

Chemical Attributes and Carbon Stratification Rates at Intercropping Corn and Palisade Grasses in No Tillage Systems

Valdinei Tadeu Paulino^{1*}, João Batista de Andrade¹, Erika Maria Celegato Teixeira¹, Keila Maria Roncato Duarte¹, Márcia Atauri Cardelli de Lucena¹

¹Institute of Animal Science, P.O. Box 60, CEP 13460-000, Centro, Nova Odessa, São Paulo State, Brazil, e-mail: paulino@iz.sp.gov.br

ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

In integrated crop-livestock systems (ICLS), grain crop and pasture development may affect the soil organic carbon stocks and chemical soil fertility and help to renew degraded pastures, increasing land use efficiency and endeavor income. Our objectives were to evaluate changes in the soil chemical properties, carbon stock in soil and carbon stratification rates of a typical Acrudox soil, with or without ICLS, liming and fertilization. The systems studied integrated with maize were: (i) *Urochloa brizantha* cv. Marandu (ICLS-Ub-Mar), (ii) *U. brizantha* cv. Piatã (ICLS-Ub-Pia), and (iii) *U. ruziziensis* ICLS-Ur) and (iv) *U. brizantha* cv. Marandu (untreated control- UC) single without maize intercropped. Experiment was performed at the Institute of Animal Science in the municipality of Nova Odessa, São Paulo State (Brazil) using a randomized blocks experimental design. ICLS increased the C stocks and CSR that are good quality indicators of the sustainability of an agricultural system. Higher values of CSR 1.7 were found in the integrated crop-livestock systems with maize and ICLS-Ur. On the other hand, without integrated-crop-livestock and no liming, no fertilization pasture of Marandu palisade grass showed the lowest and above critical CSR=0.7. It is interesting to highlight that the liming and fertilization in crops can influence the soil chemical properties and improve the soil fertility (reduce high acidity, aluminium saturation, increase exchangeable bases and C stocks), and it promotes the higher forage accumulation and maize grains or silage.

Keywords: Carbon stock, integrated crop-livestock, soil fertility, tropical grasses

1. INTRODUCTION (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

Integration can be on-farm as well as on an area-wide basis that may involve some specialization. Successful integration involves an intentional integration which reflects a synergistic relationship among the components (the whole is greater than the sum of the parts) of crops livestock and/or forestry and its synergistic relationship when appropriately managed

* Tel.: +xx xx 265xxxxx; fax: +xx aa 462xxxxx.
E-mail address: xyz@abc.com.

results in enhanced social (including community), economic and environmental sustainability and improves the livelihoods of those farmers who manage them [1]. Integrated crop–livestock systems (ICLS) are characterized by diversification, rotation, and cropping related to grain and animal production within the same land area [2]. The adoption of this system in large scale, covering many regions, with different climate and soil, is highly dependent of crops that produce high amounts of residues and straw for better soil coverage. Crop–livestock integration can be utilized to simultaneously increase corn, soybean, sorghum, cotton, sunflower productions interseeding especially perennial tropical grasses as *Urochloa* (syn. *Brachiaria*) and *Panicum* genera and became one important alternative to pasture recuperation and improvement for sustainability not just of annual crops but also one of the most important practices nowadays for animal production systems in Brazil, without expansion into new agricultural areas [3], [4] e [5]. The inclusion of forage grasses, vigorous and deep root system provides adequate amounts of chaff on the soil surface, changing the dynamics and nutrient cycling as well as the chemical and physical attributes of the soil and in turn to nutrition and productivity of ersatz cultures. The root system of forage also increases carbon stocks in the soil in areas of ICLS under no-tillage [6].

Perennial pastures can contribute to soil C sequestration [7]. Several studies have shown significant soil organic C accumulation with well-managed grazing of pastures [8, 9, 10]. The carbon stratification ratio (CSR) is the ratio between the soil organic carbon (SOC) stocks and two distinct soil layers, usually the topsoil with strong influence from soil management practices, such as tillage and cropping system, and the adjacent soil layer, which is less affected by farming operations [11]. The higher CSR values have been related to soil management practices that enhanced soil quality. However, studies of efficiency for different grasses to maintain productivity, promote an increase in soil organic C concentration and stocks, CSR and soil quality in ICLS are still scarce.

We hypothesized that an ICLS with maize cultivated under no-tillage in rotation with grazed pasture would result in accumulation of soil nutrients compared with continuously grazed or degraded pasture. The objective of this study was to evaluate the effects of liming and fertilization applied in ICLS production systems on soil chemical properties and quantifies the CSR an indicator of the quality for different forages under integrated crop-livestock system at São Paulo State, Southern Brazil.

2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

2.1 Site description

The experiment was performed at Nova Odessa, State of São Paulo, in Southeastern Brazil (22° 46' 28.8" S, 47° 17' 38.2" W, 560 m above Sea level) The climate is mesothermal humid (Köppen - Cwa) with a subtropical wet winter of rain mainly from October to April and a dry season from May to September.

