; III) economic - they are cheaper per unit of N, and generally contain other nutrients (Gil et al., 2008; Pavinato et al., 2008; Sistani et al., 2008) and also help to maintain and improve soil quality (Leite et al., 2003).

As well as reducing N losses, plants need to be able "to capture" nutrients. Plants thus need to have a root system that occupies a good mass of soil and will benefit water and nutrient absorption, especially the absorption of nutrients that are more mobile in the soil, such as N (Barley, 1970; Cantarella, 1993).

Although studies have been conducted to evaluate the use of organic N sources for grain production (Chantigny et al., 2004; Giacomini et al., 2010; Novakowiski et al., 2013), there is little data on the effects of N sources (mineral and organic) on the root morphoanatomy related to maize productivity. Thus, we hypothesized that organic N sources could replace mineral fertilizer while maintaining high yields in maize. Our study thus compared the efficiency of N supply by four organic sources applied in high-yield maize.

Results and discussion

Overall, this study evaluated the crop yield, root morphoanatomy and economic viability of the follow N sources: (A) mineral source (urea - Ur); (B) a by-product from the food industry (Fby); (C) biofertilizer from swine manure (Bs); (D) poultry bedding (Pb); (E) cattle manure (Cm); compared to (F) control (Co - without N).

Efficiency of organic N sources during maize development (V_6 and R_2 stages)

The organic N sources applied to maize had a beneficial effect on initial maize development relative to the control (zero N), as illustrated by plant height at the V6 stage (HP_{V6}), before topdressing ($p \leq 0.05$; Table 1). Application of the organic mineral (Fby) and mineral (Ur) sources produced taller plants ($p \leq 0.05$). This pattern was maintained after topdressing, as illustrated by plant height (HP_{R2}) and ear height (HE) in the R_2 stage. In contrast, swine manure (Bs) resulted in shorter plants at the V_6 and R_2 stages in relation to the other organic sources ($p \leq 0.05$). The remaining organic N sources (poultry bedding-Pb and cattle manure-Cm) presented intermediate values, which were 8% lower than Fby and the mineral source, but higher than Bs ($p \leq 0.05$).

Overall, plant height at the R_2 stage (HP_{R2}) was higher than the control regardless of the N source (mineral or organic), by 20 to 45%. Several authors have reported that maize responds positively to N supply, with a direct increment in plant height and, consequently, in productivity (Pauletti and Costa, 2000; Mar et al., 2003; Araújo et al., 2004; Efthimiadou et al., 2010, Torres et al., 2014; Cruz et al., 2015).

Effects of organic N sources on maize root morphoanatomy

The largest root diameter was found in the Fby-treated plants, followed by Bs, Ur, Co, and finally, in the Pb and Cm plants (Table 1, Fig. 1). Wilcox et al. (2004) indicated that thick roots (diameters greater than 2 mm) are associated with plant anchorage and support. On the other hand, a smaller root diameter allows contact with a larger volume of soil per unit of root surface area (Gahoonia and Nielsen, 2004), favoring the absorption of water and nutrients. Thereby, Fby may have provided enough N to the plant, requiring from the root a better anchorage capacity rather than soil exploration.

Plants treated with Fby also had the largest number of cortical parenchyma cell layers (Table 2; Fig. 1-iv). Meanwhile, plants treated with Cm had the fewest cell layers. Plants treated with Co and Ur presented intermediary values and did not differ significantly from each other ($p \geq 0.05$). As these cells retain cell division capacity even though cell differentiation has already occurred (Scatena and Scremin-Dias, 2006), the higher number of cell layers in the Fby plants may be associated with higher root growth.

As indicated by the root diameter parameter, the highest number of sclerenchyma cells was found in Fby plants and the lowest in Pb and Cm plants ($p \leq 0.05$). The similar behavior between these two parameters reflects the fact that a larger diameter of roots and vascular cylinder is associated with a higher number of sclerenchyma cells. Once lignified, these cells provide better plant protection of the vascular tissue (Scatena and Scremin-Dias, 2006).

