Soil fertility and agriculture yield with the application of organomineral or mineral fertilizers in solid and fluid forms

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Abstract – The objective of this work was to evaluate the effects of organomineral and mineral fertilizers, in their solid and fluid forms, on soils with variable charges with high fertility built up from nitrogen, phosphorus, and potassium contents in the soil and plant, as well as on corn (*Zea mays*) and black oat (*Avena strigosa*) yield. The treatments consisted of one control and four fertilizers – two organomineral and two mineral – in solid (SO, solid organomineral; and SM, solid mineral) and fluid (FO, fluid organomineral; and FM, fluid mineral) forms applied in Rhodic Kandiudox and Distrochrept soils with no-tillage. The use of organomineral or mineral fertilizers in fluid and solid forms increases total N content in the soil, maintains exchangeable K content in both soils, and may enhance available P content to the depth of 0.6 m in Distrochrept. These factors allowed significantly increasing corn yield, regardless of the fertilizer, and establishing greater residual effect for fluid organomineral fertilizer in the winter black oat yield, even in soils with high fertility.

Index terms: *Avena strigosa*, *Zea mays*, crop system fertilization, liquid pig slurry, no-tillage, poultry litters.

Fertilidade do solo e produtividade agrícola com aplicação de fertilizantes organominerais ou minerais nas formas sólidas e fluidas

Resumo – O objetivo deste trabalho foi avaliar os efeitos de fertilizantes organominerais e minerais, em suas formas sólidas e fluidas, em solos de carga variável com elevada fertilidade construída sobre os conteúdos de nitrogênio, fósforo e potássio no solo e nas plantas, bem como nas produtividades de milho (*Zea mays*) e aveia-preta (*Avena strigosa*). Os tratamentos foram constituídos de um controle e de quatro fertilizantes – dois organominerais e dois minerais –, nas formas sólida (SO e SM) e fluida (FO e FM), aplicados em Cambissolo e Nitossolo, sob plantio direto. O uso de fertilizantes organominerais e minerais nas formas sólidas e fluidas contribui para elevar o teor de N total no solo e manter o teor de K trocável em ambos os solos e pode elevar o teor de P disponível até a profundidade de 0,6 m em Cambissolo. Esses fatores permitiram aumentar significativamente a produtividade de milho, independentemente do fertilizante, e estabelecer maior efeito residual para a forma fluida do organomineral na produção de aveia-preta no inverno, mesmo em solos sob elevada fertilidade.

Termos para indexação: *Avena strigosa*, *Zea mays*, adubação de sistemas agrícolas, dejeto líquido de suíno, plantio direto, cama de aves.

Introduction

The development of new products for soil correction and fertilization constitutes a kind of strategic innovation for Brazil, since 75% of the fertilizers consumed in the country are imported (ANDA, 2016).

Of the widely-available raw materials for the production of solid or fluid organomineral fertilizers, residues from swine and poultry production chains can be used to compose formulations adapted to the nutritional demands of crops in different kinds of soils (Antille et al., 2014; Morais & Gatiboni, 2015), as well as enabling reutilization of these residues in sites at greater distances from high production locations.

The efficiency of the organomineral fertilizers is associated to the nutrient dynamics in the different soil classes. Therefore, phosphate-rich organomineral fertilizers are generally shown to be more efficient than mineral fertilization, since the presence of organic compounds can reduce the phosphorus binding to colloids in the soil (Gatiboni et al., 2008; Santos et al., 2008).

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Studies into organomineral fertilizers in solid form have shown their greater benefits to the chemical properties of the soil, and even increased crop yield, compared to mineral-derived fertilizers (Babalola et al., 2007; Correa et al., 2016). For organomineral fertilizers in fluid form, however, research has been scarce.

