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SOIL AND PLANT NUTRITION - Article

Soil chemical attributes and energetic potential of agricultural residual biomasses provided by 23-year soil management

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ABSTRACT: Residual biomass from grains has potential as an energetic source. Biomass composition determines this potential and is related to plant nutrition, which may vary according to soil fertility. The aim of this 23-year field study was to evaluate changes in chemical attributes of a Brazilian Oxisol and in the energetic potential of oat (*Avena sativa* L.) and soybean (*Glycine max* (L.) Merr) residual biomasses provided by tillage systems and fertilizer rates. The trial was performed since 1989, assessing soil chemical attributes in no-tillage (NT), conventional (CT), minimum (MT) and no-tillage plus chisel plough (NT+CP), with two fertilizer rates (normal and reduced, since 1994). Oat and soybean (2012/2013) residual biomasses were collected and analyzed by its elemental composition, higher heating value (HHV) and theoretical potential for electricity production. The NT system presented higher P-resin availability; NT and NT+CP provided higher OM and total P content on soil surface. Without appropriate amounts of K and P fertilizer, P-resin and P total contents diminished mainly in 0-0.1 m depth, while exchangeable, non-exchangeable and total K^+ fractions were mined even in deeper layers (0-0.3 m). The better general fertility conditions were achieved by conservative tillage systems, with normal fertilizer rate. Soil fertility levels changed chemical composition of both biomasses but had no effect on biomass HHV. Considering a system with oat and soybean grain production plus residual biomasses for energetic exploitation, it could be possible to generate 2,941 GWh·year^{-1}, while still achieving 70% residue coverage under no-tillage maintenance.

Key words: bioenergy, no-tillage, fertilization, *Avena sativa* L., *Glycine max* (L.) Merr.

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INTRODUCTION

The world population has surpassed 7.5 billion inhabitants, resulting in a steady increase demand for food, fiber and energy. In an attempt to supply the growing energy demand the use of alternative sources such as biomass has increased considerably along recent decades (Ambrosio et al. 2017).

Soil erosion and water loss control have been the main reasons for no-tillage adoption worldwide (Derpsch et al. 2010). In southern Brazil, most of the grain crops are managed under no-tillage, which leaves large amounts of residue on soil surface. Excessive biomass accumulation may impede germination and promote the spread of diseases in the following rotation, especially in this mild weather region. Nevertheless, studies show that up to 30% of crop residues can be removed for bioenergy production while maintaining 93% residue coverage to protect the soil (Andrews 2006). This strategy has potential to support sustainable food and energy production, since the energy output will be originated from normal biomass resources generated under conditions that promote soil conservation.

The energetic potential of agricultural residues has been defined mainly on the basis of its higher heating value (HHV) (Telmo and Lousada 2011), elemental composition (Sheng and Azevedo 2005) and ash content (Tan and Lagerkvist 2011), characteristics that are closely related to crop management and plant nutrition (Ambrosio et al. 2017).

Tillage and fertilization practices modify soil chemical, physical and biological attributes (Mbuthia et al. 2015; Valboa et al. 2015), thereby contributing to differences in soil nutrient availability and creating contrasting environments for crop development. Plants absorb mainly labile fraction of nutrients, though previous studies have demonstrated the contribution of soil structural sources to plant nutrition (Zhang et al. 2011). Because soil properties are strongly buffered, many years can be required to detect changes due to management (Kibet et al. 2016; Valboa et al. 2015), which necessitates long-term studies to better understand the processes involved.

The aim of this 23-year field study was to evaluate changes in chemical attributes of a Brazilian Oxisol and in the energetic potential of oat (*Avena sativa* L.) and soybean (*Glycine max* (L.) Merr) residual biomasses provided by tillage systems and fertilizer rates. We hypothesize that long-term tillage and fertilizer practices change soil chemical attributes, providing a different nutritional environment for crop growth, which may reflect in the energetic value of the residual biomass.

MATERIALS AND METHODS

Experimental conditions

The experiment was performed in Ponta Grossa (Paraná state, Brazil) since 1989 (25°00’53” S; 50°09’07” W; elevation: 910 m), in a sandy clay Oxisol (450 $g \cdot kg^{-1}$ clay, 450 $g \cdot kg^{-1}$ sand and 100 $g \cdot kg^{-1}$ silt), in gentle slope and subtropical climate (Cfb).

Eight treatments were arranged in split-block scheme under a randomized block design with three replications in 104.12 m^2 plots. The treatments were a combination of four soil tillage systems and two fertilizer rates. The tillage systems studied were: 1) CT – conventional tillage with one disk plowing and two light disking; 2) MT – minimum tillage, with one medium and one light disking; 3) NT – no-tillage, seeding with no tillage; and 4) NT+CP – no-tillage plus chisel plough, held in winter every three years. Two fertilizer rates were used, namely: 1) normal rate with fertilization based on the recommendation of a local survey, which consisted of fertilization during sowing (N-P_2O_5-K_2O) and later by topdressing nitrogen (N) on the standing *Poaceae*; 2) reduced rate, no P and K was applied and N was applied only by top dressing on the standing *Poaceae*, the same amount applied as in the normal rate. From the period of 1989 until 1994, however, all the plots were conducted under the normal rate of fertilization, in which the fertilizer suppression has started since 1994. All fertilizer rates and the crop rotation scheme adopted throughout the experiment are shown in Table 1.

In 1989 it was applied 304.5 $kg \cdot ha^{-1}$ of P_2O_5 (Yookarin®) and 162 $kg \cdot ha^{-1}$ of K_2O (KCl) in all plots, incorporated at 0.3 m depth. Equally, limestone was applied to all plots in 1989 (7.3 $Mg \cdot ha^{-1}$), 1992 and 1994 (2.0 $Mg \cdot ha^{-1}$ each). The first liming was incorporated at 0.3 m depth and the two other applications were performed by broadcasting before sowing.

Soil chemical attributes

The soil was sampled in 2012 using a manual soil sampling in the depths of 0.0-0.10, 0.10-0.20 and 0.20-0.30 m

Table 1. Fertilizations N-P_2O_5-K_2O held in long-term experiment with four soil tillage methods (no-tillage, conventional tillage, minimum tillage and no-tillage plus chisel plough) in Ponta Grossa, Paraná state, Brazil.

Season	Crop	Fertilizer rates (kg·ha^{-1})		Season	Crop	Fertilizer rates (kg·ha^{-1})	
		Normal	Reduced			Normal	Reduced
1989	black oat	-		2001	wheat	20(+60)*-40-40	60-00-00
89/1990	soybean	00-40-40		01/2002	soybean	00-40-40	-
1990	lupine	-		2002	black oat	-	-
90/1991	maize	30(+80)-90-48		02/2003	maize	30(+90)-60-60	90-00-00
1991	oat	-		2003	oat	20(+45)-40-40	45-00-00
91/1992	soybean	00-40-40		03/2004	soybean	00-40-40	-
1992	wheat	10(+40)-20-20		2004	wheat	24(+45)-90-60	45-00-00
92/1993	soybean	00-40-40		04/2005	soybean	00-40-40	-
1993	vetch	-		2005	black oat	-	-
93/1994	maize	30(+80)-90-48		05/2006	maize	30(+130)-60-60	130-00-00
1994	oat	-		2006	oat	30(+67.5)-60-60	67.5-00-00
94/1995	soybean	00-60-60	-	06/2007	soybean	00-50-50	-
1995	wheat	10(+40)-20-20	40-00-00	2007	wheat	30(+67.5)-60-60	67.5-00-00
95/1996	soybean	00-60-60	-	07/2008	soybean	00-60-60	-
1996	vetch	-	-	2008	black oat	-	-
96/1997	maize	36(+80)-72-48	80-00-00	08/2009	maize	36(+135)-96-90	135-00-00
1997	black oat	-	-	2009	oat	30(+45)-60-60	45-00-00
97/1998	soybean	00-60-60	-	09/2010	soybean	00-60-60	-
1998	wheat	00(+60)-40-40	60-00-00	2010	wheat	30(+67.5)-60-60	67.5-00-00
98/1999	soybean	00-40-40	-	10/2011	soybean	00-60-60	-
1999	black oat	-	-	2011	black oat	-	-
99/2000	maize	30(+90)-60-60	90-00-00	11/2012	maize	36(+135)-96-90	135-00-00
2000	oat	-	-	2012	oat	16(+76.5)-60-70	76.5-00-00
00/2001	soybean	00-40-40	-	12/2013	soybean	00-60-60	-

*Values in parentheses in the normal rate of fertilization refer to additional nitrogen (reduced rate of fertilization received only this nitrogen application on maize, wheat and oat crops). All plots received normal rate from 1989 to 1994.