The Fby plants had the highest number of protoxylem poles, while the Bs plants had the lowest number of poles ($p \leq 0.05$). A high number of protoxylem poles indicates that the plant is still producing new roots. On the other hand the low number of protoxylem poles in Bs plants in association with a high number of sclerenchymal cells indicates a more advanced stage of root development.

Based on this information and the maize productivity shown in Table 1 we can surmise that Bs did not provide an adequate N supply to the plants, as the maize productivity and morphoanatomic results of Co and Bs were similar. In an intermediate scenario, Pb and Cm plants had smaller root diameters, fewer sclerenchyma cells and more protoxylem poles. However, Pb and Cm plants grew better (productivity and root growth) than the Bs and Co plants, due to the slower mineralization of N from the organic sources and later root growth.

The numbers of layers in the central cortex and protoxylem poles are anatomical characters that may influence the root diameter. However, each of these parameters will have more or less influence on total diameter, as environmental or cultivation conditions may influence the development of fertilization had a thicker root cortex than the rice grown in soil without fertilization.

Table 1. Maize yield compounds of each N-source applied in the sowing and topdressing.

Variables [1]	Co	Ur	Fby	Bs	Pb	Cm	C.V.%[2]
			Vegetative (V_6 stage)				
Plant height 1 (cm)	102.3 c	130.6 ab	132.7 a	115.5 b	120.5 b	127.0 ab	13.5
			Reproductive (R_2 stage)				
			Aboveground				
Plant height 2 (cm)	185.0 d	259.6 a	262.6 a	224.3 c	238.7 b	240.6 b	12.7
Ear height (cm)	80.6 c	118.0 a	116.9 a	95.2 bc	100.9 b	104.0 b	15.1
Underground							
Root mass (kg ha^{-1})	2037.7 c	2614.2 b	2767.1 a	1986.6 c	2005.3 c	2261.5 b	32.3
			Harvest				
Grains in ear (g)	51.1 d	120.9 b	136.0 a	58.1 d	88.3 c	99.9 c	29.3
TKW (g)	263.2 d	305.9 b	322.3 a	267.7 d	298.7 b	293.1 c	11.9
Productivity (kg ha^{-1})	3921.5 d	9269.0 b	11260.0 a	4456.3 d	6773.5 c	7664.8 c	28.9
Crop residues (kg ha^{-1})	4417.0 d	8159.0 b	9229.8 a	4373.3 d	6595.3 c	7411.8 b	35.8
			Crop efficiency index				
Root/Shoot ratio	0.28 b	0.17 a	0.16 a	0.26 b	0.18 a	0.17 a	25.8
N-source efficiency	...	35.6 b	48.9 a	3.6 d	19.0 c	24.9 c	22.7

Vegetative – V6 = before topdressing; Reproductive = ears formation (physiologic maturity); TKW = thousand kernel weight with 13% of humidity. Co = control; Ur = mineral source - urea; Fby = by-product from the food industry; Bs = biofertilizer swine; Pb = poultry bedding; Cm = cattle manure. CV% = coefficient of variation; nd = not determined. Same letter in line do not differ according to Tukey's test (p ≤ 0.05).

