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Short-term effects of crop rotations on soil chemical properties under no-tillage condition

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Abstract

The use of crop rotation can provide sustainability for an agricultural production system by improving soil fertility and increasing nutrient use efficiency. Short-term changes in soil chemical properties were studied for different crop rotations and management of crop residues under no-till in Santa Helena, Paraná, Brazil. The investigated crops for the crop rotation were as follows: Pearl millet (*Pennisetum glaucum*), grass brachiaria (*Brachiaria brizantha*), forage sorghum (*Sorghum bicolor*) and sunn hemp (*Crotalaria juncea*), cropped in autumn–winter as well as an additional treatment in fallow ground (spontaneous weed). The crambe (*Crambe abyssinica*) was cropped in the winter on all plots. The subplots were divided into either absence or presence of straw mulch mechanical management on the soil surface (Triton©). Soil samples were collected at depths of 0–10, 10–20, and 20–40 cm after crambe harvest. Crop rotation with forage sorghum significantly increased ($p \leq 0.05$) the K^+ exchange (0.14 $cmol_c\ dm^{-3}$) and organic matter (21.8 $g\ dm^{-3}$) contents in the 0–10 and 20–40 cm soil layers, respectively; however, crop rotations had no effect on other soil chemical properties under no-tillage condition. Mechanical management of crop residues had no significant effect on soil chemical properties.

Keywords: cover crops; organic matter; soil fertility; straw management.
Abbreviations: AMM_Absence mechanical management, PMM_presence mechanical management.

Introduction

The adoption of conservation cropping systems (e.g., no-till) has been proposed as a viable alternative to assure the sustainability of soil agricultural use. However, the success of this production system depends, among other factors, on the input and maintenance of large amounts of straw on the soil surface. There is evidence that monoculture of cash-crops under no-till results in soil degradation (Tavares Filho et al., 2010) by favoring increased soil bulk density and penetration resistance, as well as reduced total porosity (Tavares Filho et al., 2001). While important benefits have been observed in soil structure, both in the short- and long-term, when cover crops with vigorous root systems and high capacity to produce dry matter are used (Costa et al., 2011; Ferrari Neto et al., 2011; Oliveira et al., 2011; Nascente; Crusciol, 2012; Crusciol et al., 2012). The use of different crop rotation systems can improve soil fertility and crop nutrient absorption efficiency, thus increasing the production potential through nutrient cycling (Moreti et al., 2007; Boer et al., 2007; Rosa et al., 2009; Cunha et al., 2011). Oliveira et al. (2011) reported that the main factors to be considered when choosing cover crop species are dry matter production and the capacity to recycle nutrients. In general, grasses used as cover crops are efficient at extracting nutrients from the soil and at recycling in crop rotation systems. Among the many plant species that can be used as cover crops in no-till in the State of Paraná, pearl millet (*Pennisetum glaucum*), grass brachiaria (*Brachiaria brizantha*), forage sorghum (*Sorghum bicolor*), and sunn hemp (*Crotalaria juncea*) are presented as excellent alternatives (Calegari, 2006). In addition to crop rotation, the mechanical management of crop residues on the soil surface, such as the horizontal straw crusher, can change the nutrient dynamics in the soil profile under no till and affect crop yields. Silva et al. (2010) and Ferrari Neto et al. (2011) found that the castor bean yield was higher in the absence of mechanical management of crop residues. However, Crusciol and Soratto (2007) found no effect of mechanical management of crop residues on the nutrition and yield of peanut crop under no till. Limited information exists on the effects of crop rotation and management of crop residues on the chemical properties of soils in southern Brazil. However, these studies are essential to evaluate the various soil management practices comprising the no-till systems in the Paraná State. The aim of this study was to investigate short-term changes in soil chemical properties under different crop rotations and management of crop residues under no-tillage condition.

Results and Discussion

Dry matter production cover crops

The overall dry matter production of forage sorghum (11,769 $kg\ ha^{-1}$), pearl millet (11,191 $kg\ ha^{-1}$) and sunn hemp (10,269 $kg\ ha^{-1}$) was higher than for grass brachiaria (5,532 $kg\ ha^{-1}$). This high dry matter production of cover crops, especially for forage sorghum, pearl millet and sunn hemp, is extremely important for the improvement of soil properties in no-till systems. The use of cover crops with vigorous root systems and high capacity to produce dry matter can improve soil fertility and crop nutrient absorption efficiency, thus increasing

Table 1. Chemical attributes in the different layers in the Red Latosol subjected to straw mulch mechanical management cover crops in no-till system crambe.