(15 sub-samples each plot). Afterwards, soil samples were air-dried, sieved (2 mm) and pH ($CaCl_2$), H+Al, exchangeable bases (Ca, Mg e K), available P by resin extraction, and organic carbon were determined (Raij et al. 2001). The parameters organic matter (OM), base saturation (V%), aluminum saturation (m%) and cation exchange capacity (CEC) were calculated from the laboratory results.

The sum of the fractions K^+ exchangeable plus K^+ non-exchangeable was obtained by extraction with HNO_3 1M at 113 °C for 30 min and determination by flame photometry. Non-exchangeable K^+ was estimated as the difference between K extracted by HNO_3 and by ion exchange resin. Total P and K were obtained by microwave soil digestions (200 °C, 1000 W) using HNO_3, HF and H_2O_2 (USEPA – 3052 method), filtering and determination by ICP-OES and flame photometry, respectively.

Biomasses energetic characterization

In the 2012/2013 growing season, oat (URS Guapa cultivar) and soybean (NA5909RG cultivar) were cultivated and the weed, pest and disease controls were performed according to the recommendations for each species. The seeds were inoculated with *Rhizobium* every time that soybean was the summer crop. Cumulative precipitation during the development of both crops was 1,174 mm (July/2012-March/2013), with low rainfall during the initial period of oat development. The rainfall during the oat crop cycle in →

2012 was 32% lower than the historical average rainfall of the ten years prior (Fig. 1).

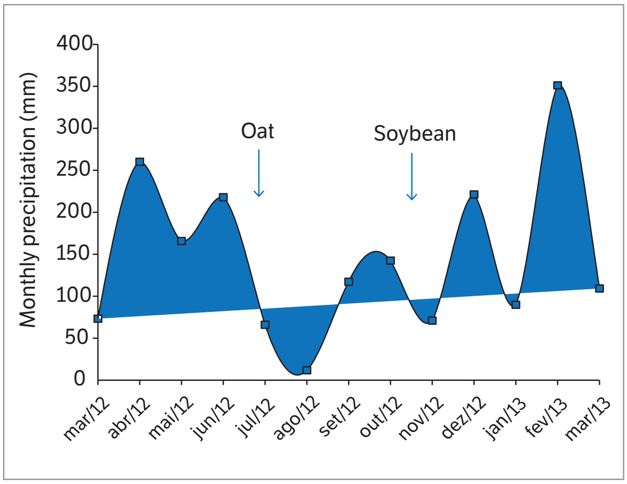

Figure 1. Precipitation (mm) in Ponta Grossa, Paraná state, Brazil, between March/2012 and March/2013 (SEAB 2013, adapted). Arrows indicate sowing dates for oat (06/29/2012) and soybean (11/16/2012).

At the point of physiological maturity, the harvest was conducted with a plot harvester machine. Samples were separated in grain and residual biomass, and it was calculated the residual biomass and grain yield by correcting moisture to 130 $g{\cdot}kg^{-1}$. Additionally, the residual biomass remaining in the field (due to the cutting height) was collected and added to the harvested residual biomass in order to calculate the total residual biomass.

After correcting the total residual biomass to kg of dry matter (drying at 60 °C), sub-samples were ground in a Wiley knife mill (20 mesh size) and the concentrations of C, H, O, N and S in the biomass were determined by dry combustion. The elements P, K, Ca, Mg, Na, Fe, Cu, Mn and Zn were extracted by acid digestion (Martins and Reissmann 2007) and the element Si by basic digestion (Furlani and Gallo 1978), with subsequent determination by ICP-OES. After obtaining the concentrations of each element, the nutrient content was calculated considering the total residual biomass produced by each species.

The biomass ash contents were quantified by burning the samples at 550 °C during 3 h. Lignin, hemicellulose and cellulose composition was obtained by bromatological analysis as described in Berchielli et al. (2001), only for the contrasting treatments (NT with normal fertilization and the CT with reduced fertilization).

The HHV was determined using an adiabatic calorimeter model IKA®-WERKE C5000 according to standard 8633 of the Brazilian Association of Technical Standards (ABNT 1984). From biomass H concentrations, the lower heating value (LHV) on a dry basis was determined according to Kollmann and Cotê (1968) (Eq. 1):

$$\text{LHV} = \text{HHV} - 600 \times 9 \times (\text{H}/100) \qquad (1)$$

where LHV is the lower heating value, in $kcal{\cdot}kg^{-1}$; HHV, the higher heating value, in $kcal{\cdot}kg^{-1}$; 600, the latent heat of vaporization of water at 20 °C, in $kcal{\cdot}kg^{-1}$; 9, the mass of water formed in the combustion per each 1 kg of H in the biomass, in kg; and H, the hydrogen concentration in the biomass, in %.

Finally, for the conversion of HHV values to the theoretical potential for electrical energy production it was used the Eq. 2, based on Andrews (2006), EPE (2014) and Nogueira and Lora (2003):

$$\text{EPP} = \{[\text{TRB} \times \text{LHV} \times 0.3]/860\} \times 0.2 \qquad (2)$$

where EPP is the electrical production potential, in $kWh{\cdot}ha^{-1}$; TRB, total residual biomass, in $kg.ha^{-1}$; LHV, lower heating value, in $kcal{\cdot}kg^{-1}$; 0.3 (30%) the percentage of total residual biomass removal from the field which still allows sufficient coverage to no-tillage; 860, equivalence between the kcal and kWh units; and 0.2 the average electric conversion efficiency (20 %) of boilers.

Statistical analysis

The Bartlett test was used to verify the homogeneity of variances ($p > 0.05$), followed by ANOVA. When significant, the factorial treatments were compared by Tukey test at 5% probability, except for the lignin, cellulose and hemicellulose, in which statistical analysis was not performed. For soil parameters, each depth was analyzed independently. In addition, correlations among variables were analyzed by Pearson linear coefficient method. All statistical analyses were performed using R® statistical software version 2.15.1.

RESULTS AND DISCUSSION

Soil chemical attributes

There was no effect of tillage on chemical attributes up to 0.30 m depth while fertilizer rates promoted changes but →

restricted to the 0.0-0.10 m layer (Figs. 2 and 3). Moreover, the interaction effect between tillage systems and fertilizer rates was observed for OM, Mg^{2+} and P-resin contents in 0.0-0.10 m layer (Figs. 2 to 4).

Long-term reduction on fertilizer application resulted in higher soil pH until 0.20 m (Fig. 2b, upper axis). Acidification by nitrification process and higher cationic bases exported when full fertilizer rate was applied could explain the results (Congreves et al. 2015). Agreeing with soil pH, potential acidity (H + Al) was higher under full fertilizer rate but differing only within 0-10 cm depth (Fig. 2b, bottom axis).

According to the evaluations made by Pauletti et al. (2005) in this same area in 1994 (and thus, before the fertilization suppression), the pH values ranged between 6.0 and 6.1 in 0.0-0.10 m; 5.6 and 6.0 in 0.10-0.20 m; and 5.1 and 5.6 in 0.20-0.30 m. Our results, however, showed that soil acidity decreased over depth regardless of treatment. This could be expected since all lime applications, exceptionally at the beginning of the experiment, were made to the soil surface and the subsoil acidity may be ameliorated by surface-applied amendments (Cifu et al. 2004) due to the leaching of small limestone particles. It can be either noticed that the three liming applications throughout 23 years were able to buffer the pH above 4.8 until 0.30 m depth (Figs. 2a and 2b), confirming the long-term residual effect of liming (Cifu et al. 2004).