Subtropical soils with variable load with fertility built up through prolonged agricultural use may display distinct response patterns to different fertilizers (Hentz et al., 2016). Over recent decades, the intensive use of technologies, associated to good soil correction and fertilization practices, has generated highly fertile soils. However, the ever-increasing yield potential imposed by genetic enhancement challenges research to increase the efficiency of fertilizer use (Lacerda et al., 2015). In view of the foregoing, this work has the unprecedented feature of assessing the effects of new fertilizers, in this case, organomineral fertilizers in fluid and solid forms in relation to the traditional mineral forms, under a no-tillage farming system.

The objective of this work was to evaluate the effects of organomineral and mineral fertilizers in solid and fluid forms in Rhodic Kandiudox and Distrochrept, with built-up fertility, on the nitrogen, phosphorus and potassium levels in the soil and in the plant, and on the corn and black oat dry matter yields, with no-tillage.

Materials and Methods

The experiment was conducted during the 2010/2011 and 2011/2012 harvest years, in the municipality of Concórdia, in the state of Santa Catarina, Brazil, in an area situated at an altitude of 569 m, 27º14'2"S and 52º1'40"W. The climate in the region is humid subtropical (Cfa), according to the Köppen climate classification. Average precipitation is greater than 1,500 mm and well distributed throughout the year, with an average maximum temperature of 26ºC in the hottest month (January) and average minimum of 12°C in the coldest month (July).

The soils of the experimental area were described as Rhodic Kandiudox and Distrochrept. The chemical and physical characteristics of the soils are shown in Table 1. The areas had previously been farmed with corn crops in the summer, and oat in the winter, between 1994 and 2009. During that period, two liming procedures were performed with 5 Mg ha^{-1} of dolomitic limestone, incorporated into the layer at 0.0–0.2 m, and fertilizations were performed only with pig slurry at a dosage of 50 m^3 ha^{-1}, in addition to the recommended mineral fertilization for the summer crop, which left the soils highly fertile (built-up fertility).

The undergrowth plants were desiccated with glyphosate herbicide (2.2 kg ha^{-1} of i.a.), always 14 days or more prior to sowing of the winter crops in 2011 and 2012, and of the summer crops of 2010/2011 and 2011/2012.

The study was carried out in experiment groups, and each type of soil was considered an individual experiment, with five treatments and four repetitions, in a random block design. Following individual analysis of each experiment, they were grouped for joint analysis, testing the effect of the fertilizers and their interaction with the soil types.

The experimental units were distributed according to canonical multivariate analysis methodology (Hair et al., 2009), based on initial chemical analysis of the soil of each experimental portion, at a depth of 0.0–0.2 m, to group the most similar treatments.

The treatments consisted of one control, with no fertilization, and four fertilizers: two organomineral and two mineral, in solid and fluid forms, all with a 03-12-06 formulation of N-P_2O_5-K_2O. The solid mineral fertilizer (SM) was composed of urea (45% N), monoammonium phosphate (MAP) (48% P_2O_5 and 9% N) and potassium chloride (KCl) (60% K_2O); the solid organomineral (SO) was formulated on a poultry litter basis supplemented with urea, natural phosphorus from municipality of Registro, in the state of São Paulo, Brazil (24% P_2O_5 total, 0.8% P_2O_5 in water, 3.2% P_2O_5 in neutral ammonium citrate plus water and 7.7% P_2O_5 in citric acid) and KCl; the fluid mineral (FM) was composed of water, urea, MAP and KCl; and the fluid organomineral (FO) was formulated on a swine waste basis with added urea, MAP and KCl.

The fertilizers were applied in grooves alongside the seed row, with subsequent manual incorporation, only in the corn crop, at a depth of 0.1 m.

The pig slurry waste (PSW) used to form the FO fertilizer was obtained from finishing swine, via collection from the biodigestor discharge tubing of Embrapa Suínos e Aves, in the municipality of Concórdia, in the state of Santa Catarina. The chemical properties of the PSW were 7.2, 1.7 and 2.8 g L^{-1} in 2011; and 5.0, 1.1 and 2.8 g L^{-1}, for N, P and K, respectively

– these values were determined in 2012, according to methodology described by Rice et al. (2012). The SO fertilizer consisted of poultry litter, collected after six batches, and had a composition of 20, 40, and 22 g kg^{-1} of total N, P_2O_5, and K_2O, respectively. For granulation, the poultry litter was micronized to 1 mm particles, and received 0.5% manioc starch as an aggregation conditioner and 0.5% calcium silicate to increase the hardness of the granule.

