

Fertilization of high-yield corn with poultry litter based on nitrogen doses

Juliano Corulli Corrêa⁽¹⁾, Marco André Grohskopf⁽²⁾,
Agostinho Rebellatto⁽³⁾, Amanda Zolet Rigo⁽⁴⁾ and Arlei Coldebella⁽¹⁾

⁽¹⁾Embrapa Suínos e Aves, BR 153, Km 110, Caixa Postal 321, CEP 89715-899 Concórdia, SC, Brazil. E-mail: juliano.correa@embrapa.br, arlei.coldebella@embrapa.br ⁽²⁾Universidade Estadual Paulista, Faculdade de Ciências Agrônômicas, Rua José Barbosa de Barros, nº 1.780, CEP 18160-307 Botucatu, SP, Brazil. E-mail: marcogrohskopf@gmail.com ⁽³⁾Instituto Federal Catarinense, Campus Concórdia, SC 283, Km 08, CEP 89703-720 Concórdia, SC, Brazil. E-mail: agostinho.rebellatto@ifc-concordia.edu.br ⁽⁴⁾Universidade do Estado de Santa Catarina, Avenida Luiz de Camões, nº 2.090, Conta Dinheiro, CEP 88520-000 Lages, SC, Brazil. E-mail: amanda.z.rigo@gmail.com

Abstract – The objective of this work was to recommend nitrogen doses from poultry litter-based organic fertilizers in powder and pellet forms, compared with mineral fertilizer, in a high-yield corn crop under no-tillage. The treatments consisted of a 3×3+1 factorial arrangement, with: three fertilizers, two organic derived from poultry litter in powder (OPo) and pelletized (OPe) forms and one mineral fertilizer (M); three N doses of 65, 100, and 135% of the recommended N requirement for corn; and an unfertilized control. After five corn crops farmed under no-tillage in a Rhodic Kandiodox, the recommended doses for fertilization with poultry litter organic fertilizers, with an expected yield equal to or greater than 8,000 kg ha⁻¹, could be achieved from doses of 100 kg ha⁻¹ N in OPe and M and of 121 kg ha⁻¹ N in OPo. Increasing doses of the OPe, OPo, and M fertilizers raise the contents of organic carbon, N, and available P in the surface soil layer (0.0–0.1 m) and of exchangeable K up to a depth of 0.2 m, allowing to obtain N, P, and K contents in the plant tissue within the sufficiency range of the corn crop.

Index terms: no-tillage farming, organic waste, pelletized fertilizer, powder fertilizer.

Adubação de milho de alto rendimento com cama de aves tendo como critério o nitrogênio

Resumo – O objetivo deste trabalho foi recomendar doses de nitrogênio a partir de fertilizantes orgânicos produzidos com cama de aves, nas formas farelada e peletizada, em comparação ao fertilizante mineral, na cultura do milho de alto potencial produtivo, em sistema plantio direto. Os tratamentos foram dispostos em arranjo fatorial 3×3+1, com: três fertilizantes, dois orgânicos com cama de aves nas formas farelada (OF) e peletizada (OP) e um mineral (M); três doses de nitrogênio de 65, 100 e 135% da necessidade de N recomendada para milho; e controle sem adubação. Após cinco safras de milho em sistema plantio direto, em Nitossolo Vermelho distroférico, as doses recomendadas para adubação com fertilizantes orgânicos a partir de cama de aves, com expectativa de produtividade igual ou superior a 8.000 kg ha⁻¹, poderá ser realizada a partir das doses de 100 kg ha⁻¹ de N na forma de OP e M e 121 kg ha⁻¹ de N na OF. Doses crescentes dos fertilizantes OP, OF e M elevam os teores de carbono orgânico, N e P disponível no solo, na camada superficial (0,0–0,1 m), e de K trocável até 0,2 m, o que permite obter teores de N, P e K no tecido vegetal dentro da faixa de suficiência na cultura do milho.

Termos para indexação: plantio direto, residuo orgânico, fertilizante peletizado, fertilizante farelado.

Introduction

Of all farming practices, the use of correctives and fertilizers is the most important in terms of increasing productivity and minimizing the farmed area (FAO, 2013). For this reason, highly soluble mineral fertilizers have been given considerable attention compared with organic fertilizers (Lopes & Guilherme, 2016). Adequate nutrient management is currently necessary

to meet the nutritional requirements imposed by the high extraction and exportation of new genetic material with yield potential in corn (*Zea mays* L.) (Resende et al., 2016b). This is a challenging scenario regarding progress in fertilization strategies and a possible review of critical nutrient levels.