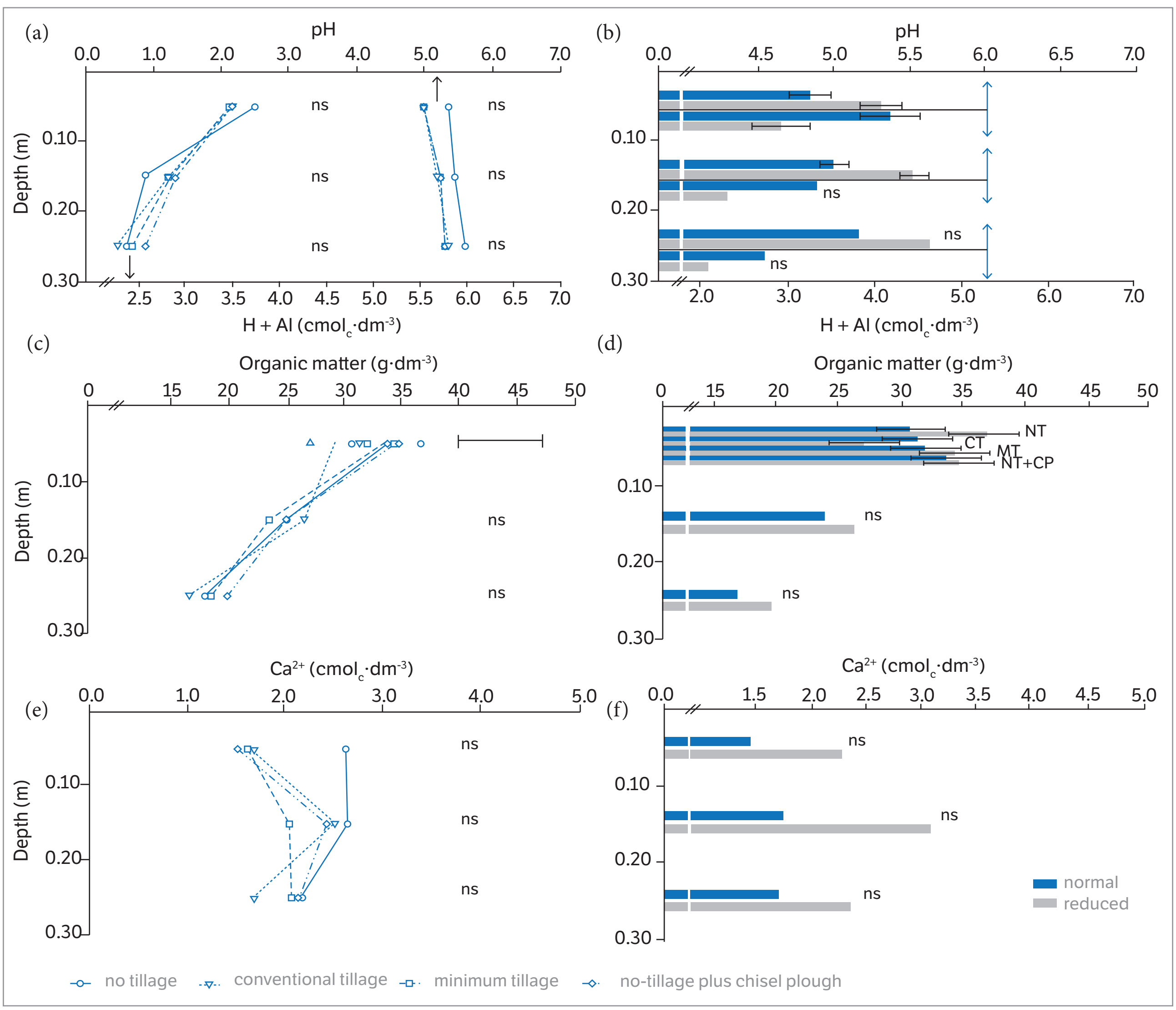

Figure 2. (a) and (b) pH and $H^+ + Al^{3+}$; (c) and (d) organic matter; and (e) and (f) Ca^{2+} contents of a Brazilian Oxisol (0.0-0.10, 0.10-0.20 and 0.20-0.30 m depth) according to soil tillage methods. Rods indicate the honestly significant difference (Tukey, $p < 0.05$); ns: non-significant. First layer (0-0.1 m depth) to organic matter (c and d): interaction between tillage and fertilizer rates.

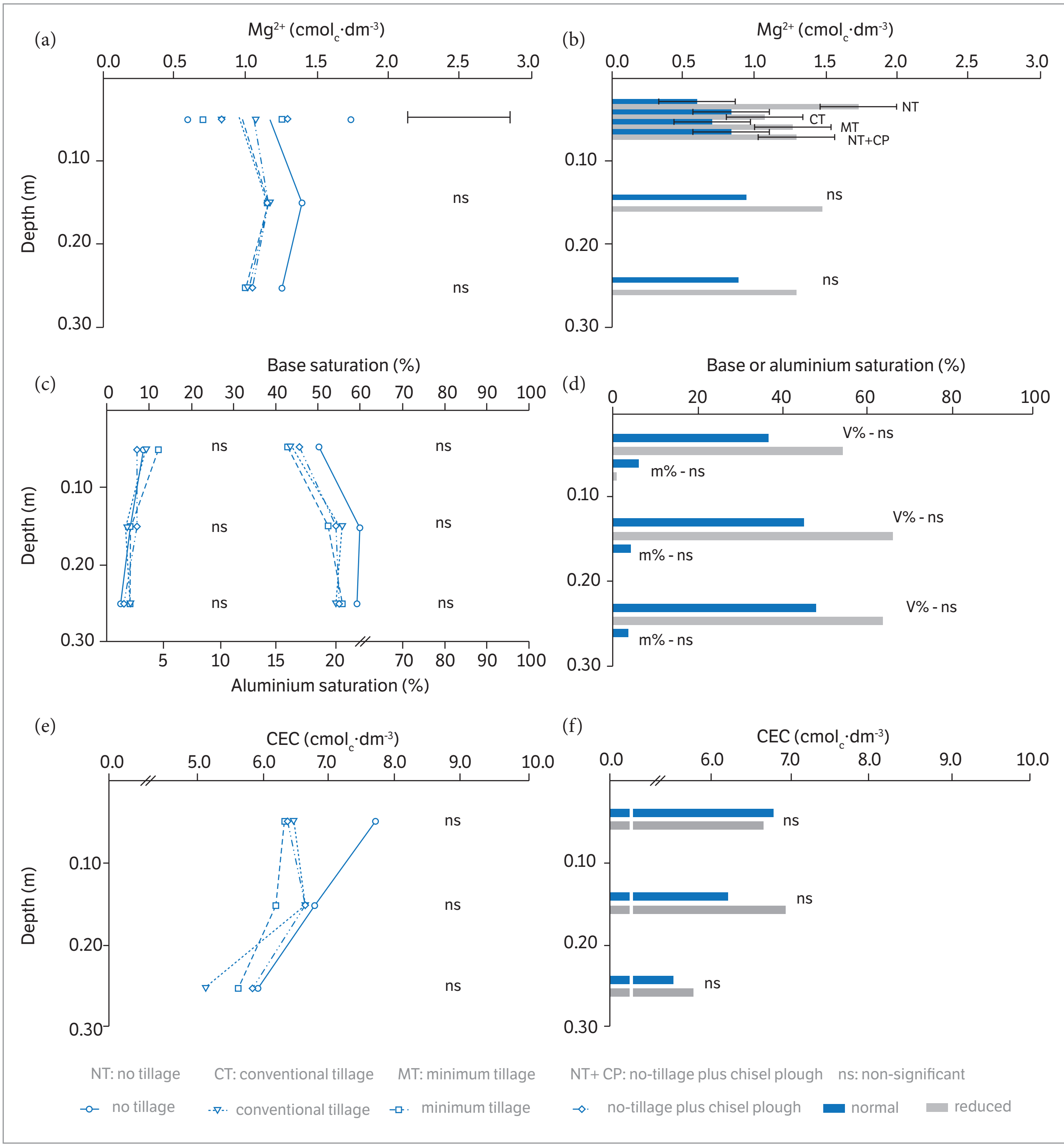

Figure 3. (a) and (b) Mg^{2+} content; (c) and (d) base saturation and aluminum saturation; (d) and (f) cation exchange capacity (CEC) of a Brazilian Oxisol (0.0-0.10, 0.10-0.20 and 0.20-0.30 m depth) according to soil tillage methods and fertilizer rates. Rods indicate the honestly significant difference (Tukey, $p < 0.05$); ns: non-significant. First layer (0-0.1 m depth) to Mg^{2+} (a) and (b): interaction between tillage and fertilizer rates.