Two harvests of hybrid corn (*Zea mays* L.) were cultivated in the summer period, and two black oat (*Avena strigosa* Schreb) harvests in the winter, all under a no-tillage system. The fertilizers were applied to both corn crops, with the aim of achieving a 10 Mg ha^{-1} yield, as recommended by Silva et al. (2016). The N dose was defined at 150 kg ha^{-1}, with 50 kg of N applied to the base, corresponding to an application of 1,667 kg ha^{-1} of the 03-12-06 formulation and 100 kg of N with urea applied to the topsoil. The doses of P_2O_5 and K_2O applied with the different fertilizers were 200 and 100 kg ha^{-1}, respectively. The choice of the 03-12-06 formula sought to add a greater P concentration in order to achieve a possible residual effect on the black oat crop, to which the treatments were not reapplied.

High yield, early cycle single hybrids were used for the corn plantations: the DKB 240 Yieldgard (Dekalb), considered highly demanding as regards soil fertility, in the 2010/2011 harvest; and in 2011/2012, the cultivar Celeron LT (Syngenta). Corn was always sown in the second fortnight of November, seeking a density of 70,000 plants ha^{-1}, with a distribution of 5.6 seeds per meter and an interrow distance of 0.8 m. The oat was sown in the second fortnight of April, with a density of 50 kg ha^{-1}, with approximately 80 seeds sown per meter, and at a space of 0.20 m between rows.

Table 1. Chemical attributes and clay content of the layer 0.0–0.2 m of the utilized soils, prior to installation of the experiment.

Treatments(1)	Clay	pH	C	P	K	Ca	Mg
	(g kg^{-1})	H_2O	(g dm^{-3})	(mg dm^{-3})	-----(mmol$_c$ dm^{-3})-----		
			Distrochrept				
C	690	5.7	24.5	66.9	8.3	73.8	30.3
SM	660	5.7	25.5	79.5	9.4	95.9	44.7
SO	660	5.6	24.9	63.7	8.6	83.1	31.7
FM	700	5.6	23.0	63.8	7.1	97.5	40.8
FO	690	5.8	24.7	78.5	7.4	99.1	42.5
			Rhodic kandiudox				
C	700	5.4	25.4	83.0	8.7	64.0	32.0
SM	700	5.3	25.9	78.0	8.8	59.9	32.2
SO	700	5.3	24.2	84.0	9.1	64.3	35.5
FM	700	5.2	23.4	61.0	8.5	56.0	31.3
FO	700	5.3	25.4	89.7	8.3	61.8	34.2

(1)C, control; SM, solid mineral; SO, solid organomineral; FM, fluid mineral; and FO, fluid organomineral.

The corn and black oat dry matter yields were recorded. The corn was harvested manually, and cobs, measuring 2.0 m long, were collected from two rows, with a total harvested area per portion of 3.2 m^2. Next, manual threshing, weighing and drying of the grains were conducted, with a 13% moisture correction value considered for yield calculation. In the black oat crop, in the winter, dry matter yield of the aerial part of the plant was determined by means of weighing after drying in a forced air circulation oven at 65°C, until constant weight of the harvested plants in three micro-portions of 0.25 m^2 per experiment unit, cut close to the soil.

For determining the N, P, and K levels in the leaf tissue, 30 leaves were collected from the central third of the corn plants, opposite and under the cob, during the bolting phase (50% of plants bolted), as described by Silva et al. (2016). The samples were dried in a forced air circulation oven at 65°C, to a constant weight. Subsequently the material was ground and the levels were determined in accordance with Tedesco et al. (1995).