Fertilization doses should be carefully recommended, especially for traditional systems, as they offer greater buffer in terms of nutrient stocks, due

to the role of soil organic matter (SOM) conservation, complicating the interpretations of soil fertility (Sá et al., 2015). Excess fertilization causes “nutrient saturation” and subsequent fertilizations that do not correspond to gains in productivity, increasing the chance of nutritional losses and imbalances; however, not using any fertilization compromises nutrient stocks, limits the quantity and quality of SOM and the use of high-yield cultivars (Resende et al., 2016a).

Knowledge about the cycle of nutrients from organic fertilizers in traditional farming systems allows understanding the synchronism between nutrient release and plant demand (Hentz et al., 2016), both from a productivity point of view and in terms of reducing environmental risk (Grohskopf et al., 2016). This is important since the losses and additions of carbon and other nutrients modify the functioning of long-term farming system (Loss et al., 2011).

Of the organic fertilizers applied, poultry litter is the most commonly used byproduct of animal origin in the South of Brazil due to its abundance, price, and ease of use (Rogerri et al., 2016). Considering 16,243,286 tons of litter are produced annually by the broiler poultry industry in the country (Diagnóstico..., 2012), estimated contributions of 568,515, 645,731, and 487,298 tons of N, P₂O₅, and K₂O, respectively, are expected for the average contents of 35, 40, and 30 g kg⁻¹ N, P₂O₅, and K₂O in dry matter. In other words, this raw material alone would be accountable for recycling 8.9 and 35%, respectively, of the N used and produced in Brazil; these values are 12.5 and 25.6% for P₂O₅ and 5.2 and 57.3% for K₂O (Anuário..., 2008).

It has been reported that the agronomic efficiency of organic fertilizers derived from poultry litter is equal or superior to that of soluble mineral products in no-tillage systems (Endale et al., 2010; Hentz et al., 2016).

Long-term studies have also shown that poultry-litter based organic fertilizers applied to corn crops increased yield and sustainability in the system (Scherer & Nesi, 2009; He et al., 2016; Adeli et al., 2017). In this context, the present work seeks to define technical criteria to fertilize high-yield corn cultivars with poultry litter, without it being considered a potential environmental pollutant.

The objective of this work was to recommend nitrogen doses from poultry litter-based organic fertilizers in powder and pellet forms, compared with mineral fertilizer, in a high-yield corn crop under no-tillage.

Materials and Methods

The experiment was conducted in field conditions from 2010 to 2015, at the experimental unit of Embrapa Suínos e Aves, in the municipality of Concórdia, in the state of Santa Catarina, Brazil (27°14'2"S, 52°1'40"W, at 569 m altitude). The climate of the region is Cfa, according to Köppen's classification. The monthly mean rainfall and maximum and minimum air temperatures during the experiment are shown in Figure 1. The soil of the area is classified as a Nitossolo Vermelho distroférico (Santos et al., 2013), i.e., a Rhodic Kandiodox, and presented the following initial chemical characteristics in the 0.0–0.2-m layer: pH 5.0 in H₂O; 19 g dm⁻³ organic C; 60, 35, 15, and 40 mmol_c dm⁻³ Ca, Mg, K, and H+Al, respectively; 35 mg dm⁻³ P; 1.2 g dm⁻³ soil density; and 50% base saturation. Prior to installing the experiment, liming was carried out with 2 Mg ha⁻¹ dolomitic limestone and 75% PRNT, applied to the soil surface with the purpose of raising base saturation to 70%.

The experimental design was a randomized complete block in a 3x3+1 factorial arrangement, with four replicates, and the experimental unit consisted of a total area of 5x6 m and a usable area of 3.2x4 m. Increasing N doses (0, 65, 100, and 135% of the recommended N dose for a high-yield corn crop) were applied via three types of fertilizers (treatments): two poultry-litter based organic fertilizers in powder (OPo) and pellet (OPe) forms, compared with a mineral (M) fertilizer composed of soluble urea, single superphosphate and potassium chloride; all fertilizers had the same N, P, and K contents. It should be noted that the recommended dose is 90 kg N for corn with an expected yield of 8 Mg ha⁻¹, according to Silva et al. (2016).

The mineral fertilizer was incorporated in the furrow alongside and under (0.05 m) the seeds, whereas the organic fertilizers (OPo and OPe) were applied to the soil surface. For all treatments, the pre-established single doses were applied during corn sowing.

The OPo and OPe fertilizers were derived from the litter of six batches of poultry, each with 42 days, composed of 2.0, 1.5, and 1.0 g kg⁻¹ total N, P, and K on a dry basis, with similar breakdown for all years of planting. Before being used for the production of the powder and pelleted fertilizers, the poultry litter underwent a 25-day compost process, being revolved whenever the interior reached a temperature of 50°C;

once the temperature had stabilized, the litter was sieved through a 4-mm mesh screen to produce the powder fertilizer or sent to a pellet extruder to make 1.5-cm long and 0.5 cm-wide fertilizer pellets.