Cover crops	Depth (cm) 0–10	10–20	20–40	0–10	10–20	20–40
	P			K^+		
	mg dm^{-3}			$cmol_c\ dm^{-3}$		
Forage sorghum	19.02	14.58	11.00	0.11 ab	0.09	0.09
Pearl millet	27.02	17.87	10.15	0.14 a	0.10	0.10
Sunn hemp	17.08	15.98	10.26	0.08 b	0.08	0.07
Grass brachiaria	18.41	15.32	9.16	0.10 ab	0.08	0.08
Fallow	15.86	12.55	9.90	0.09 ab	0.08	0.08
CV (%)	36.78	34.61	23.07	32.08	24.24	26.03
	Ca^{2+}			Mg^{2+}		
	$cmol_c\ dm^{-3}$					
Forage sorghum	6.40	6.31	5.98	3.38	3.28	3.14
Pearl millet	6.63	6.26	5.69	3.32	3.23	3.07
Sunn hemp	6.82	6.80	6.17	3.24	3.26	2.99
Grass brachiaria	6.64	6.59	5.95	3.43	3.19	3.13
Fallow	6.48	6.20	5.88	3.06	3.03	2.78
CV(%)	9.84	12.31	12.96	12.39	17.60	12.35
	OM			V		
	g dm^{-3}			%		
Forage sorghum	22.4	21.1	21.1 ab	64.14	63.40	61.29
Pearl millet	23.5	22.4	21.8 a	64.26	61.75	60.20
Sunn hemp	22.1	19.6	18.1 bc	66.49	66.14	63.18
Grass brachiaria	22.6	22.4	17.9 bc	65.83	63.47	61.18
Fallow	21.3	21.6	16.9 c	62.96	61.48	60.22
CV(%)	7.75	11.93	11.05	7.80	9.23	9.41

P: phosphorus; K^+: exchangeable potassium; Ca^{2+}: calcium; Mg^{2+}: magnesium; OM: organic matter; V: base saturation. Means followed by the same letter in the column do not differ by Tukey's test ($p \leq 0.05$). Means without letters in columns indicate no significance by Tukey's test ($p \leq 0.05$).

Table 2. Chemical attributes in the different layers in the Red Latosol subjected to straw mulch mechanical management cover crops in no-till system crambe.

Cover crops	Depth (cm) 0–10	10–20	20–40	0–10	10–20	20–40
	pH			$H+Al^{3+}$		
	$CaCl_2$			$cmol_c\ dm^{-3}$		
Forage sorghum	5.28	5.25	5.15	5.51	5.56	5.80
Pearl millet	5.21	5.12	5.06	5.58	5.97	5.86
Sunn hemp	5.40	5.38	5.32	5.07	5.26	5.39
Grass brachiaria	5.35	5.28	5.15	5.26	5.64	5.79
Fallow	5.15	5.11	5.03	5.67	5.83	5.76
CV(%)	6.63	6.59	7.06	14.27	14.97	15.49
	SB			CEC		
	$cmol_c\ dm^{-3}$					
Forage sorghum	9.90	9.68	9.22	15.41	15.25	15.03
Pearl millet	10.09	9.60	8.87	15.68	15.57	14.73
Sunn hemp	10.15	10.15	9.24	15.22	15.41	14.64
Grass brachiaria	10.18	9.87	9.16	15.44	15.51	14.96
Fallow	9.64	9.31	8.75	15.32	15.15	14.52
CV(%)	9.42	11.30	11.09	3.79	3.71	4.02
	Al^{3+}			m		
	$cmol_c\ dm^{-3}$			%		
Forage sorghum	0.00	0.01	0.03	0.04	0.19	0.40
Pearl millet	0.00	0.01	0.01	0.00	0.17	0.14
Sunn hemp	0.00	0.00	0.00	0.00	0.00	0.06
Grass brachiaria	0.00	0.01	0.02	0.05	0.14	0.30
Fallow	0,00	0.01	0.01	0.09	0.11	0.13
CV(%)	394.26	265.39	159.97	384.75	275.29	164.73

Soil pH; $H+Al^{3+}$: potential acidity; SB: sum of bases, CEC: Cationic exchange capacity; Al^{3+}: exchangeable aluminum; m: aluminum saturation. Means followed by the same letter in the column do not differ by Tukey's test ($p \leq 0.05$). Means without letters in columns indicate no significance by Tukey's test ($p \leq 0.05$).

production potential through nutrient cycling (Boer et al., 2007; Crusciol et al., 2012). No significant spontaneous weeds on the soil surface at 80 days after the experiment installation was found in the fallow treatment, due to chemical control of weeds during the seeding of cover crops.