Stratified soil samples were taken at the end of the summer crop, at levels of 0.0–0.1, 0.1–0.2, 0.2–0.4, and 0.4–0.6 m deep, with random selection of the three single samples from the useful area of the portions, two from between rows and one on the crop row. The single samples were homogenized to constitute the compound samples, which were then dried in forced air circulation ovens at 65°C, until attaining a constant weight, and subsequently screened through a 2 mm mesh for determination of the total N content by Kjeldahl, and P and extractable K in Mehlich 1, according to Tedesco et al. (1995).

The data were subjected to homogeneity of variances and normality tests. Once analysis of variance premises were met, the parametric statistics was performed according to the experiment groups. The treatment means were then compared by the Student's t-distribution test, protected by the significance of a

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global F-test. A 5% degree of probability was adopted as the rate of error for decision-making purposes. The analysis was performed following the GLM procedure of the SAS (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

The total N content in the soil was related to the concentration of organomineral and mineral fertilizers in solid and fluid forms, especially after the second fertilization. It was found that the nutrient levels at depth decreased, with distinction between the soil classes in certain conditions with the same fertilizer (Table 2).

During the first crop, the difference between the effects of the fertilizers on the total N content in the soil was greater in the Distrochrept, where the solid fertilizers (SM and SO) raised the total N levels at depths of 0.1–0.2 and 0.2–0.4 m, compared to the control treatment. The opposite result was observed with the fluid fertilizer FO, which reduced the total N content when compared to the control treatment at the surface level of 0.0–0.1 m (Table 2). In deeper soils (Rhodic Kandiudox), a difference between fertilizers regarding the total N content was found only at the depth level of 0.1–0.2 m, where the SM produced lower levels than the control treatments, FO and FM, and similar results to the SO. When there was a difference between the soils, the highest levels were observed in the Rhodic Kandiudox.

Table 2. Total N content in different layers of Rhodic Kandiudox and Haplic Distrochrept, in response to the application of mineral and organomineral fertilizers in solid (SM and SO) and fluid (FM and FO) forms, following two corn crops, in 2011 and 2012(1).

Soil	Total N content (g dm^{-3})				
	Control	SM	SO	FM	FO
			0.0–0.1 m in 2011		
Distrochrept	1.7Bab	1.8Ba	1.8a	1.9a	1.6Bb
Rhodic	1.9A	2.0A	2.0	1.9	2.0A
			0.1–0.2 m in 2011		
Distrochrept	1.6Bbc	1.7a	1.8a	1.7ab	1.5Bc
Rhodic	1.8Aa	1.6b	1.7ab	1.8a	1.8Aa
			0.2–0.4 m in 2011		
Distrochrept	1.4b	1.6a	1.5a	1.5ab	1.4Bb
Rhodic	1.5	1.6	1.5	1.6	1.7A
			0.4–0.6 m in 2011		
Distrochrept	1.0B	1.3	1.1B	1.2	1.2
Rhodic	1.3A	1.3	1.4A	1.3	1.2
			0.0–0.1 m in 2012		
Distrochrept	1.90Ac	1.96Abc	2.07Ab	1.91c	2.19a
Rhodic	1.63Bc	1.82Bb	1.67Bc	1.82b	2.22a
			0.1–0.2 m in 2012		
Distrochrept	1.9b	1.8Bb	2.9Aa	2.2a	2.2a
Rhodic	1.8c	2.0Aab	2.0Bbc	2.2a	2.1a
			0.2–0.4 m, in 2012		
Distrochrept	1.7ab	1.6b	1.9a	1.9a	1.7b
Rhodic	1.72	1.7	1.8	1.8	1.8
			0.4–0.6 m in 2012		
Distrochrept	2.0c	1.8Ba	1.4Ab	1.4b	1.5b
Rhodic	1.1b	1.2Ab	1.2Bb	1.4a	1.6a

(1)Means followed by the same letters, lower case between treatments and upper case between soils, do not differ by the Student's t-test, at 5% probability. Treatments: SM, solid mineral; SO, solid organomineral; FM, fluid mineral; and FO, fluid organomineral.