In summer, the following single hybrids of corn were sown: DKB 240 yieldgard in 2011/2012; AG 8060 YG in 2012/2013; and Syngenta in 2013/2014, 2014/2015, and 2015/2016, at a spacing of 0.80 m between the lines, with 5.3 seeds per meter for a population of 60,000 plants per hectare. In the winter of 2013, 2014, and 2015, white oat (*Avena sativa* L.) was sown as a cover crop, without fertilization, at a density of 50 kg ha⁻¹, with approximately 80 seeds per linear meter, and at a spacing of 0.20 m between lines. The winter plants were desiccated 14 days prior to the planting season of the summer crops, using of 1,800 g ha⁻¹ a.i. glyphosate, and invasive plants were controlled manually during the initial stages of crop cultivation.

In the 2011/2012, 2012/2013, 2013/2014, 2014/2015, and 2015/2016 crop years two rows of corn were

harvested manually, each 2 m long and with 0.8 m between rows, totaling 3.2 m² of usable area. In sequence, the following procedures were carried out: manual threshing, weighing and subsequent drying of wet grains, and separating the chaff and grains. Once the weight of the harvested grains was determined, yield was calculated, by applying a 13% moisture correction value.

To determine the total levels of N, P, and K in the tissue, 30 leaves were collected from the middle third opposite of and below the cob, during the bolting phase of corn (50% of plants bolted), according to Silva et al. (2016). The plant tissue samples collected were dried in an oven with forced-air circulation at 65°C until reaching constant weight. The material was subsequently ground to determine the total concentrations of N, P, and K, as described by Tedesco et al. (1995).

Soil sampling was conducted at the end of the corn crop cycle, in 2016, in the fifth year of the experiment, at the depths of 0.0–0.1, 0.1–0.2, and 0.2–0.4 m. Random soil