The NT system with the reduced rate of fertilizer had the highest amount of OM in 0.0-0.10 m. The opposite occurred in CT, i.e., in this tillage system it was observed the lowest amount of OM when fertilization was suppressed (Figs. 2c and 2d). Although it was firstly expected that the OM decomposition would be faster with higher N input (normal rate of fertilizer), this result can be explained by a priming effect inducement, which may be stimulated when the microbial community seeks nutrients for its metabolism, contributing to OM mining (Dimassi et al. 2014). Besides, CT system causes inversion and burial of the organic residues in deepest layers, increasing soil-residue contact and, thus,

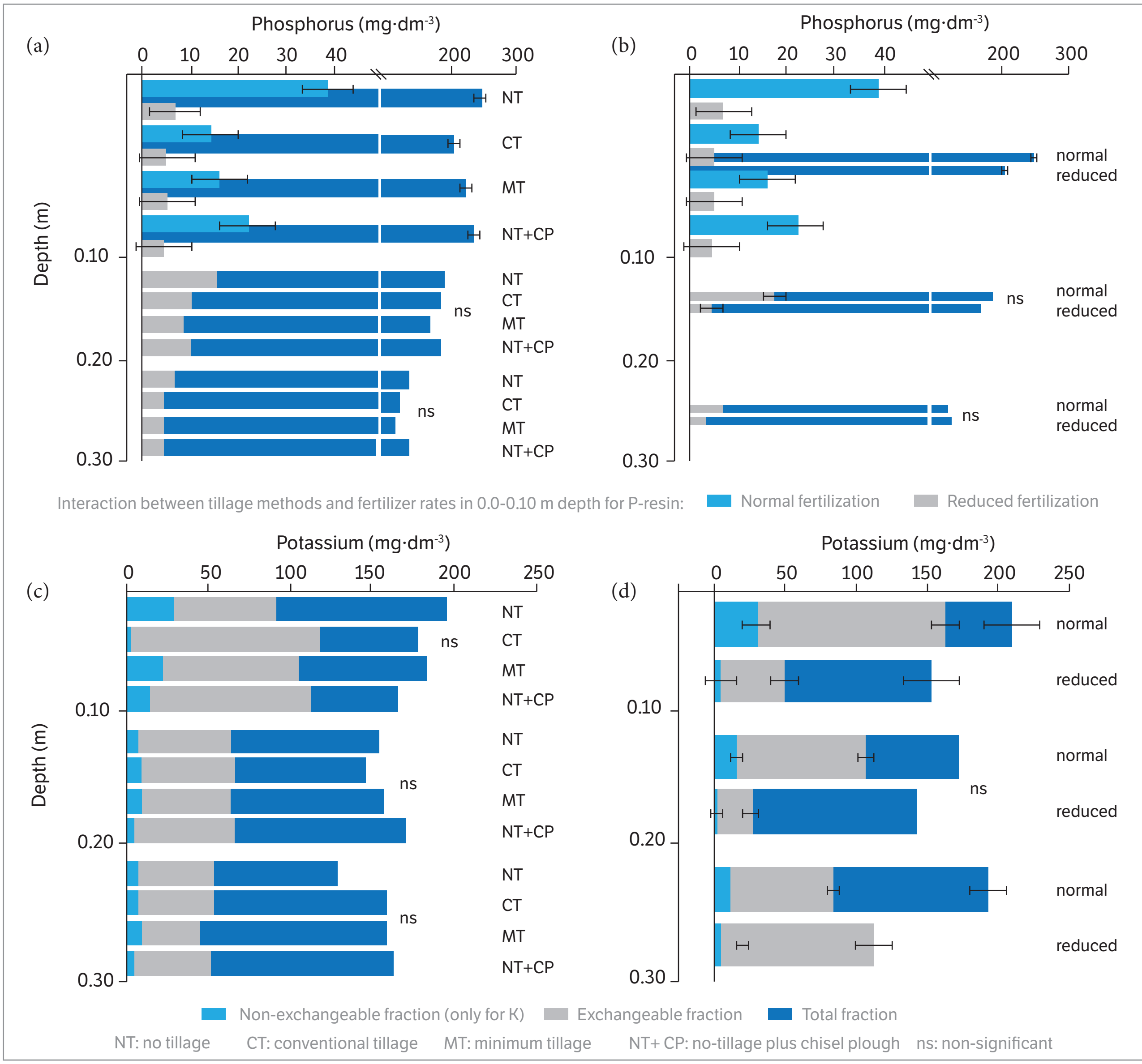

Figure 4. (a) and (b) Phosphorus (P); and (c) and (d) potassium (K) contents in a Brazilian Oxisol (0.0-0.10, 0.10-0.20 and 0.20-0.30 m depth) according to soil tillage methods and fertilizer rates (normal and reduced). Rods indicate the honestly significant difference (Tukey, $p < 0.05$); ns: non-significant.

further stimulating OM oxidation (Kibet et al. 2016). On the other hand, higher contents and superficial OM accumulation in conservative tillage systems is widely reported in many papers (Derpsch et al. 2010; Valboa et al. 2015; Vogeler et al. 2009) due to slower OM turnover as a consequence of non-disturbance on soil (Kibet et al. 2016). It is important to highlight, however, that in this same area Pauletti et al. (2005) reported close OM contents to ours within 0.0-0.10 m depth (NT: 37.8 g·dm^{-3}; CT: 36.1 g·dm^{-3}; MT: 37.8 g·dm^{-3}; and NT+CP: 43.0 g·dm^{-3}), which can be an indicative of an OM content steady state over time.

Soil chemical attributes seem to respond more slowly to soil management than biological attributes, requiring a longer time for the effects to be recognized (Kibet et al. 2016; Mbuthia et al. 2015). The differences also have been related to sampling depth (Congreves et al. 2015; Dimassi et al. 2014) and site-specific properties (Valboa et al. 2015; Zhang et al. 2015). In this sense, even after 23 years it was not possible to identify differences regarding soil management on Ca^{2+} availability (Figs. 2e and 2f), V%, m% and potential CEC, exceptionally to Mg^{2+} content in the first layer (Fig. 3). Significant tillage effects have been reported in previous studies with more stratified samples (Deubel et al. 2011; Dimassi et al. 2014). Comparing the normal fertilizer rate with the soil analysis performed by Pauletti et al. (2005) in 1994, however, it can be noted that higher cationic base exportation occurred in these plots, since Ca^{2+} and Mg^{2+} contents and V% decreased in 1.1 to 3-fold over time.

The interaction between soil tillage and fertilizer rates regarding P-resin within 0.0-0.10 m depth resulted in higher content of this nutrient in conservative tillage systems (NT and NT+CP) when normal fertilizer rate was adopted (Figs. 4a and 4b), which is addressed to the surficial application and low mobility of P in soil (Messiga et al. 2012). Considering that the P suppression started in 1994, after 18 years without P application, it was observed depletion in the superficial layers for NT and NT+CP systems in about 35%, but the same was not observed for CT and MT systems. On the other hand, with normal rate of fertilizer, the available P buildup occurred for all tillage systems, increasing the P-resin contents in 0.0-0.10 m in 2.7 to 3.5 times (Pauletti et al. 2005). Regarding the current data, the reduced rate of fertilizer accounted for 18%, 35%, 33% and 21% of P-resin contents found in NT, CT, MT and NT+CP systems, respectively, in comparison with normal rate of fertilizer (Figs. 4a and 4b). The P reduction extended until 0.0-0.20 m depth, indicating root exploration. It is possible that under NT growth root concentrated close to soil surface, increasing P uptake and depletion. Additionally, NT system had 2.7 times higher available P than in CT in the same fertilizer rate. This can be associated with higher P adsorption sites in CT provided by soil exposure (Al-Kaisi and Kwaw-Mensah 2007), once there was no indication of erosion and runoff due to the landscape condition.