In this first crop, the similarity in the N levels between fertilizers and between soil types may be related to the application of 100 kg ha^{-1} of N in the form of urea, to the topsoil, for the corn crop, including in the control treatment. Another factor that might explain the similar results is the buffering capability of the crop environment, provided by the SOM (soil organic matter) content in both soils. The organic fraction of the nutrient corresponds to 95% of the total N present in the soil (Müller et al., 2011). The SOM levels in this study may be classified as medium and high (Silva et al., 2016), which would allow them to stabilize the N content in the soil (Mafra et al., 2014; Grohskopf et al., 2015).

After the second year of corn crops, in 2012, greater differences were found in the total N content in the soil at each level of depth by virtue of the type of fertilizer used (Table 2). It was found that these levels increased at the depths up to 0.6 m, with prominent results for the following treatments: FO, at superficial levels (0.0–0.1 and 0.1–0.2 m), and in both soils; FM, at 0.1–0.2 m in both soils, and at 0.2–0.4 m in Distrochrept, and 0.4–0.6 m in Rhodic Kandiudox; SO, at 0.1–0.2 and 0.2–0.4 m in Distrochrept; and SM, at 0.4–0.6 m in Distrochrept. The great variability in the total N levels observed between the different fertilizers in this second crop may be related to the mineralization of organic N in the soil, which occurs at a variable rate due to edaphoclimatic characteristics, use and management practices, soil type and the quality of the crop or organic residue (Müller et al., 2011).

Available P in the soil also varied in response to the application of solid and fluid fertilizers in the evaluated soil layers and periods (Table 3). It is worth highlighting that the values of available P in the soil were at a level considered "very high" at all the assessed layers (Silva et al., 2016).

In the first crop year, the fertilizers that contributed to the significant increase in the P content in the soil, in relation to the control, were: FM, at the depth of 0.0–0.1 m, Rhodic Kandiudox, and 0.1–0.2 m in Distrochrept; FO, at 0.1–0.2 m in both soils; and SM, at 0.1–0.2 m, in Rhodic Kandiudox, and 0.2–0.4 m in Distrochrept, where greater nutrient displacement at depth was found (Table 3). When there was significant influence of the soil type on the available P, it was found that Rhodic Kandiudox had the highest values, except for the SM treatment at a depth of 0.2–0.4 m.

It should be stressed that after the second crop year of the system, there was P displacement at the depths up to 0.6 m in both soils, regardless of the fertilizer used (Table 3). This displacement may have resulted from the saturation of positive loads by the P itself applied in previous years.

Table 3. Total P content in different layers of Rhodic Kandiudox and Haplic Distrochrept, in response to the application of mineral and organomineral fertilizers in solid (SM and SO) and fluid (FM and FO) forms, following two corn crops, in 2011 and 2012⁽¹⁾.

Soil	Total P content (g dm^{-3})				
	Control	SM	SO	FM	FO
	0.0–0.1 m in 2011				
Distrochrept	69.6B	79.8B	68.1B	67.4B	85.9
Rhodic	99.2Ab	102.0Ab	111.0Ab	135.1Aa	98.3b
	0.1–0.2 m in 2011				
Distrochrept	48.0Bb	55.2Bb	47.5Bb	92.0a	91.6a
Rhodic	79.1Ab	95.7Aa	74.4Ab	88.9ab	101.0a
	0.2–0.4 m in 2011				
Distrochrept	30.0Bb	62.6Aa	42.1c	42.3c	56.2b
Rhodic	52.2Aa	34.7Bc	36.6bc	42.1b	50.6a
	0.4–0.6 m in 2011				
Distrochrept	28.7	28.7	29.3	30.1	28.4
Rhodic	31.1	32.5	26.8	29.6	29.3
	0.0–0.1 m in 2012				
Distrochrept	86.9b	124.0a	109.0a	122.0Aa	123.0Ba
Rhodic	94.8bc	108.0b	102.0bc	80.6Bc	149.0Aa
	0.1–0.2 m in 2012				
Distrochrept	47.2d	84.7b	66.1c	107.0Aa	73.1c
Rhodic	51.6c	90.9a	70.0b	78.3Bb	74.2b
	0.2–0.4 m in 2012				
Distrochrept	32.4Bc	24.5Bc	53.0Bc	71.0a	65.7ab
Rhodic	53.3Abc	41.5Ac	67.3Aa	65.0a	65.4ab
	0.4–0.6 m in 2012				
Distrochrept	20.2Bc	32.4a	25.9bc	26.7ab	28.3ab
Rhodic	35.7A	29.6	30.9	30.8	29.8