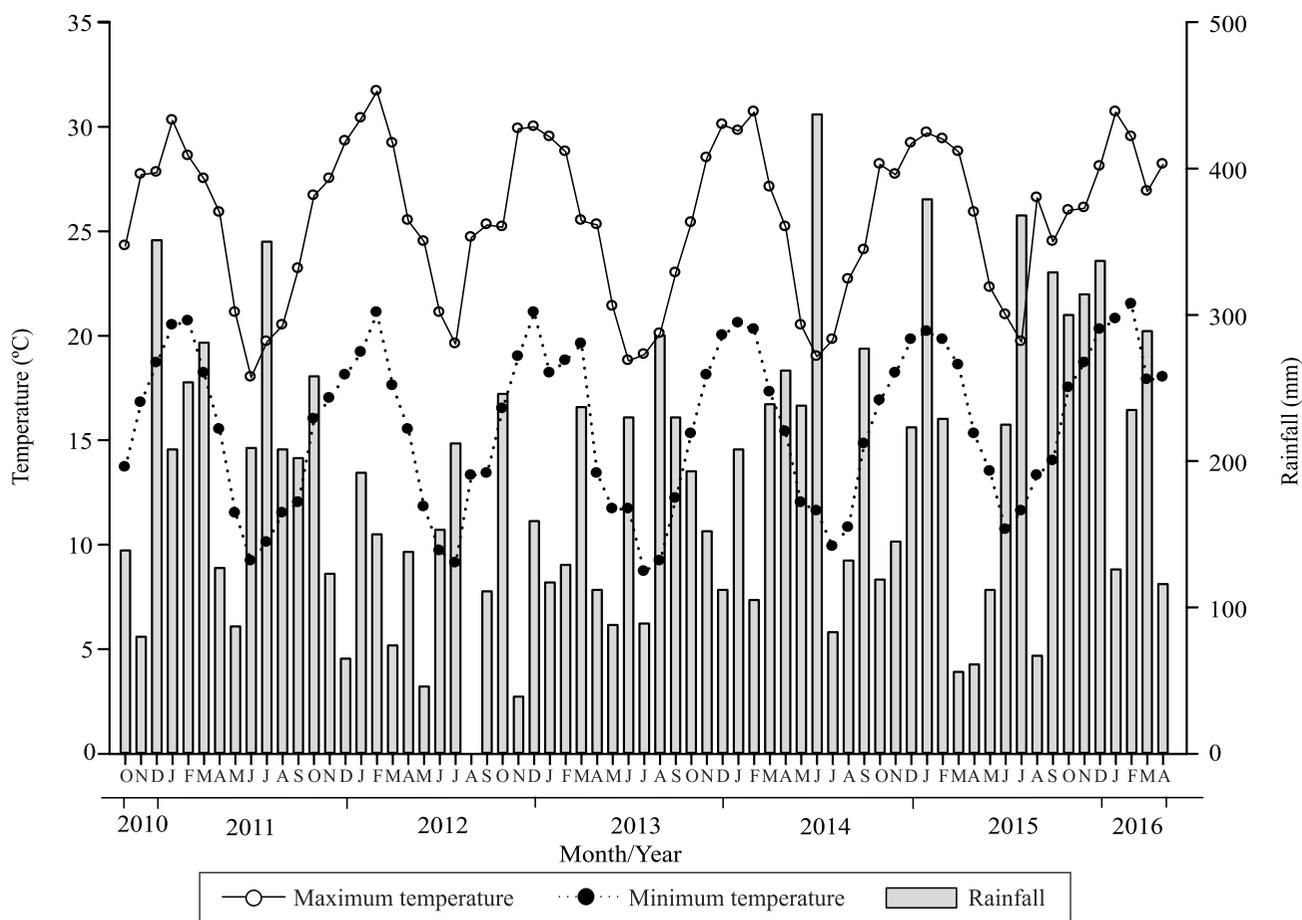


Figure 1. Mean monthly rainfall and maximum and minimum temperatures during the experimental period from 2010 and 2016.

samples were taken, two in between rows and one on the row for each layer, forming a composite sample, which was air-dried and screened in a 2-mm mesh. The sample was then subjected to chemical analysis to determine organic carbon, total N, available P, and exchangeable K, according to Tedesco et al. (1995).

The data were analyzed for homogeneity and normal distribution, and no data transformation was required. The treatment means were then compared by Tukey's test, at 5% probability, protected by the significance of a global F-test. Furthermore, the regression analysis was performed to determine the behavior of the variables in response to the applied doses of the organic and mineral fertilizers.

Results and Discussion

In the high-yield corn farmed under a no-tillage system (NTS) for five years, increasing doses of N from the OPo and OPe had a direct relationship with soil organic carbon (SOC) content. From the 100% dosage onwards, both fertilizers were only more efficient than the mineral one in the 0.0–0.01-m layer (Table 1).

After five years, the application of the organic fertilizers at the recommended dosage of 135% of N for corn promoted increases of up to 25% in the SOC

content in relation to the mineral fertilizer (Table 1). Similar were obtained by Adeli et al. (2007), who found an increase of 20% in SOC after 6.7 Mg ha⁻¹ poultry litter were applied annually under three years, compared with a mineral fertilizer, in a traditional soil management system. Watts et al. (2010) reported SOC contents of 2.2 and 1.8 g kg⁻¹ in corn and soybean crops with poultry litter fertilization, but 1.7 and 1.1 g kg⁻¹ for the same crops with mineral fertilization, at a depth of 0.0–0.05 m.

Considering total N, a direct relationship was only observed between N content and doses in the layer of 0.0–0.1 m (Table 2). In addition, there was a greater linear coefficient for the organic fertilizers than for the mineral one, but no difference between the fertilizers within the same dosage. In organic fertilization, N reactions differ from those of the mineral sources; for example, mineralization was slower in poultry litter, which favors microbial activity and immobilization components, allowing the momentary reduction in the transformation of N into inorganic forms momentary (Müller et al., 2011). Schomberg et al. (2011) found that the application of poultry litter in no-tillage farming increases the efficacy of N mineralization in the soil and improves the synchrony of nutrient availability throughout the corn crop cycle, when compared with the mineral source.

Table 1. Mean organic carbon content, evaluated in 2016, in three soil layers in response to increasing nitrogen doses (0, 65, 100, and 135% of the recommended N dose), applied via poultry litter-based organic fertilizers in pellet (OPe) and powder (OPo) forms, compared with a mineral fertilizer (M), after five corn (*Zea mays*) harvests in a no-tillage system⁽¹⁾.

Fertilizer	Organic carbon (mg dm ⁻³)				Regression equation ⁽²⁾	R ²
	0	65	100	135		
0.0–0.1 m						
OPe	21	25	28A	28A	$\hat{y} = 21 + 0.09x + 0.0002x^2$	0.86
OPo	21	24	28A	27A	$\hat{y} = 21 + 0.08x + 0.0002x^2$	0.91
M	21	24	24B	22B	$\bar{y} = 22$	
0.1–0.2 m						
OPe	16	18	19	18	$\bar{y} = 18$	
OPo	16	17	18	18	$\bar{y} = 17$	
M	16	18	18	18	$\bar{y} = 18$	
0.2–0.4 m						
OPe	15	17	17	18	$\bar{y} = 17$	
OPo	15	16	17	16	$\bar{y} = 16$	
M	15	17	18	16	$\bar{y} = 16$	

⁽¹⁾Means of four replicates followed by equal letters, lowercase in the lines and uppercase in the columns, do not differ by Tukey's test, at 5% probability. ⁽²⁾Regression equations significant at 1% probability. R², coefficient of determination.