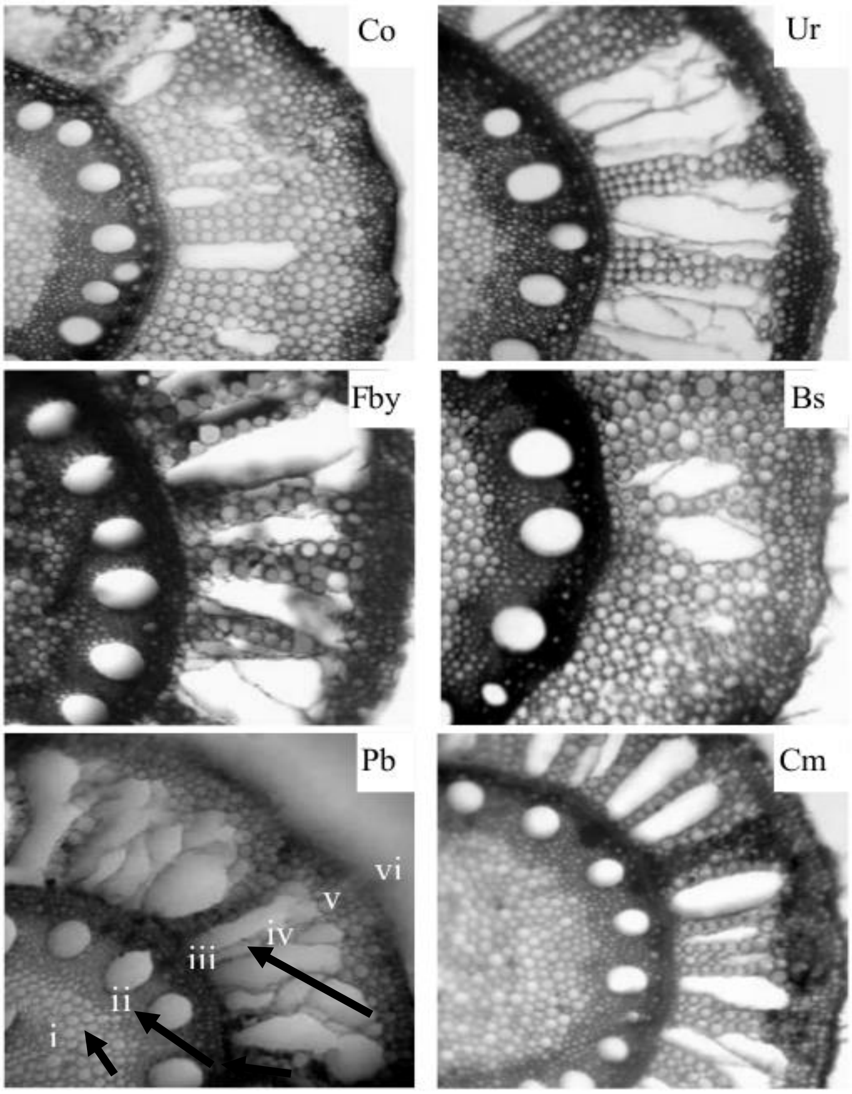

Fig 1. Transversal sections of maize roots; i) central cylinder – endoderm; ii) metaxylem and protoxylem iii) endoderm with U-thickening tissue and sclerenchyma; iv) cortex – aerenchyma; v) cortex – parenchymatous cells; vi) epiderm. Treatments: Co – control; Ur – urea; Fby – by-product from the food industry; Bs – biofertilizer swine; Pb – poultry bedding; Cm – cattle manure.

Table 2. Biometry and morphoanatomy of maize roots of each N-source applied in the sowing and topdressing.

Treatments	Diameter	Cortex	Vascular cylinder	
	mm	Parenchyma	Sclerenchyma	Protoxylem
Co	1.6 b	13.2 c	4.1 b	19.8 d
Ur	1.6 b	12.8 c	4.1 b	24.2 b
Fby	2.5 a	16.0 a	5.5 a	30.2 a
Bs	1.7 b	11.8 d	4.2 b	17.2 e
Pb	1.2 c	14.8 b	2.2 c	21.8 c
Cm	1.3 c	10.8 c	2.8 c	19.8 d
CV (%)	2	3.1	14.6	2.1

Cortex and vascular cylinder = number of cells. Co = control; Ur = mineral source - urea; Fby = by-product from the food industry; Bs = biofertilizer swine; Pb = poultry bedding; Cm = cattle manure. Same letter in column do not differ according to Tukey's test ($p \leq 0.05$); CV.% = coefficient of variation.