⁽¹⁾Means followed by the same letters, lower case between treatments and upper case between soils, do not differ by the Student's t-test, at 5% probability. Treatments: SM, solid mineral; SO, solid organomineral; FM, fluid mineral; and FO, fluid organomineral.

In 2012, the added P raised the available levels of the nutrient at the superficial level of Distrochrept (0.0–0.1 m), regardless of its physical form (solid or fluid), which was repeated at the next layer (0.1–0.2 m), with prominent results for FM, which produced higher levels than the other fertilizers. In the deepest layers, the fertilizers that differed significantly from the control were: FM and FO at 0.2–0.4 and 0.4–0.6 m, and SM at 0.4–0.6 m (Table 3).

In Rhodic Kandiudox, the high fertility observed at the superficial level (0.0–0.1 m), even in the control treatment, meant that only the FO fertilizer raised the P levels significantly. In the next layer (0.1–0.2 m), all the fertilizers contributed to raising the available P, especially the SM. In the next layers, FM and FO stood out, at 0.2–0.4 and 0.4–0.6 m, and SM at 0.4–0.6 m (Table 4).

The SO fertilizer demonstrated the same efficiency at increasing available P content in the soil as the other fertilizers, though the presence of carbon in its composition may potentially reduce P absorption in the soil, through competition for the same phosphate absorption sites in the soil. Furthermore, the organic fertilizer has polyphosphate compounds and phosphoesters with lower specific absorption and, consequently, greater displacement throughout the section (Lombi et al., 2004). Therefore, it is possible that the lack of greater efficiency in phosphate-rich fertilization using SO was not due to the presence of low solubility natural phosphate (0.8% P_2O_5 soluble in water) in its composition.

The organomineral and mineral fertilizers, both in solid and fluid forms, also influenced the K content in the soil, and the following treatments had significantly higher levels of the nutrient than the control: FO in Rhodic Kandiudox, at 0.0–0.1 and 0.2–0.4 m in 2011, and 0.1–0.2 and 0.2–0.4 m in 2012; and SO and FM in Distrochrept at 0.1–0.2 m, in both years (Table 4). The K levels in the control treatment were classified as very high, down to a depth of 0.4 m in 2011, and to 0.2 m in 2012 (Silva et al., 2016). This high availability reduces the responses to fertilization with the nutrient.

The treatments had little influence on the leaf N content in corn (Table 5), with significant difference

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found only in the 2011/2012 crop. The treatments that produced higher levels of the nutrient than the control were: SO in Distrochrept; and SM, SO and FM in Rhodic Kandiudox. In the 2010/2011 crop, the N levels were within the sufficiency range (27 to 35 g kg^{-1}) and, in 2011/2012, these values were lower than those reported by Silva et al. (2016).

Following implementation of the no-tillage system, the treatments increased the leaf P content in the corn crop only in the second crop year. The highest values obtained were: SM, SO and FM in Distrochrept; and SO, FM and FO in Rhodic Kandiudox, all greater than the control (Table 5). It is worth underlining that both crops demonstrated P levels in the vegetable tissues within the range considered adequate, from 2.0 to 4.0 g kg^{-1} (Silva et al., 2016).