Table 2. Mean total nitrogen content, evaluated in 2016, in three soil layers in response to increasing nitrogen doses (0, 65, 100, and 135% of the recommended N dose), applied via poultry litter-based organic fertilizers in pellet (OPe) and powder (OPo) forms, compared with a mineral fertilizer (M), after five corn (*Zea mays*) harvests in a no-tillage system⁽¹⁾.

Fertilizer	Total N content (mg dm ⁻³)				Regression equation ⁽²⁾	R ²
	0	65	100	135		
0.0–0.1 m						
OPe	1.7b	2.6a	2.9a	2.9a	$\hat{y} = 1.8 + 0.02x - 0.00007x^2$	0.91
OPo	1.7b	2.6a	2.8a	2.9a	$\hat{y} = 1.7 + 0.02x - 0.00008x^2$	0.90
M	1.7b	2.4ab	2.7a	2.8a	$\hat{y} = 1.7 + 0.01x - 0.00005x^2$	0.92
0.1–0.2 m						
OPe	1.6	1.7	1.8	1.8	$\bar{y} = 1.7$	
OPo	1.6	1.7	1.8	1.8	$\bar{y} = 1.7$	
M	1.6	1.6	1.7	1.8	$\bar{y} = 1.7$	
0.2–0.4 m						
OPe	1.4	1.4	1.5	1.6	$\bar{y} = 1.4$	
OPo	1.4	1.6	1.6	1.6	$\bar{y} = 1.4$	
M	1.4	1.3	1.4	1.5	$\bar{y} = 1.4$	

⁽¹⁾Means of four replicates followed by equal letters, lowercase in the lines and uppercase in the columns, do not differ by Tukey's test, at 5% probability. ⁽²⁾Regression equations significant at 1% probability. R², coefficient of determination.

For the total N content in the soil, the most effective doses were 142, 125, and 100% for OPe, OPo, and the mineral fertilizer (Table 2), respectively, with the greatest linear coefficients for OPo and OPe being related to the differentiated N liberation rate into the system, which is dependent on the degree of polymerization of the organic components (Grohskopf et al., 2015). The lower coefficient is a consequence of its supply in amide form ($\text{CO}(\text{NH}_2)_2$), which after ammonification and nitrification is rapidly transformed into a nitrate (N-NO_3^-), a form of N that is scarcely absorbed into the soil colloids, remaining almost exclusively in the soil solution, and that is subject to losses through leaching or denitrification (Zhang et al., 2011) if not absorbed by the plants.

In relation to available P in the soil, a response was observed only in the layer of 0.0–0.1 m, with an increasing quadratic behavior for OPe and an increasing linear behavior for OPo and the mineral fertilizer; the most effective doses were 91% for OPe and 135% for OPo and the mineral fertilizer (Table 3). Between fertilizers, a difference was only verified at the dose of 135% of recommended N, in alignment with the following order of magnitude: $\text{OPo} \geq \text{mineral fertilizer} > \text{OPe}$. These results corroborate those of Scherer & Nesi (2009) and Hentz et al. (2016), who observed increased available P in function of poultry

litter fertilization in NTS and integrated crop-livestock system for corn production.

The concentration of P in the soil-plant system promoted increased available P to a depth of 0.1–0.2 m, starting at the dose of 65% for the organic fertilizers (OPe and OPo) and of 100% for the mineral one (Table 3). These results are justified by the competition between organic anions and P for the same soil absorption sites, which enables increased nutrient availability and subsequent displacement with depth (Shuai & Zinati, 2009).

The response to available P content on soil surface is related to absorption reactions and rainfall, which control the destination of the P from the fertilizers, especially its absorption in soils of oxydic character, due to the high covalent bonding energy between the phosphate anion and the functional groups on mineral surface (Montalvo et al., 2015). The continued application of poultry litter to the soil in NTS for long-term corn production increases the available P content in the soil; therefore, excessive doses can lead to environmental risks (Endale et al., 2010).

For the level of exchangeable K in the soil, a quadratic behavior was observed in function of the fertilizers to a depth of 0.2 m, and no significant difference was verified between fertilizers for the same dose (Table 4).