Chemical soil properties affected by cover crops

Crop rotations affected the K^+ and organic matter (OM) contents in the 0–10 and 20–40 cm layers, respectively (Table 1). Crop rotations had no significant effect on the other soil chemical properties. Based on the criterion of Warrick and Nielsen (1980), the soil pH, OM and CEC variables showed low coefficient of variation (CV) values at the three depths (CV ≤ 12%), while for the other variables the CV values were average (12% < CV < 60%), except for Al^{3+} and aluminum saturation (m) (CV ≥ 60%). According to Zanão Junior et al. (2007), these average CV values can be attributed to the residual effect of fertilization and continuous application of fertilizer in the sowing row. The P contents were not significantly affected by crop rotations (Table 1). In a two years study conducted for in the western region of Paraná, Costa et al. (2011) also found no effects of crop rotations on the soil P content under no-till. However, in an experiment conducted on a Red Latosol of the Brazilian Cerrado, Santos et al. (2012) found an effect of different cover crops on the P contents, with the highest concentrations observed in the rotations with pearl millet and pigeon pea. The highest P concentration in the top soil layer (up to 10 cm depth) was due to lack of soil tillage under no-till, maintenance of crop residues on the soil surface, and fertilizer applications in the surface layer, resulting in accumulation of organic matter and nutrients in the topsoil. The P contents observed in the soil were above the critical level (9 mg dm^{-3}) at three depths and are considered high. Exchangeable K^+ contents in the surface layer of 0–10 cm were lower in soil cultivated with sunn hemp (0.08 $cmol_c$ dm^{-3}) when compared to other cover crops and fallow treatment (Table 1). Pearl millet rotation had the highest absolute average of soil exchangeable K^+ (0.14 $cmol_c$ dm^{-3}); however, this did not differ from forage sorghum and grass brachiaria rotations and fallow. The results presented here are similar to those reported by Moraes (2001), Correia and Durigan (2008), and Santos et al. (2012), who found the highest levels of soil K^+ in rotation with pearl millet. Rosa et al. (2009), however, found that soil K^+ contents were not changed due to the different cover crops studied. Pearl millet is a crop adapted for relatively warm and wet regions, due to its vigorous root system and capacity to extract large amounts of soil nutrients (especially P and K^+) from the deepest soil layers (Molina et al., 2000; Alvarenga et al., 2001), confirming the importance of this cover crop for soil nutrient cycling. Crop rotations had no significant effect on the soil pH, potential acidity ($H + Al^{3+}$), and Ca^{2+} and Mg^{2+} contents at the three soil depths (Table 2). Evaluating the soil pH in a Haplic Cambisol under different crop rotations, Rosa et al. (2009) also found no effects of crop rotations on the soil pH under no-tillage; with a pH value that ranged from 5.7 to 5.9. Costa et al. (2011) and Souza et al. (2013) also reported no effects of crop rotations after two years, on the soil pH and potential acidity. In this study, pearl millet rotation increased the OM content in the 20 to 40 cm layer compared to sunn hemp and grass brachiaria rotations and fallow treatment. This probably occurred due to the mineralization of its vigorous root system. Pearl millet is a crop with great potential for soil management and has a high capacity for grow and develop in compacted soils; and may decrease the soil bulk density due to its root growth and increased organic matter content in the soil (Gonçalves et al., 2006; Silveira Neto et al., 2006). The CEC and soil base saturation (V%) values were not influenced by crop rotations (Table 2 and 3), confirming the results obtained by Cunha et al. (2011). These authors evaluated two soil tillage systems and crop rotations (sunn hemp, pigeon pea, velvet bean, sorghum and fallow) and identified no treatment effect on the soil CEC and V% under no-tillage. Similar results were reported by Nascimento et al. (2003) and Moreti et al. (2007), which confirmed that crop rotations did not affect the CEC and V% of soils. However, the positive effects of input and maintenance of crop residues on the soil surface and increased soil base saturation were reported by Pavinato and Rosolem (2008) and Santos et al. (2012). For soil exchangeable acidity (Al^{3+}), there was no significant difference between the different cover crops at the three soil depths tested (Table 2). Whereas Correia and Durigan (2008) found higher exchangeable Al^{3+} contents in the 5–20 cm layer in soils with millet rotation. According to Santos et al. (2003), this inference can be attributed to the successive application of ammonium fertilizer and mineralization of crop residues on the soil surface. Soil m values were low (<1.0 $cmol_c$ dm^{-3}) and not significantly affected by crop rotations (Table 2). Correia and Durigan (2008) did not observe the presence of Al^{3+} in the first 5 cm of soil; however, in the 5 to 20 cm layer the highest values were verified in the common millet, forage millet, and finger millet rotations.