Table 3. Chemical composition of the organic materials.

Materials	N	P	K	Ca	Mg	O.M.	pH
	--------------------- (g/100g) ----------------------					%	
Fby	7.5	3.0	2.2	9.0	7.2	21.5	4.9
Bs	2.0	0.04	0.07	0.02	0.009	21.9	6.0
Pb	2.3	2.4	3.6	2.3	0.7	65.5	8.2
Cm	2.5	1.6	1.4	1.4	0.4	67.0	6.5

Fby = organic-mineral food by-product; Bs = biofertilizer swine; Pb = poultry bedding; Cm = cattle manure; O.M. = organic matter.

Table 4. Treatments description and identification, quantities of each N-source applied in the sowing and topdressing.

Treatment	Id	Sowing (eq. 30 kg N ha^{-1})	Topdressing (eq. 120 kg N ha^{-1})
Control (without N)	Co	...	...
Mineral fertilizer (urea)	Ur	70 kg ha^{-1}	250 kg ha^{-1}
Food by- product	Fby	320 L ha^{-1}	1280 L ha^{-1}
Biofertilizer swine manure	Bs	1500 L ha^{-1}	6000 L ha^{-1}
Poultry bedding	Pb	1300 kg ha^{-1}	5200 kg ha^{-1}
Cattle manure	Cm	1200 kg ha^{-1}	4800 kg ha^{-1}

Table 5. Quantity of N (%), Amount of negotiated product (kg), total cost and per unit of each source used in São Lourenço Site, Leme, SP.

Source	Formulation	N	Retail	Total cost	Per unit
	NPK	%	kg	A$	A$ kg^{-1}
Mineral with N – planting	06-24-10	6	50	31.80	0.64
Mineral with N – cover	18-00-18	18	50	34.20	0.68
Mineral without N – planting	00-24-10	0	50	22.40	0.45
Mineral without N – cover	KCl	0	50	14.80	0.30
Fby	nc	7.5	1000	47.10	0.05
Bs	nc	2	1000	38.60	0.04
Pb	nc	2.3	1000	42.90	0.04
Cm	nc	2.5	1000	42.90	0.04

Fby = by-product from the food industry; Bs = biofertilizer swine; Pb = poultry bedding; Cm = cattle manure.

Table 6. Yield (sacks per hectare), fertilization costs during planting, cover and total (AUD $); Gross revenue (AUD $); Net revenue (AUD $); Fertilization cost for maize production (%) in the study realized in the São Lourenço Site, municipality of Leme, SP.

Treatments	Yield	Fertilization costs			Gross revenue	Net revenue	Fertilizer cost
		Planting	Cover	Total			
	sc ha^{-1}	---------------------------------- A$ ----------------------------------					%
Co	65.3	260.80	221.80	482.50	994.40	511.90	49
Ur	154.5	357.30	513.30	870.60	2352.80	1482.20	37
Fby	237.6	272.70	306.60	579.30	3618.30	3039.00	16
Bs	74.4	316.50	482.10	798.70	1133.00	334.30	70
Pb	112.8	314.30	473.30	787.70	1717.80	930.10	46
Cm	127.7	309.30	453.20	762.50	1944.70	1182.20	39

Co = Control; Ur = Mineral source; Fby = by-product from food industry; Bs = biofertilizer from swine manure; Pb = poultry bedding; Cm = Cattle manure these structures in the roots and, consequently, the final root diameter (Moreira and Isaias, 2008).