Table 3. Mean phosphorus availability, evaluated in 2016, in three soil layers in response to increasing nitrogen doses (0, 65, 100, and 135% of the recommended n dose), applied via poultry litter-based organic fertilizers in pellet (OPe) and powder (OPo) forms, compared with a mineral fertilizer (M), after five corn (*Zea mays*) harvests in a no-tillage system⁽¹⁾.

Fertilizer	P availability (mg dm^{-3})				Regression equation ⁽²⁾	R ²
	0	65	100	135		
0.0–0.1 m						
OPe	45	62ab	67a	67Ba	$\hat{y} = 45 + 0.364x - 0.002x^2$	0.86
OPo	45b	65b	70b	90Aa	$\hat{y} = 44 + 0.31x$	0.91
M	45b	60b	72a	80Aa	$\hat{y} = 45 + 0.26x$	0.92
0.1–0.2 m						
OPe	24	34	31	30	$\bar{y} = 30$	
OPo	24	27	31	28	$\bar{y} = 27$	
M	24	21	28	31	$\bar{y} = 29$	
0.2–0.4 m						
OPe	20	23	21	26	$\bar{y} = 22$	
OPo	20	24	21	23	$\bar{y} = 22$	
M	20	21	22	21	$\bar{y} = 21$	

⁽¹⁾Means of four replicates followed by equal letters, lowercase in the lines and uppercase in the columns, do not differ by Tukey's test, at 5% probability. ⁽²⁾Regression equations significant at 1% probability. R², coefficient of determination.

Table 4. Mean exchangeable potassium content, evaluated in 2016, in three soil layers in response to increasing nitrogen doses (0, 65, 100, and 135% of the recommended N dose), applied via poultry litter-based organic fertilizers in pellet (OPe) and powder (OPo) forms, compared with a mineral fertilizer (M), after five corn (*Zea mays*) harvests in a no-tillage system⁽¹⁾.

Fer-tilizer	Exchangeable K (mg dm^{-3})				Regression equation ⁽²⁾	R ²
	0	65	100	135		
0.0–0.1 m						
OPe	6	10	13	13	$\hat{y} = 6.0 + 0.009x - 0.0003x^2$	0.91
OPo	6	13	14	13	$\hat{y} = 27 + 0.06x - 0.00007x^2$	0.76
M	6	13	13	12	$\hat{y} = 27 + 0.16x - 0.001x^2$	0.77
0.1–0.2 m						
OPe	8	9	11	10	$\hat{y} = 8.2 + 0.03x - 0.0001x^2$	0.68
OPo	8	10	12	10	$\hat{y} = 8.1 + 0.05x - 0.0003x^2$	0.76
M	8	9	11	12	$\hat{y} = 8.2 + 0.02x + 0.00007x^2$	0.75
0.2–0.4 m						
OPe	8	8	9	9	$\bar{y} = 8$	
OPo	8	6	9	9	$\bar{y} = 8$	
M	8	6	8	8	$\bar{y} = 8$	

⁽¹⁾Means of four replicates followed by equal letters, lowercase in the lines and uppercase in the columns, do not differ by Tukey's test, at 5% probability. ⁽²⁾Regression equations significant at 1% probability. R², coefficient of determination.

The values obtained for exchangeable K in the soil remained in the range considered “very high” in the treatments where this nutrient was supplied, but were reduced in the control treatment, compared with the initial analysis.

The displacement of K to a depth of 0.1–0.2 m due to organic or mineral fertilization is related to low-energy ionic bonds formed in the soil by this nutrient with mineral surfaces or organic compounds that have a negative load (Kaminski et al., 2010). This condition allows increased mobility and the accumulation of K at deeper levels if not absorbed by the plants, especially

in predominantly argilomineral soils of type 1:1 in the forms of kaolinite and of the Fe and Al oxides, abundant in Nitisols.

An increasing response was verified for corn grain yield in function of increasing doses of the mineral fertilizer and OPo and OPe (Table 5). In the 2011/2012 crop, a quadratic behavior was observed for OPe and the mineral fertilizer, and a linear behavior for OPo, whereas, in 2012/2013, there was quadratic behavior for OPe and a linear one for OPo and the mineral fertilizer. In the 2013/2014, 2014/2015, and 2015/2016 harvests, a linear behavior was verified in function

Table 5. Corn (*Zea mays*) grain yield in response to increasing nitrogen doses (0, 65, 100, and 135% of the recommended N dose), applied via organic and mineral fertilizers, in a no-tillage system⁽¹⁾.