It was observed main effects of both tillage systems and fertilizer rates regarding total P within 0.0-0.10 m depth, with higher amounts for NT and in normal rate (Figs. 4a and 4b). Although it appears that long-term phosphate fertilization has been reflected in total P contents, low contribution of P-resin was accounted to this fraction (3% up to 10%) as a consequence of high P fixation.

There was no influence of tillage systems in any K fraction, contrasting with large effects of K fertilization. Exceptionally for the non-exchangeable fraction at 0.20-0.30 m and the total fraction at 0.10-0.20 m depths, all the others K fractions were higher in normal fertilizer rate up to 0.30 m (Figs. 4c and 4d). The average exchangeable K contents reported by Pauletti et al. (2005) before nutrient suppression has started indicates that the reduced fertilizer rate declined this fraction in 2.7 to 3.0-fold within 0.0-0.30 m over the years. Like P, the result reinforces the exhaustion of K without reposition. On the other hand, K decrease extends in depth due to higher K mobility in comparison to P and the normal rate of fertilizer kept exchangeable K contents constant over time (K exchangeable contents within 0.0-0.10 m reported by Pauletti et al. (2005) in 1994 were: 164, 133, 156 and 156 $mg \cdot dm^{-3}$ to NT, CT, MT and NT+CP, respectively).

Most of the total K is represented by the exchangeable fraction, mainly in 0.0-0.10 m depth and when normal fertilizer rate was applied (Fig. 4d). As annual additions of potassium fertilizers maintained exchangeable K^+ contents up to 3.0 folds in comparison to reduced rate, this may have been reflected in the total contents. In deeper layers, there was a considerable reduction of the exchangeable K^+ but total contents remained slightly altered. Thus, it is an indicative that soil minerals (e.g. mica and feldspars) had contributed more to total K contents in 0.10-0.20 and 0.20-0.30 m layers, whereas potassium fertilizers seemed to supply total K in 0.0-0.10 m.

The reduction in the exchangeable K^+ fraction after 18 years without fertilization, in comparison to the normal rate, was 69%, 75% and 76% in 0.0-0.10, 0.10-0.20 and 0.20-0.30 m, respectively. Nonetheless, regarding the non-exchangeable fraction, the reduction was 88%, 90% and 73% for the same conditions. This may mean that there was higher depletion of non-exchangeable K^+ fraction in the upper layers due to potassium fertilization restriction. Previous authors have discussed the contribution of non-exchangeable K^+ fraction to plant nutrition (Zhang et al. 2011) especially when there was limitation on K availability.

In order to verify how K and P fertilization negligence on long-term affects soil reserves, it was calculated the element's stock until 0.3 m depth based on P and K total contents previously measured and the soil bulk density, according to the excavation method proposed by Blake and Hartge (1986) to the depths 0-0.05, 0.05-0.10, 0.10-0.20 and 0.20-0.30 m. The single measures of 0-0.05 and 0.05-0.10 m layers were converted to an arithmetic average value of 0.0-0.10 m depth. Then, a correction →

was made from the equivalent soil mass, to avoid any differences regarding soil bulk densities among tillage systems (Sisti et al. 2004), taking as a reference the CT with reduced fertilization (Eq. 3).

$$stock = \sum_{i=1}^{n-1} Pi \text{ or } Ki + [M_n - \\ - (\sum_{i=1}^{n} M_i - \sum_{i=1}^{n} M_{Ri})] \cdot \left[\frac{P_n \text{ ou } K_n}{M_n}\right] \quad (3)$$

where $\sum_{i=1}^{n-1} P_i or K_i$ are the stock of P or K from the first to the penultimate layer; M_n is the soil mass in the deepest layer; M_i is the soil mass from the first to the deepest layer; M_{Ri} is the soil mass from the first to the deepest layer, in CT with reduced fertilization; and P_n or K_n are the P or K stock in the deepest layer (all data in Mg·ha^{-1}).

The K stock was influenced by fertilization diminishing in 301.8 kg·ha^{-1} (approximately 13 kg·ha^{-1}·year^{-1}), while the P stock was not affected by restriction in P fertilization, with a difference between normal and reduced rates of 46.3 kg·ha^{-1} (Fig. 5). This result contrasted with the sharp decrease described for P availability within 0.0-0.10 m. The P fertilization in the experiment establishment (304.5 kg·ha^{-1} of P_2O_5) could have contributed to supply P due to residual effect, since possibly structural forms might not provide P to plant nutrition under restriction of this element in soil. Otherwise, non-exchangeable K^+ fractions supplied the plant nutrition in the reduced fertilizer rate, resulting in a mining of soil natural resources. Additionally, deeper soil layers may have supplied K nutrition to plants (Zhang et al. 2011), what was not accounted in the stock calculations.

Despite some of the soil chemical attributes had not showed response to the treatments, this long-term experiment demonstrated that better fertility condition and, as a consequence, better crop environment regarding soil nutrition was achieved with conservative tillage systems and following the fertilization scheme to replace nutrients exported by harvesting, which is in agreement with the main literature (Congreves et al. 2015; Mbuthia et al. 2015; Zhang et al. 2015). This management provided non-depletion of natural soil reserves and maintenance of OM contents over time, with the additional benefit of soil protection against wind and water erosion.

Biomasses energetic characterization

There was no interaction between soil tillage systems and fertilizer rates regarding grain yield and total residual biomass for both cultures, but the two crops responded differently to the treatments. Crop yield may be changed when conventional tillage is replaced for less intensive soil revolving systems such as no-tillage. However, these responses are complex and seem to differ among geographical regions and species, resulting in yield increment (Zhang et al. 2015), decrease (Messiga et al. 2012) or no change (Vogeler et al. 2009).

Oat presented higher grain yield in NT system than in CT (Fig. 6a), which may be attributed to better general fertility in the arable layer in that system, as previously discussed. Also, higher total residual biomass was observed to oat in NT and NT+CP (Fig. 6b). However, soybean grain yield and total residual biomass were not influenced by tillage methods, with 3,207 and 2,185 kg·ha^{-1} on average, respectively.

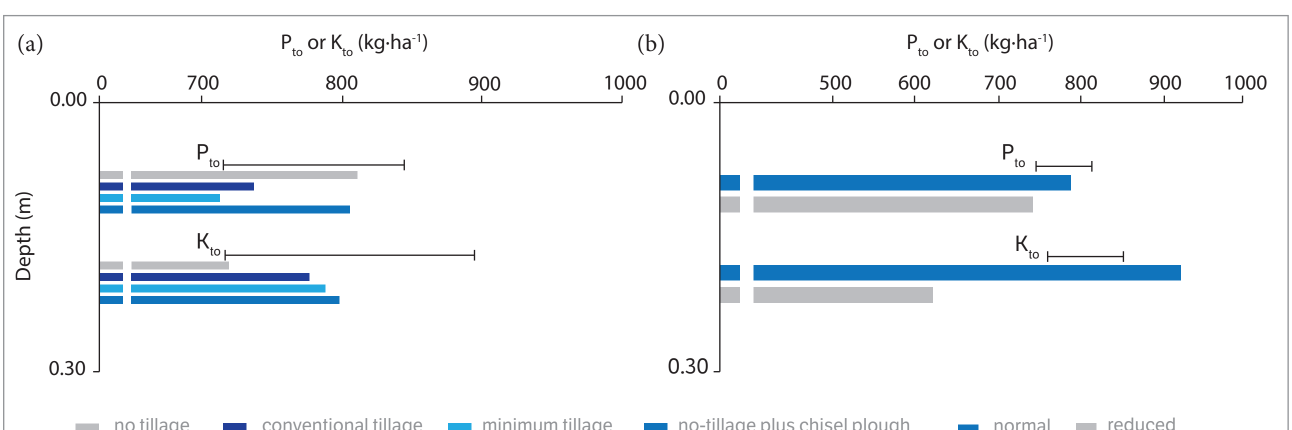

Figure 5. Total stock of phosphorus (P) and potassium (K) of a Brazilian Oxisol (0-0.30 m depth) according to (a) four soil tillage methods, and (b) two fertilizer rates (normal and reduced) after 23 management years (average of three replicates). Rods indicate the honestly significant difference (Tukey, p < 0.05).