Duarte et al. (1993) observed that, rainfed rice grown on soil with limestone application and high N concentrations from

Venkatraman and Thomas (1922) noted anatomical differences in sugarcane roots grown under different fertilization conditions, as the cortex and vascular cylinder thickness were higher in irrigated soils than in dry ones and there were more sclerified cells in roots grown under dry conditions with organic N sources than in irrigated conditions. The root/shoot ratio was higher in the Co and Bs plants and lower in plants treated with the other N sources ($p \leq 0.05$). In a very well known study, Anderson (1988) reported the same result, showing that as the N content increased, the maize root/shoot ratio decreased. In addition, a higher soil N content benefits the plant by allowing it to utilize the photosynthate products for shoot growth and grain yield, instead of root development.

Maize yield components and efficiency of N sources

At harvest, all yield components - mass of grains in ear, TKW, productivity and crop residues production were higher in Fby ($p \leq 0.05$). It is possible that due to their physic-chemical characteristics (high density liquid, where total-N content its compost by 60% as ammoniacal-N readily available, and 40% as amidic-N associated to organic material with slow release) this source resulted in a better N availability to plants, remaining closer to the seeds in sowing and, later, in topdressing, in greater contact with maize root system. Therefore, this source fulfills two functions: I) provides the nutrient in quantity to the crop demand and, II) reduces possible losses by volatilization and leaching. The productivity found in the mineral source, considering the quantities of N applied (a total of 150 kg N ha^{-1}), corroborated with the literature (Araújo et al., 2004; Borghi and Crusciol, 2007) and resulted in a production of ~10,000 kg ha^{-1}. The lower-yield ($p \leq 0.05$), as expected, was found in control (~3,900 kg ha^{-1}), similar to presented by Coelho et al. (1992). Among organic sources, Bs presented the lowest yield ($p \leq 0.05$), being close to the control. This result was contrastant to expected, as well as in literature (Berenguer et al., 2008; Giacomini and Aita, 2008; Giacomini et al., 2010) that also used liquid biofertilizer from swine manure to N-supply for maize. However, these same authors reported a low N recovery (14-22%), being more than 50% of N applied lost by leaching due to water excess. In agreement with all production components, the N-source effiency was higher in Fby, indicating that this source was more efficient to provide N to the plant than the others N sources, but Bs showed the lowest value ($p \leq 0.05$). Thus, the Pb and Cm showed N intermediate efficiency. As only Fby was more efficient than Ur, with indicates that this source can be a good alternative for mineral fertilization. Finally, all organic N-source studied here provided N to the plants, but in differents efficiency levels. Fby was an altenative N-source that showed better results than urea. In contrast, Pb e Cm was less productive than Fby and Ur, but better than Bs and Co. However long-term studies and under different environmental conditions must be conducted to a better understanding of the processes and efficiency of organic N-sources.

Maize economic yield when fertilized with organic N sources

The economic analysis was based on the sale price of maize in the first half of June 2018 in the municipality of Leme, SP. The commercial price of a sack of maize (60 kg) was A$ 15.20. The gross revenue was obtained by multiplying the quantity of sacks produced in one hectare by the sale value. The cost of fertilization was based on the individual cost of each source multiplied by its respective N amount applied (Table 5 and 6). Along with the cost of N fertilization was included the cost of phosphorus and potassium. The cost of transport was not included, because of the relatively small experimental area, which meant that only a small amount of each source was required.

Among the N sources, mineral fertilizer (Ur) was the most expensive (Table 5). This information indicates why famers are searching for alternative sources to replace mineral fertilization.

Regarding the alternative N sources, Fby was the most expensive, while Bs was the cheapest (Table 5). This was probably due to the origin of each product. Fby is a commercial by-product that comes from a large industry with cost control and revenue. On the other hand, the other organic sources were purely waste products that need to be discarded in order not to accumulate at the site of their production. Besides a suitable destination, Bs handling and transportation is a more complex operation than that required for other sources, as a substantial proportion of this waste is water, resulting in a higher cost for both transportation and fertigation.

The gross revenue followed productivity, but after discounting the cost of fertilization, the ranking of benefits changed (Table 6). The control treatment was economically more viable than the Bs treatment. The mineral source produced a revenue three times higher than the control, while the Fby treatment produced a revenue twice that of the mineral source.