Fertilizer ⁽²⁾	Corn grain yield (kg ha ⁻¹)				Regression equation ⁽³⁾	R ²
	0	65	100	135		
2011/2012 harvest						
OPe	4,920d	7,741Bc	10,824Aa	9,180Bb	$\hat{y} = 4,748 + 83.3x - 0.35x^2$	0.82
OPo	4,920d	6,735Cc	7,500Bb	8,911Ba	$\hat{y} = 4,863 + 28.7x$	0.82
Mineral	4,920c	8,376Ab	10,230Aa	10,118Aa	$\hat{y} = 4,862 + 76.0x - 0.28x^2$	0.91
2012/2013 harvest						
OPe	3,706c	6,806b	7,741Aa	7,623a	$\hat{y} = 3,690 + 67.7x - 0.28x^2$	0.98
OPo	3,706c	6,328b	6,227Bb	7,400a	$\hat{y} = 3,967 + 26.0x$	0.88
Mineral	3,706c	6,638a	6,886Ba	7,176a	$\hat{y} = 4,154 + 26.0x$	0.73
2013/2014 harvest						
OPe	7,384c	8,652Bb	10,921Ca	10,423Ba	$\hat{y} = 7,393 + 25.7x$	0.75
OPo	7,384b	8,567Ba	8,910Ba	9,039Ca	$\hat{y} = 7,482 + 12.8x$	0.62
Mineral	7,384c	10,545Ab	10,554Ab	11,363Aa	$\hat{y} = 7,802 + 28.8x$	0.73
2014/2015 harvest						
OPe	6,901d	8,389c	9,525b	10,080a	$\hat{y} = 6,894 + 24.3x$	0.92
OPo	6,901d	8,856c	9,435b	10,030a	$\hat{y} = 7,060 + 23.3x$	0.94
Mineral	6,901c	8,634b	9,542a	9,845a	$\hat{y} = 7,033 + 22.6x$	0.93
2015/2016 harvest						
OPe	3,923b	4,567a	4,896a	5,180a	$\hat{y} = 3,939 + 9.4x$	0.94
OPo	3,923c	4,676b	4,932a	5,071a	$\hat{y} = 3,998 + 8.7x$	0.90
Mineral	3,923b	4,722a	4,640a	4,849a	$\hat{y} = 4,040 + 6.6x$	0.75
Mean						
OPe	5,367c	7,225Bb	8,781Aa	8,497Aa	$\hat{y} = 5,301 + 44.7x - 0.2x^2$	0.94
OPo	5,367c	7,004Bb	7,400Cb	8,090Ba	$\hat{y} = 5,474 + 19.9x$	0.96
Mineral	5,367c	7,783Ab	8,371Ba	8,670Aa	$\hat{y} = 5,670 + 25.0x$	0.90
Sum ⁽⁴⁾						
OPe	26,834c	36,125Bb	43,906Aa	42,410Aa	$\hat{y} = 26,013 + 259.1x - 1.0x^2$	0.91
OPo	26,834c	35,022Bb	37,005Bb	40,451Ba	$\hat{y} = 27,371 + 99.4x$	0.89
Mineral	26,834c	38,916Ab	41,953Aa	43,349Aa	$\hat{y} = 26,858 + 241.0x - 0.88x^2$	0.93

⁽¹⁾Means of four replicates followed by equal letters, lowercase in the lines and uppercase in the columns, within each corn harvest do not differ by Tukey's test, at 5% probability. ⁽²⁾OPe, organic fertilizer in pellet form; and Opo, organic fertilizer in powder form. ⁽³⁾Regression equations significant at 1% probability. ⁽⁴⁾Sum of the yields of the five corn crops and two wheat crops obtained during the experiment.

of the increasing doses of OPe, OPo, and the mineral fertilizer. The frequent and ongoing application of poultry litter over a long period of time in NTS has increased yield in corn crops: up to 42% against 27% when there was no organic fertilization (Endale et al., 2010), and the addition of 2,608 kg ha⁻¹ with 42 kg ha⁻¹ N in NTS under eroded soil (Adeli et al., 2017).

In the 2012/2013 and 2015/2016 harvests, there was a serious decline in the yield of the corn plants due to the lack of rainfall (Figure 1) in the initial period of growth and development, primarily during germination and emergence. These results may be related to the infiltration, storage, and availability of water in the soil, responsible for the displacement of nutrients in the system, interfering directly in soil fertility and its effects on plants.

Among the fertilizers, the mineral one showed the greatest efficiency at the doses of 65 and 100% in the 2011/2012 harvest, and, at all doses, in the 2013/2014 harvest; OPe was superior to the others at the 100% dose in the 2012/2013 harvest (Table 5). From the fourth harvest onwards, the fertilizers were similar due to the high soil fertility, shown here by the chemical analyses of C, N, P, and K after six years of farming (Tables 1, 2, 3, and 4). When the chemical properties are preserved or improved over time, it is possible to achieve high corn yield in NTS (Nicolodi et al., 2008).