Chemical soil properties affected by mechanical management of crop residues

The use of implements for mechanical management of crop residues on the soil surface did not affect chemical soil properties in the short-term (Table 3), indicating that the mechanical management of crop residues is not necessary, confirming the results of Crusciol and Soratto (2007), Ferrari Neto et al. (2011) and Silva et al. (2010) in growing oilseed species (i.e., groundnut and castor). By crushing the crop residues into particles of approximately 50 to 70 mm, increases their susceptibility to decomposition processes, as well as high cost, lowering operational efficiency and having greater susceptibility to soil compaction (Denardin; Kochhann, 1993). This is possibly due to the temporal proximity of the mechanical management of stubble and soil sampling. Souza et al. (2013) also observed no influence of mulch management of cover crops after cover crop management and harvesting onions in the first year.

Materials and Methods

Plant materials

The crambe (*Crambe abyssinica* Hochst. Former. RE Fries) cultivar was FMS–Brilhante originated from the Foundation Mato Grosso do Sul, MT, Brazil (FMS). Cover crops used for crop rotation were Pearl millet (*Pennisetum glaucum*), grass brachiaria (*Brachiaria brizantha*), forage sorghum (*Sorghum bicolor*) and sunn hemp (*Crotalaria juncea*).

Study site description

The experiment was carried out in Santa Helena, Paraná State, Brazil (24º57' S, 54°18' W, altitude of 282 m). The soil was a Rhodic Hapludox (Red Latosol in the Brazilian classification), with 700, 150, and 150 g kg^{-1} of clay, silt and

Table 3. Chemical attributes in the different layers in the Red Latosol subjected to straw mulch mechanical management cover crops in no-till system crambe.

Cover crops	Depth (cm) 0–10	10–20	20–40	0–10	10–20	20–40
	P			K^+		
	mg dm^{-3}			$cmol_c$ dm^{-3}		
AMM	21.32	16.76	10.78	0.11	0.08	0.09
PMM	17.63	13.77	9.41	0.09	0.08	0.08
CV(%)	32.19	30.30	19.24	24.73	14.90	19.87
	Ca^{2+}			Mg^{2+}		
	$cmol_c$ dm^{-3}					
AMM	6.53	6.37	5.94	3.24	3.14	2.97
PMM	6.66	6.49	5.93	3.33	3.26	3.07
CV(%)	6.99	6.39	7.41	8.13	7.83	10.96
	OM			V		
	g dm^{-3}			%		
AMM	2.21	2.19	1.91	64.05	62.26	60.63
PMM	2.26	2.10	1.91	65.42	64.24	61.80
CV(%)	8.52	14.61	12.66	5.34	6.64	5.81
	pH			$H+Al^{3+}$		
	$CaCl_2$			$cmol_c$ dm^{-3}		
AMM	5.25	5.18	5.12	5.52	5.81	5.83
PMM	5.30	5.28	5.16	5.32	5.49	5.61
CV(%)	3.95	4.44	3.76	10.01	13.24	9.24
	SB			CEC		
	$cmol_c$ dm^{-3}					
AMM	9.64	9.61	9.01	15.41	15.43	14.84
PMM	10.10	9.84	9.09	15.42	15.33	14.71
CV(%)	6.18	5.46	6.81	2.41	2.50	2.42
	Al^{3+}			m		
	$cmol_c$ dm^{-3}			%		
AMM	0.00	0.01	0.01	0.03	0.18	0.24
PMM	0.00	0.00	0.01	0.04	0.07	0.17
CV(%)	230.35	260.42	163.75	241.55	270.41	173.05

P: phosphorus; K^+: exchangeable potassium; Ca^{2+}: calcium; Mg^{2+}: magnesium; OM: organic matter; V: base saturation; soil pH; $H+Al^{3+}$: potential acidity; SB: sum of bases, CEC: Cationic exchange capacity; Al^{3+}: exchangeable aluminum; m: aluminum saturation. AMM=Absence mechanical management; presence mechanical management=PMM. Means without letters in columns indicate no significance by Tukey's test ($p \leq 0.05$).

sand respectively. The regional climate is relatively warm and wet. The 30-year mean annual temperature is 22.1°C with a July minimum of 16.8°C and a January maximum of 27.6°C, and mean annual precipitation of 1,800 mm. The experimental area had been under no-till for seven years, cropped to soybean/corn in succession. Before starting the experiment, soil samples were taken from the surface layer (0–20 cm), air dried, sieved through a 2 mm mesh, and analyzed as in Embrapa (1997). Soil chemical analyses returned values of: pH in $CaCl_2$ (0.01 M) of 5.1; 14 g dm^{-3} of organic carbon; 21 mg dm^{-3} of P (Mehlich-1); 0.13 $cmol_c$ dm^{-3} of K^+; 6.07 $cmol_c$ dm^{-3} of Ca^{2+}; 2.50 $cmol_c$ dm^{-3} of Mg^{2+}; 12.98 $cmol_c$ dm^{-3} of cationic exchange capacity (CEC); and 67 % of soil base saturation.