Including the cost of fertilizer in the calculation of gross revenue also showed that Fby was better than other N sources. This was due to the better relation between the amount of N and the cost of the source, as well as the synchronism between nutrient availability and the absorption rate of the maize, factors that determine productivity and profitability in the maize crop.

In contrast, Bs caused the greatest reduction in the net revenue (Table 6). The cost of Pb was similar to that of the control, but it resulted in higher productivity and net revenue. The cost of Cm was similar to that of mineral fertilization, but resulted in a lower final income.

Materials and methods

Site description

The experimental site is located in the southeast region of Brazil, into the municipality of Leme (São Paulo state) (Lat. 22º 11’ 08” S; Long. 47º 23’ 25” W). The climate is Cwa (subtropical humid with hot summer and dry winter) according to Köppen’s classification, with an annual average temperature of 23ºC (ranging from 7º to 30ºC) and an average annual precipitation of 1380 mm. The soil was classified as an Oxisol (Typical Acrudox) with clayed texture (Soil Survey Staff, 2014) with 48% clay, 12% of silt and 40% of sand, bulk density of 1.12 g cm^{-3}, pH ($CaCl_2$) of 5.6, 2.4% organic matter, 1.4 g of N kg^{-1}, 8.6 mmolc of K kg^{-1}, 76 mg of

available-P dm^{-3}, 91 mmol$_c$ dm^{-3} cations exchange capacity and 53% base saturation.
The experimental area is historically cultivated over more than 50 yr and was being managed in conventional tillage until 1996, with monoculture of maize (*Zea mays* L.) followed by fallow. The maize variety used was the Maximus® (Syngenta Company).With the implantation of the no-tillage system, lupine (*Lupinus albus* L.) came to be planted as a second crop in succession to maize.

Experimental design and treatments

The experiments were set in a complete randomized block design, with six treatments (five N-sources + control) and four replications. The treatments were: (A) mineral source (Ur- urea); (B) an organic-mineral by-product from food industry commercially called Ajifer (Fby); (C) biofertilizer from swine manure (Bs); (D) poultry bedding (Pb); (E) cattle manure (Cm) and (F) Control (Co -without N). The chemical composition of organic materials is detailed in Table 3. Each block has a useful area of 504 m^2 (21 x 24 m). Each experimental plot has an area of 42 m^2 with nine sown lines (0.75 interline) of 6 m which had five evaluated central lines (useful lines).
The maize sowing was carried in November 16, 2015. Base fertilization (at sowing) was 25 kg P_2O_5 ha^{-1} and 10 kg K_2O ha^{-1}. Nitrogen was applied in two times, first in sowing (30 kg N ha^{-1}), and 27th days after emergence (V_6 stage) as topdressing (120 kg N ha^{-1}). The each source was applied to reach the equivalent N dose showed in Table 4. N-fertilization for all treatments (sowing and topdressing) was made manually. All sources were applied in the line of sowing and beside plants as topdressing. Bs treatment was applied using a watering garden and, due the large volume applied in topdressing, their application was fractionated in three days. Others crop operations (control of pests, diseases and weeds) were conducted according to standard farm management.

Yield components

After emergence, the final stand was determined in each plot. During the vegetative development (V_6 stage) - one day before topdressing and, at physiological maturity (R_2 stage - started of grains formation) plants height were measured (HP_I and HP_{II}, respectively) and still, in R_2 was included the ears insertion height (HE).
The maize yield components were determined after harvest of all ears in the useful area from each plot, but leaved the husks with plants. The crop residues production was determined for twenty plants per plot at random, which were cut at 7 cm from the soil. In laboratory, ear was dried for 48h at 60 °C and after that, threshed grain was weighed. Afterwards, 250 grains were counted at random and weighted to calculate the thousand kernel weight (TKW). The crop residues were dried for 72h at 60 °C and weighted. Grain yield and crop residues mass were calculated based to the final stand in each plot. The N-source efficiency was calculated by dividing the grain yield from each N-source discounted control by total N input.