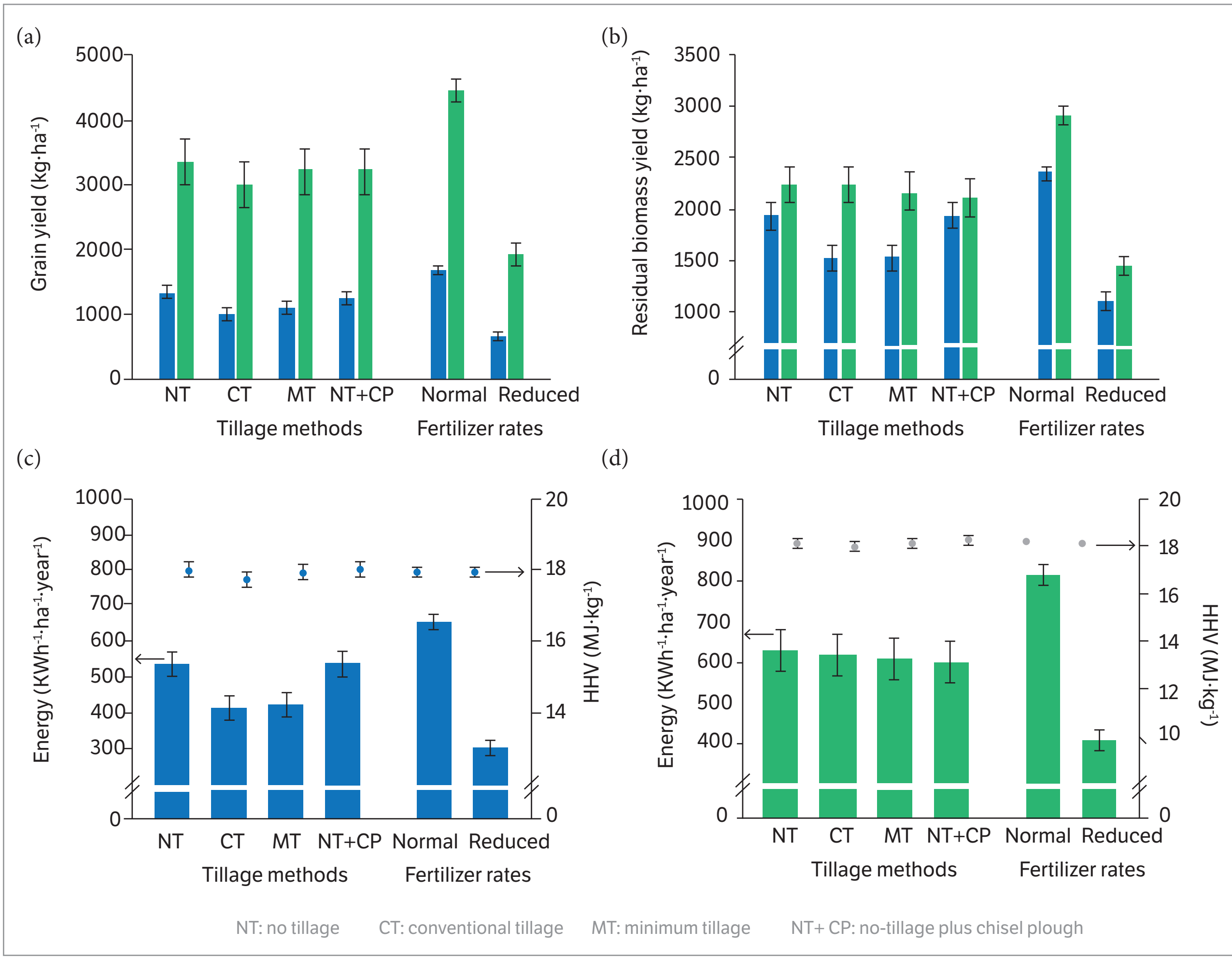

Figure 6. (a) Grain and (b) residual biomass yield; (c) and (d) theoretical potential for electricity production and higher heating value (HHV) of oat (blue) and soybean (green) according to soil tillage methods and fertilizer rates (normal and reduced). Rods indicate the honestly significant difference (Tukey, $p < 0.05$).

Difference response to tillage systems between oat and soybean could be addressed to water availability, since oat grew under water restriction (Fig. 1) and conservative tillage systems promotes higher soil humidity maintenance (Zhang et al. 2015).

Soil tillage and fertilizer management influenced nutrient dynamics in soil, which leads to alteration in nutrient use efficiency (Al-Kaisi and Kwaw-Mensah 2007). Although there was no influence of tillage systems on soybean yields, fertilization efficiency with P and K in NT increased approximately 6 kg.ha^{-1} of soybeans for every 1 kg.ha^{-1} of P_2O_5 and K_2O applied when compared to the CT. As expected, reduction in fertilizer application diminished grain and residual biomass yields for both crops. Oat produced 2.5 times more grain and 2.1 times more residual biomass in the normal rate compared to the reduced one. Soybean yield increased 2.3 and 1.9 fold under the same condition for grains and residual biomass, respectively.

Biomass composition affects their energetic quality because the minerals remain virtually unchanged after burning in boilers, since they do not participate in the combustion process. All the nutrient contents that responded to the treatments were observed in those that provided higher biomass yields (Table 2). Ca and Mg contents were higher in NT and NT+CP for oat, which had higher biomass in these systems, and did not differ for soybean, that had the same yield in all tillage. Similarly, nutrient contents were always higher in the normal rate of fertilizer than in the reduced rate, which corresponds to the higher yields found.

The normal fertilizer rate increased the levels of P and K in the biomass in 3.5 and 4 fold until 0.0-0.20 m, compared to the reduced rate. Because of this, there was a considerable

Table 2. Nutrient content, ash content and chemical fractionation in the residual biomass of oat (season 2012) and soybean (season 2012/2013) according to soil tillage methods (no-tillage – NT; conventional tillage – CT; minimum tillage – MT; and no-tillage plus chisel plough – NT+CP) and fertilizer rates (normal and reduced).