Experimental design and treatments

The experiment was set up in randomized complete blocks in a split-plot design with four replications. Pearl millet, grass brachiaria, forage sorghum, sunn hemp, and an additional treatment in fallow ground were grown on the whole plots. Sub-plots consisted of absence or presence of straw mulch mechanical management of crop residues on the soil surface. A total of 40 sub-plots, 3.2 m wide × 6.0 m long, comprised the entire study area.

Field management

The four experimental crop rotations and fallow were initially established on February 01, 2013. Cover crops were sown in 0.45 m spaced rows at densities of 20, 40, 15, and 20 kg seeds ha^{-1} of pearl millet, grass brachiaria, forage sorghum and sunn hemp, respectively (Muraishi et al., 2005; Simidu et al., 2010). Fertilization of cover crops was carried out by applying 100 kg ha^{-1} of 10-15-15 formulation at sowing. These crops remained in the area until desiccation on April 22, 2013 with glyphosate (1.44 kg ha^{-1} a.i.) at a spray volume of 200 L ha^{-1}. Seven days after the management of cover crops and spontaneous weed, in half of each experimental plot, crop residues were crushed into particles of approximately 50 to 70 mm long using a mechanical crusher of crop residues (Triton©). In another sub-plot, crop residues were manually cut close to soil and accommodated on the soil surface. Crambe was planted on May 10, 2013, in rows spaced 45 cm with a density of 20 seeds m^{-1}, fertilized with 10, 30 and 30 kg ha^{-1} of N, P_2O_5 and K_2O respectively, and applied in the seed furrows, as recommended by Pitol (2010).

Soil and residue sampling and measurements

In April 2013, immediately prior to management of cover crops and spontaneous weed, pearl millet, grass brachiaria, forage sorghum and sunn hemp were sampled, from three random points per plot, using 0.50 × 0.50 m wooden frames. The collected plant material was then oven-dried at 65°C for five days to determine dry matter yield. In September 2013, after crambe harvest, soil samples were collected at depths of 0 to 10, 10 to 20 and 20 to 40 cm using a hole-auger at five different points per plot. Soil samples were oven-dried at

55°C for 48 h and ground to pass through a 2 mm mesh screen. Soil pH was measured potentiometrically in 0.01 mol L^{-1} $CaCl_2$ suspensions (1:2.5 soil:solution ratio). Organic matter (OM) was quantified by oxidation with potassium dichromate in the presence of sulfuric acid, followed by titration with ammonium Fe (II) sulfate (Embrapa, 1997). Potential acidity ($H + Al^{3+}$) was estimated using the method of equilibrium pH of the soil suspension with the SMP solution. Potassium (K^+) and phosphorus (P) were extracted with Mehlich-1 solution (1:10 [w:v] soil-to-extractant solution ratio) (Embrapa, 1997) and P determined by colorimetry at 725 nm wave length and K^+ determined by flame photometry. Calcium (Ca^{2+}), magnesium (Mg^{2+}) and exchangeable aluminum (Al^{3+}) were extracted by 1 mol L^{-1} KCl solution (Embrapa, 1997). Calcium and magnesium were determined by atomic absorption spectrophotometry and Al^{3+} determined by titration with 0.025 mol L^{-1} sodium hydroxide. The CEC was estimated by the summation method ($CEC = Ca^{2+} + Mg^{2+} + K^+ + H + Al^{3+}$).

Statistical analysis

Original data were submitted to ANOVA and the results of different crop rotations and management of crop residues were compared using the Tukey's test ($p \leq 0.05$) and F test ($p \leq 0.05$), respectively. All analyses were performed using Sisvar 5.0 software for Windows (Statistical Analysis Software, UFLA, Lavras, MG, Brazil).

Conclusions

Crop rotation with forage sorghum increased the exchange K^+ and OM contents in the 0 to 10 and 20 to 40 cm soil layers, respectively; however, crop rotations had no effect on other soil chemical properties under no-tillage conditions. Mechanical management of crop residues had no significant effect on the soil chemical properties.

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