Root system assessment

The root mass was determined from five soil monoliths (20 x 20 x 20 cm) which were excavated from each plot and contained two plants (R_2 stage). The decision to sample 0-20 cm was based on the literature which pointed that 80–90% of the total root is distributed in the top soil layer (Yu et al., 2015; Zhang et al., 2015). In laboratory, soil and root samples were placed on a 1 mm mesh sieve, and with water jets, roots were separated from the soil. The roots were dried for 72h at 60 °C, weighed and then, root mass was calculated to the final stand in each plot.
The root:shoot (R/S) ratio was calculated as the ratio of root dry weight (corrected using a percentage of 85% as the proportion of root in the 0-20 cm soil layer) to the crop residues dry mass plus grain production at harvest (i.e. stem, leaves and ears - husks plus grain).
For the analysis of root morphoanatomical, five fresh roots were sampled. These roots were fixed in formalin-acetic alcohol (FAA) 50% and preserved in ethanol 70% (Johansen, 1940). Using a rotation microtome, transversal section cuts of the median region of roots were made (Sass, 1951). For the slides, these sections were stained with 0.05% astra blue and safranin (Bukatsh, 1972) and mounted in glycerin. The starch was identified by Lugol solution (Bürcherl, 1962); lignin by hydrochloric fluoroglucine (Jansen, 1962); lipids by Sudan III (Jansen, 1962) and flavonoids by potassium hidroxide (Costa, 1982). The morphoanatomical aspects were recorded with a digital camera coupled to an Olympus microscope (model BX51, Tokyo Japan).
The main morphoanatomic characteristics observed were: i) central cylinder; ii) metaxylem and protoxylem iii) endoderm with U-thickening tissue and sclerenchyma; iv) cortex – aerenchyma; v) cortex – parenchymatous cells; vi) epiderm.
The maximum physiological development of maize, its roots are formed by vascular cylinder (i-iii), cortex (iv, v) and epidermis (vi).The central area (vascular cylinders) aggregates the pericycle and vascular tissues (xylem and phloem).The largest element in vascular cylinder is the metaxylem (ii), which is encircled by protoxylem elements. Normally, there is a metaxylem element for 2-3 protoxylem elements. The cortex corresponds for the area between the vascular cylinder and epidermis, being formed by several layers of parenchymatous cells (v). The epiderm is most external area of the root (vi), consisting of a single row of thin cells. Along with root hairs helps in the absorption of water and mineral salts from the soil (Feldman, 1994; Appezzato-da-glória; Hayashi, 2006).

Economic analysis

The economic analysis was made by computing the total revenue subtracting the total cost of production for each N-source. Total productivity revenue was obtained from the maize sale at the time of the producers normally sell in the region, as described in Pavinato et al. (2008).

Data analysis

The normality of data was confirmed by Shapiro-Wilk's test ($p \geq 0.05$). The data was analyzed using analysis of variance (ANOVA) and if the F-values were significant ($p \leq 0.05$), the means were compared by Tukey's test ($p \leq 0.05$).
All analysis was made using the Statistical Analysis System – SAS v.9.3 (SAS Inc, Cary, USA).

Conclusions

The organic N source Ajifer (Fby) promoted the highest grain yield and best morphoanatomic parameters, highest economic revenue and the lowest fertilizer cost for each unit produced, demonstrating its potential to replace mineral N (Ur). The other organic sources used as an N source (Pb, Cm and Bs) were only effective in relation to the control. However, Bs was expensive and its use reduced the economic returns to farmers. In summary, according to our findings the N efficiency of the organic sources that are alternatives to mineral sources in high-yield maize can be ranked as Fby >Ur> Pb > Cm > Bs > Co.

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