Nutrient	NT*	CT	MT	NT+CP	nor.**	red.	frac.[1]	
				oat				
N (kg·ha^{-1})	8.7	7.6	7.3	8.0	9.3a	6.5b	Lignin	6.0
Ca (kg·ha^{-1})	4.1a	3.1b	3.2b	3.8ab	4.6a	2.5b	Cellulose	33.7
Mg (kg·ha^{-1})	3.5a	2.6b	2.6b	3.1ab	3.5a	2.4b	Hemicellulose	24.6
K (kg·ha^{-1})	35.4	31.3	30.6	34.6	49.5a	16.5b		
P (kg·ha^{-1})	0.3	0.3	0.3	0.3	0.4a	0.2b		
Si (kg·ha^{-1})	12.7	12.7	10.4	12.9	15.8	8.5		
Na (g·ha^{-1})	634	541	612	786	846a	440b		
Cu (g·ha^{-1})	7.6	5.6	5.4	7.3	7.8	5.2		
Fe (g·ha^{-1})	354	320	328	298	361	288		
Mn (g·ha^{-1})	125	148	132	172	241	47.4		
Zn (g·ha^{-1})	60.1	37.9	79.9	64.8	80.2	41.2		
Ash (%)	5.3	4.9	5.5	5.7	5.7a	5.0b		
				soybean				
N (kg·ha^{-1})	21.3	18.2	17.8	19.2	21.4a	16.9b	Lignin	14.2
Ca (kg·ha^{-1})	9.5	9.9	8.7	9.3	11.6a	7.1b	Cellulose	36.9
Mg (kg·ha^{-1})	9.9	9.9	9.0	8.9	10.7a	8.2b	Hemicellulose	16.5
K (kg·ha^{-1})	27.7	30.9	29.6	24.6	50.2a	6.1b		
P (kg·ha^{-1})	0.6	0.5	0.5	0.6	0.7a	0.4b		
Si (kg·ha^{-1})	0.3	0.6	0.3	0.4	0.3	0.4		
Na (g·ha^{-1})	449	445	432	421	582a	291b		
Cu (g·ha^{-1})	12.0	11.1	10.9	10.5	14.0a	8.3b		
Fe (g·ha^{-1})	458	575.7	549	438	418	593		
Mn (g·ha^{-1})	36.4	43.1	37.8	38.8	57.3a	20.7b		
Zn (g·ha^{-1})	31.8	31.3	37.2	34.6	36.3	31.2		
Ash (%)	4.2	3.9	4.2	4.5	4.8a	3.6b		

Values followed by different letters in the column differ by Tukey test ($p < 0.05$); ns = not significant. * Average values of the two fertilization rates; ** average values of the four soil tillage methods. [1]no statistical test was performed.

difference of K contents in both residual biomasses between normal and reduced rates, but regarding P the maximum difference was 300 g.ha^{-1} (Table 2). This behavior can be associated with the redistribution of elements in the plant since most of the P absorbed is allocated to the grains (Deubel et al. 2011), while K absorbed remains mainly in straw (Zhang et al. 2011).

K was the nutrient that most influenced oat and soybean ash contents, especially when fertilizer was applied (Fig. 7). The biomass ash content was not influenced by tillage systems, but it was higher in the normal fertilizer rate (Table 2). There was a significant correlation between the content of this nutrient in the soil arable layer (0.0-0.20 m) and the biomass ash contents ($r = 0.84$ for soybean and $r = 0.65$ for oat, $p < 0.01$) as well as between ash and K in the biomasses ($r = 0.89$ for soybean and $r = 0.92$ for oat, $p < 0.01$) (Figs. 8 and 9). Ash contains several elements that can be reused for nutrient replacement to the soil (Tan and Lagerkvist 2011), especially regarding to K. So, considering that all the biomass is used to energetic production, returning back the ashes to soil could account up to 49.5 and 50.2 kg.ha^{-1} of K. However, one negative perspective regarding high K and Si contents in biomass is that this may lead to corrosion of boilers and decreased combustion system efficiency →

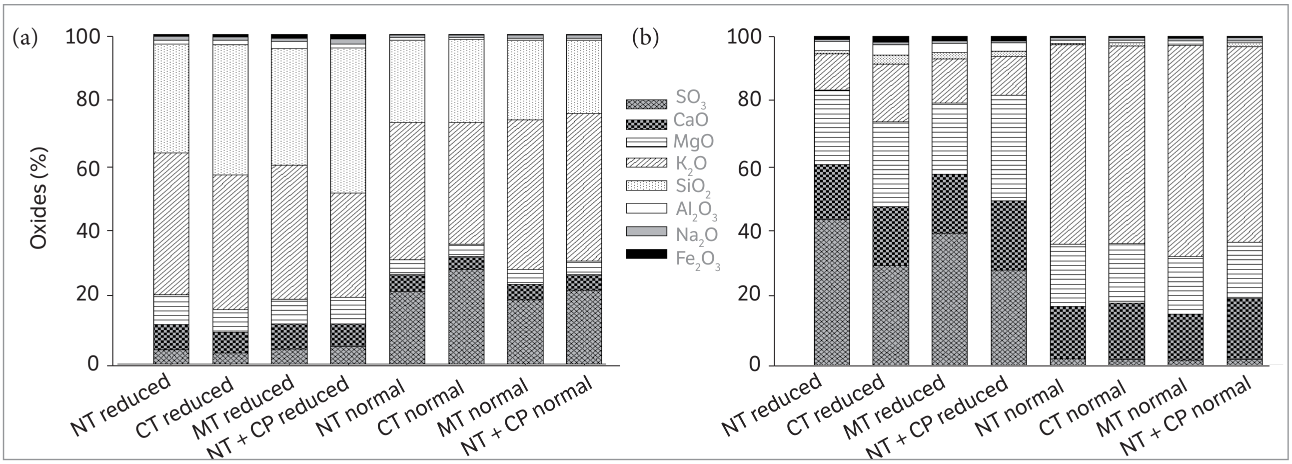

Figure 7. Ash composition (%) of (a) oat and (b) soybean biomass cultivated in a Brazilian Oxisol, according to soil tillage methods and fertilizer rates (normal and reduced).

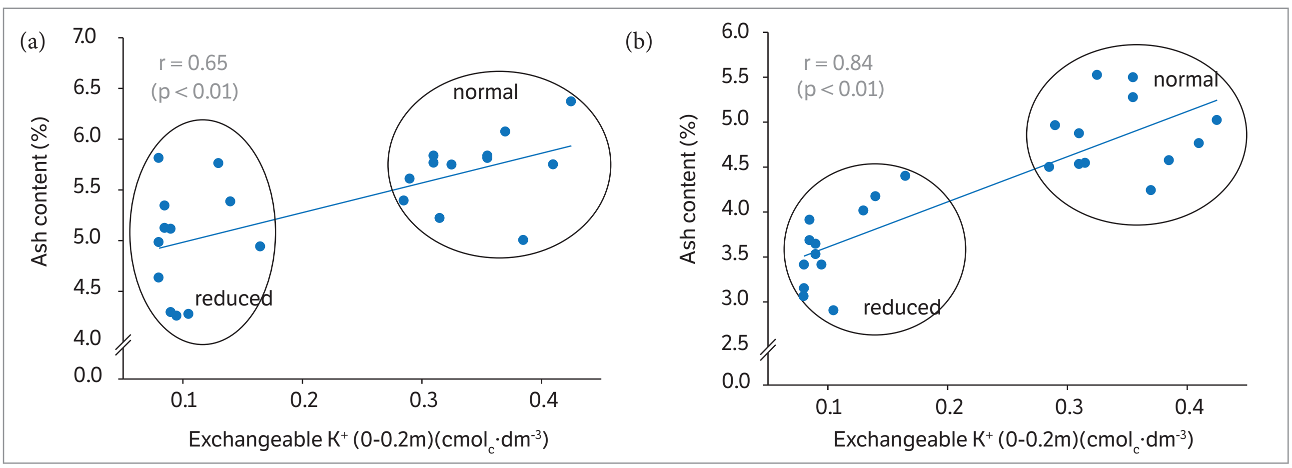

Figure 8. Pearson correlation ($p < 0.01$) between (a) oat and (b) soybean residual biomass ash contents and the exchangeable K^+ in the arable layer (0-0.2 m) of a Brazilian Oxisol, according to soil tillage methods and fertilizer rates (normal and reduced).