The mean of the five corn yields showed a growing response in function of the applied doses, with a quadratic behavior for OPe and a linear one for OPo and the mineral fertilizer (Table 5). Considering that 90 kg ha⁻¹ N are required for an expected yield of 8 Mg ha⁻¹ (Silva et al., 2016), 100 kg ha⁻¹ N via OPe and 121 kg ha⁻¹ N via OPo and the mineral fertilizer could be recommended for corn crops based on an average production of five corn harvests in NTS. The need to apply a greater amount of OPo than OPe may be due to the greater surface contact between the powder fertilizer and the soil, which increases its reaction, explaining its lower efficiency.

An increasing quadratic behavior was observed for the N, P, and K contents in the tissue of the diagnosed corn leaf in function of the application of increasing doses of N via OPe, OPo, and the mineral fertilizer; doses only differed regarding N and K contents, and only the 0% dose differed from the others in OPe, OPo, and the mineral fertilizer (Table 6). The N, P, and K contents in the tissue, based on mean values obtained

Table 6. Mean content of nitrogen, phosphorus, and total potassium in the diagnosed corn (*Zea mays*) leaf for five harvests in response to increasing nitrogen doses (0, 65, 100, and 135% of the recommended N dose), applied via organic and mineral fertilizers, in a no-tillage system⁽¹⁾.

Fertilizer ⁽²⁾	Dose (%)				Regression equation ⁽³⁾
	0	65	100	135	
Nitrogen (g kg ⁻¹)					
OPe	29.3b	31.6a	31.8a	32.1a	$\hat{y} = 29.4 + 0.045x - 0.0002x^2$ R ² = 0.89
OPo	29.3b	31.2a	31.9a	31.6a	$\hat{y} = 29.3 + 0.044x - 0.0002x^2$ R ² = 0.88
Mineral	29.3b	32.0a	31.9a	32.9a	$\hat{y} = 29.4 + 0.044x - 0.0001x^2$ R ² = 0.85
Phosphorus (g kg ⁻¹)					
OPe	3.5	3.9	3.9	3.8	$\hat{y} = 3.5 + 0.01x - 0.00005x^2$ R ² = 0.94
OPo	3.5	3.8	3.8	3.7	$\hat{y} = 3.5 + 0.008x - 0.00004x^2$ R ² = 0.94
Mineral	3.5	3.8	3.8	3.8	$\hat{y} = 3.5 + 0.006x - 0.00003x^2$ R ² = 0.94
Potassium (g kg ⁻¹)					
OPe	20.7b	22.9a	22.9a	22.7a	$\hat{y} = 20.7 + 0.05x - 0.0003x^2$ R ² = 0.90
OPo	20.7b	23.1a	22.9a	22.7a	$\hat{y} = 20.7 + 0.05x - 0.0003x^2$ R ² = 0.87
Mineral	20.7b	22.5a	22.4a	23.1a	$\hat{y} = 20.8 + 0.03x - 0.00009x^2$ R ² = 0.87

⁽¹⁾Means followed by equal letters, lowercase in the lines and uppercase in the columns, represent the difference within each element and do not differ by Tukey's test, at 5% probability. ⁽²⁾OPe, organic fertilizer in pellet form; and OPo, organic fertilizer in powder form. ⁽³⁾Regression equations significant at 1% probability. The sufficiency range in the tissue of the diagnosed corn leaf is: 27–35, 2–4, and 17–35 g kg⁻¹ N, P, and K, respectively, according to Tedesco et al. (2004).

over five years, remained within the range considered adequate for the crop, i.e., 27–35, 2–4, and 17–35 g kg⁻¹ for N, P, and K, respectively, according to Silva et al. (2016), which is explained by the fact that the soil at the start of the experiment already showed built-up fertility.

Conclusions

1. After five corn (*Zea mays*) crops farmed under a no-tillage system in a Rhodic Kandiodox, the recommended fertilization with poultry-litter based organic fertilizers, with an expected yield equal to or greater than 8,000 kg ha⁻¹, can be achieved from doses of 100 kg ha⁻¹ N in pelletized (OPe) and mineral forms and of 121 kg ha⁻¹ N in powder (OPo).

2. Increasing doses of OPe, OPo, and mineral fertilizers raised the contents of organic carbon, N, and available P in the surface soil layer (0.0–0.1 m) and of exchangeable K to a depth of 0.2 m, allowing to obtain N, P, and K contents in the plant tissue within the sufficiency range for the corn crop.

3. The greater need for fertilization with OPo than OPe may be due to the greater surface contact between the powder fertilizer and soil, which increases its reaction and explains its lower efficiency.

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