Table 4. Exchangeable K content in different layers of Rhodic Kandiudox and Haplic Distrochrept, in response to the application of mineral and organomineral fertilizers in solid (SM and SO) and fluid (FM and FO) forms, following two corn crops, in 2011 and 2012(1).

Soil	Exchangeable K content (mmol$_c$ dm^{-3})				
	Control	SM	SO	FM	FO
			0.0–0.1 m in 2011		
Distrochrept	12.5	12.5	12.6	13.7	13.4
Rhodic kandiudox	11.8b	11.8b	11.6b	12.3b	14.0a
			0.1–0.2 m in 2011		
Distrochrept	6.6Bc	7.6Bbc	9.5a	9.5ab	8.5Babc
Rhodic kandiudox	9.7A	10.3A	10.2	9.8	11.7A
			0.2–0.4 m in 2011		
Distrochrept	6.1	7.7	7.1	7.2	7.9
Rhodic kandiudox	7.3b	7.0b	8.3ab	8.0ab	9.3a
			0.4–0.6 m in 2011		
Distrochrept	4.1	4.2A	4.5	3.5B	3.7B
Rhodic kandiudox	4.2ab	3.2Bc	3.6bc	4.9Aa	4.8Aa
			0.0–0.1 m in 2012		
Distrochrept	11.2	12.1	12.3	13.0	12.2
Rhodic kandiudox	10.3	11.1	11.5	11.6	11.7
			0.1–0.2 m in 2012		
Distrochrept	6.5Bc	7.6B	8.3a	8.2ab	7.0Bbc
Rhodic kandiudox	7.9Ab	9.0Aab	8.3b	8.5b	10.1Aa
			0.2–0.4 m in 2012		
Distrochrept	5.6c	6.1bc	7.6Aa	6.8ab	6.9ab
Rhodic kandiudox	5.7b	5.8b	5.4Bb	6.0b	8.0a
			0.4–0.6 m in 2012		
Distrochrept	4.6	5.4	4.8	5.6	5.2
Rhodic kandiudox	4.6	4.3	5.3	5.5	6.2

(1)Means followed by the equal letters, lower case between treatments and upper case between soils, do not differ by the Student's t-test, at 5% probability. Treatments: SM, solid mineral; SO, solid organomineral; FM, fluid mineral; and FO, fluid organomineral.

The evaluated fertilizers showed no significant influence on the leaf K content in corn, in any of the harvests (Table 5). The K levels in the vegetable tissue, however, were within the adequate range for the crop, from 17 to 35 g kg^{-1} (Silva et al., 2016). These results for K are justified by the high levels of the nutrient in both soils, even in the control (Table 4).

In the 2011/2012 harvest, both the fertilizers and the soil types influenced the corn yield (Table 6). In the Distrochrept, the highest yields were achieved in the FO and SM treatments, whereas in the Rhodic Kandiudox, there was no difference between the fertilizers, which produced higher yields only compared to the control. In the comparison between soils with the same fertilizer, the highest yields were found in the Rhodic Kandiudox, with applications of SO and FM.

As regards the yield of dry matter from the aerial part of black oat, in 2011, differences between the soils were observed for the same fertilizer (Table 6). The highest yield occurred with the use of FO, in both soils,

Table 5. Nitrogen, phosphorus, and potassium content in leaves in the 2010/2011 and 2011/2012 corn crops, in Rhodic Kandiudox and Haplic Distrochrept, in response to the application of mineral and organomineral fertilizers in solid (SM and SO) and fluid (FM and FO) forms(1).