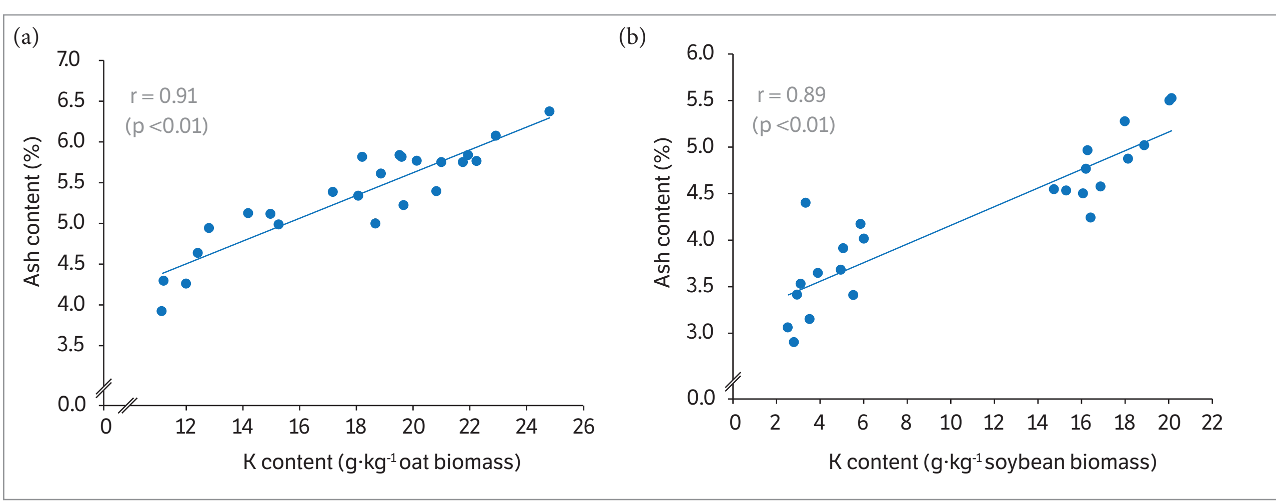

Figure 9. Pearson correlation ($p < 0.01$) between (a) oat and (b) soybean ash contents and the K contents in the residual biomass.

(Tan and Lagerkvist 2011). The ash content of residual biomass from agricultural crops is usually higher than forest species (Demirbas and Demirbas 2004). On the other hand this material is already produced and do not represent a competition with food production, as what happens with forestry biomass.

The HHV of oat and soybean residual biomass was not affected by soil tillage systems and fertilizer rates (Figs. 6c and 6d), which contradicts the initial hypothesis of this work. Despite the influence of the treatments on soil chemical attributes and on biomasses energetic quality, the highest ash contents observed in the normal fertilizer rate (Table 2) were not enough to affect HHV, although the inverse correlation between these two characteristics is often mentioned in the literature (Sheng and Azevedo 2005; Tan and Lagerkvist 2011).

The C and H contents are the elements positively related to HHV due to its high energetic density (Ambrosio et al. 2017; Demirbas and Demirbas 2004; Sheng and Azevedo 2005), while higher O contents tend to decrease the caloric value because it acts as an oxidizer agent. The contents observed to these elements ranged between 468 and 997 kg·ha^{-1} of C, 69 and 144 kg·ha^{-1} of H, and 507 and 1063 kg·ha^{-1} of O to oat biomass; and 610 and 1214 kg·ha^{-1} of C, 92 and 182 kg.ha^{-1} of H, and 678 and 1353 kg·ha^{-1} of O to soybean biomass. Again, the differences observed were a consequence of higher biomasses yields in NT and NT+CP tillage systems and normal fertilizer rate. Despite the significant and positive correlation between the HHV and the C concentration in the soybean biomass ($r = 0.70$, $p < 0.01$) (Fig. 10), the treatments did not influence the C, H and O concentrations (%) of both residual biomasses (data not shown), which may explain the little variation observed in the HHV.

The biomass HHV, on average (17.9 MJ kg^{-1} for oat and 18.2 MJ kg^{-1} for soybean), was comparable to the HHV of forest species commonly used for firewood, like pine and eucalyptus (Telmo and Lousada 2011). The soybean HHV was slightly superior to that found in oat biomass, which can be attributed to a lignin content 2.4 times higher and ash content 1.3 lower (Sheng and Azevedo 2005) (Table 2), although the difference regarding the chemical fractions was not statistically evaluated. Soybean also had higher total residual biomass (Fig. 6b) and 15% less K and 97% less Si in its composition (Table 2), which suggests that this species presents a more favorable potential to energetic exploitation in relation to oat.

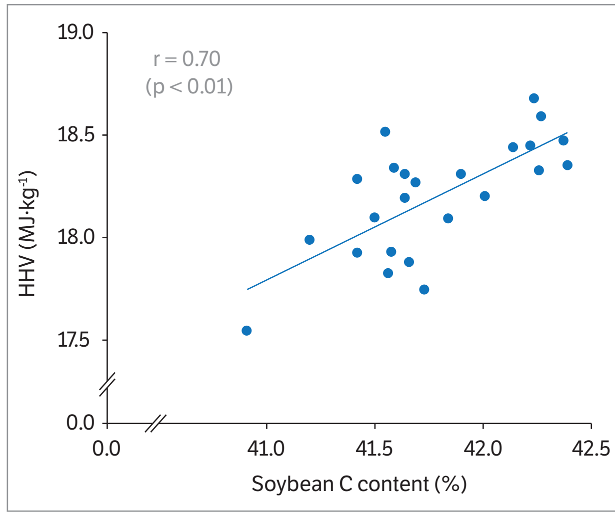

Figure 10. Pearson correlation ($p < 0.01$) between C content (%) and Higher Heating Value (HHV) (MJ·kg^{-1}) in a soybean biomass cultivated in a Brazilian Oxisol, according to soil tillage methods and fertilizer rates (normal and reduced).

Because there were no differences in HHV, the theoretical potential for electricity production obtained from the studied biomasses followed the same pattern observed in yields. Thus, the more biomass produced (in NT and NT+CP for oat, and in normal fertilizer rate for both cultures), the greater the potential energy output per area unit (Figs. 6c and 6d). For this reason, the management that promotes highest grain yield (and consequently of residual biomass) should be adopted when the objective is the dual-purpose exploration of grain and energy.

Considering an agricultural season with oat (winter) followed by soybean (summer) in NT system and in normal fertilizer rate (collecting 30% of the residual biomass), the main harvested area in Paraná state during 2012/2013 (CONAB 2013) and the residential consumption of electricity in the Paraná state in 2013 as 6,986 GWh·year^{-1} (EPE 2014), the destination of residual biomass of the two crops could supply 42% of this demand (Table 3). This calculation considered a boiler efficiency of 20%, although this value can reach up to 40% (Evans et al. 2010) and, hence, can be even more promising. This potential of energetic supply is inserted into a scenario that also encompasses the production of grains for human and animal consumption and the maintenance of 70% of the biomass above soil for its conservation in NT. Therefore, the energy exploration from agricultural residual biomass can significantly contribute to the energy matrix of countries with expressiveness in agriculture.

Table 3. Residential electricity consumption that could be supplied by oat and soybean residual biomass in Paraná during the season of 2012/2013.

Description	Unit	Value
[a]Residential consumption of electricity	GWh	6,986
[b]Soybean harvested area (†)	ha	4,752,800
[b]Oat harvested area (‡)	ha	61,900
[c]Average theoretical potential for electricity production from soybean residual biomass (i)	$kWh \cdot ha^{-1} \cdot year^{-1}$	612
[c]Average theoretical potential for electricity production from oat residual biomass (ii)	$kWh \cdot ha^{-1} \cdot year^{-1}$	479
[d]Theoretical potential for electricity production from soybean residual biomass († x i) (a)	$GWh \cdot year^{-1}$	2,911
[d]Theoretical potential for electricity production from oat residual biomass (‡ x ii) (b)	$GWh \cdot year^{-1}$	30
Total theoretical potential for electricity production (a + b)	$GWh \cdot year^{-1}$	2,941
Residential consumption supplied by residual biomass	%	42

[a]Residential consumption of electricity in PR in 2013 (EPE 2014); [b]Harvested area in PR during 2012/2013 (CONAB 2013); [c]Average values of soil tillage methods and fertilization rates; [d]Considering 30% of biomass removal and 20% of boiler efficiency.

CONCLUSION

After 23 years of management, the best soil fertility status obtained by tillage systems with none or less intense soil disturbance, added to normal fertilization rate, promoted changes in oat and soybean biomass composition. The differences, however, were not enough to modify neither their HHV nor their theoretical potential for electricity production. A synergic system with grain and energy production plus the permanence of soil coverage to no-tillage maintenance can be feasible in regions with high crop yields.

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AUTHOR'S CONTRIBUTION

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