Soil	N, P, and K content in leaves (g kg^{-1})				
	Control	SM	SO	FM	FO
			Nitrogen – 2010/2011		
Distrochrept	32.2	30.1B	30.7	31.7	31.4B
Rhodic	34.1	33.6A	31.6	32.7	34.1A
			Nitrogen – 2011/2012		
Distrochrept	24.0b	25.3ab	26.4a	25.7ab	25.0b
Rhodic	23.0b	25.8a	26.5a	26.4a	25.0b
			Phosphorus – 2010/2011		
Distrochrept	3.9	3.6	3.8	3.8	4.0
Rhodic	3.6	3.7	3.8	3.6	4.0
			Phosphorus – 2011/2012		
Distrochrept	2.2b	2.5Aa	2.4a	2.6a	2.4ab
Rhodic	2.0c	2.2Bbc	2.5ab	2.6a	2.6a
			Potassium – 2010/2011		
Distrochrept	21.5	19.5	21.4	22.9	23.2
Rhodic	22.2	21.7	21.3	21.6	23.2
			Potassium – 2011/2012		
Distrochrept	21.1	20.3	21.4	22.6	20.9
Rhodic	19.0	18.5	19.4	19.1	19.5

(1)Means followed by the equal letters, lower case between treatments and upper case between soils, do not differ by the Student's t-test, at 5% probability. Treatments: SM, solid mineral; SO, solid organomineral; FM, fluid mineral; and FO, fluid organomineral.

but this fertilizer did no differ significantly from FM in Distrochrept. The gains in yield in relation to the control were 2,304 and 2,799 kg ha^{-1} for Distrochrept and Rhodic Kandiudox, respectively.

In 2012, the highest yields of dry matter were achieved with FO, which generated gains of 1,563 and 1,982 kg ha^{-1} in Distrochrept and Rhodic Kandiudox, respectively (Table 6). In the Distrochrept, FM produced a yield equivalent to that of FO, with gains of 951 kg ha^{-1} in relation to the control. The increased dry matter yield has favorable consequences for the subsequent summer crops due to their slower decomposition, which allows gradual release of the nutrients into the haystacks (Ferreira et al., 2014).

The results for the black oat in general demonstrated greater residual effect for the following crop when the FO fertilizer was used, the results of which exceeded those from the use of the traditional solid form, in both soils (Table 6). The same result was also observed with the FM fertilizer in Rhodic Kandiudox. These results should be considered for the recommended fertilization of the production system as a whole (Lacerda et al., 2015), rather than a recommendation only for the main crop.

Table 6. Corn grain yield and yield of dry matter mass (DMM) from the aerial part of black oat (kg ha^{-1}), in the crops of 2010/11 and 2011/12, in response to the application of mineral and organomineral fertilizers in solid (SM and SO) and fluid (FM and FO) forms(1).

Soil	Corn grain yield (kg ha^{-1}) and DMM black oat (kg ha^{-1})				
	Control	SM	SO	FM	FO
			Corn – 2010/2011		
Distrochrept	10,700b	14,339a	12,991ab	14,393a	13,645a
Rhodic	10,528	12,298	12,479	11,779	12,297
			Corn – 2011/2012		
Distrochrept	10,019b	13,108a	11,014Bb	10,518Bb	13,955a
Rhodic	10,562b	13,000a	13,134Aa	12,861Aa	13,467a
			Black oat – 2011		
Distrochrept	2,415Bc	3,157Bbc	3,152Bbc	4,084Bab	4,719Ba
Rhodic	3,694Ac	4,991Ab	5,055Ab	6,604Ab	6,493Aa
			Black oat – 2012		
Distrochrept	5,557b	6,007b	5,473b	5,724b	7,120a
Rhodic	4,869b	5,668b	5,566b	5,820b	6,851a

(1)Means followed by the same letters, lower case between treatments and upper case between soils, do not differ by the Student's t-test, at 5% probability. Treatments: SM, solid mineral; SO, solid organomineral; FM, fluid mineral; and FO, fluid organomineral.

Conclusion

1. The use of organomineral or mineral fertilizer in fluid and solid forms increases total N content and maintains exchangeable K in both soils, and enhances available P content to the depth of 0.6 m in Distrochrept.
2. These increased levels enabled significant gains in corn (*Zea mays*) yield, regardless of the fertilizer used, even in highly fertile soils.
3. The fluid organomineral fertilizer enabled a greater residual effect on the black oat (*Avena strigosa*) dry matter yield in the winter.

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