Long-term mean annual precipitation is 1280 mm yr⁻¹ and annual temperature is 21.7°C. Soil was classified as a Typic Acrudox [12] composed of 55% sand, 16% silt, and 29% clay. Native vegetation of the area was woodland Atlantic Forest biome. Before the experiment the soil had the following composition: organic matter (SOM) = 20 g.dm⁻³; P = 4 mg. dm⁻³; pH em CaCl₂ = 4.0; K = 1.9; Ca = 3.0; Mg = 1.0; H + Al = 44 mmol.dm⁻³; Cation exchange capacity (CEC) = 49.9 mmol.dm⁻³ and base saturation (BS) = 11.8%.

2.2 Treatments and experimental design

The ICLS was established in pasture areas cultivated with *Urochloa brizantha* cv. Marandu, *U. brizantha* Piatã or *U. ruziziensis* and another area located immediately adjacent to the ICLS evaluation, which was cultivated for 25 years with pasture of Marandu (palisade grass) had low productivity and high degradation from the original condition was chosen as untreated control. In November (summer) initial management upon conversion of a portion of the land area to ICLS consisted of surface application of 2.17 ton ha⁻¹ of lime (containing 26.6% CaO and 19.1% MgO and relative power of total neutralization - RPTN = 90.5%), was aimed at raising the saturation of bases to 70% as recommended for corn by [13]. Forages were desiccated 10 days before immediately before maize sowing by applying glyphosate at 5L ha⁻¹. This was equivalent to using a boom sprayer with a spray volume of 250 L ha⁻¹. In January 2008, the first planting of maize (*Zea mays* L.) variety CATI AI34, was made with no-tillage in the mulch of grassy residues, using the chisel plow with cutting discs and winged tips. The adjustment of the machine was carried out to a population of 55,000 corn plants per hectare in a space of 0.90 m between rows. Maize was fertilized with 350 kg ha⁻¹ of 8-26-16 (NPK) applied in the groove at planting and 360 kg ha⁻¹ of 5-20-20 (NPK) as top dressing with mechanical incorporation to the soil with a trencher at 5 cm depth.

Three integration models were tested: (i) *U. brizantha* (Hochst. ex A.Rich.) Webster cv. Marandu (ICLS-Ub-Mar), (ii) *U. brizantha* cv. Piatã (ICLS-Ub-Pia), and (iii) *U. ruziziensis* Germain & Evrard (ICLS-Ur) and (iv) *U. brizantha* cv. Marandu

(untreated control - UC) a continuously grazed pasture which was cultivated by 25 years, used without ICLS. The 2.5 ha of original pasture area was divided into three portions of ~0.8 ha each to test these systems. This study done for two years with the same annual cycle repeated. In March (early fall), maize was harvested and produced 14.2 Mg ha⁻¹ of dry matter. At harvest, undersown grass pasture was already established and available for animal grazing during the dry season, until the next rainy season of maize planting. Animal grazing (from March to November) was with average stocking rate of 540 kg ha⁻¹ live weight.

The dry matter productivity of grasses evaluated in dry matter for the year 2009 in areas with ICLS were 9.0; 8.9 and 7.9 Mg ha⁻¹ yr⁻¹, respectively for *U. ruziziensis*; *U. brizantha* var. Marandu and *U. brizantha* var. Piatã. Dry matter in the reference areas were 5.5 Mg ha⁻¹ yr⁻¹ for UC –Pasture. Thus, the evaluation was from three manipulative situations (ICLS with different grasses) and the references situation, here called untreated control, which were unreplicated, but areas distributed in space. It was assumed soil and environmental conditions were uniform in the sampled areas, and therefore chose to sample pseudo-replications from the large experimental units [14]. Five pseudo-replications were sampled within each ~0.8 ha of treatment area.

2.3 Soil Analysis

Soil in the experiment was sampled seven years after treatment initiation, in September (Spring) at depths of 0-10, 10-20, 20-30 and 30-40 cm. Soil cores (five per pseudoreplication) were collected using a stainless steel cylinder (100 cm³) and diameter of 5 cm. Soil was air-dried and sieved through 2 mm). A portion of the sample was ground and sieved through 60 mesh sieves (0.250 mm) and sent to the Environmental Biogeochemistry Laboratory (CENA-USP) to determine the total C concentration.

Soil dry weight and water content was measured in the laboratory and soil bulk density was calculated [15]. Soil texture was determined with a hydrometer after dispersing with hexa-metaphosphate and digesting organic matter using H₂O₂. Soil pH was determined in KCl (1 mol L⁻¹) using a 1:2.5 soils: solution ratio. Cation exchange capacity at pH 7.0, percent base saturation, and aluminum saturation were calculated by determining exchangeable cations, potential soil acidity, and aluminum, respectively.

Soil sampling was conducted in next April (fall). The samples were collected in trenches up to 40 cm deep in each area, and sectioned into layers (0 - 5; 5 - 10; 10 - 20; 20 - 30; 30 - 40 cm). Collected soil samples were air-dried and submitted to sieve loosening (2 mm) before analysis. A portion of the sample was ground and sieved through 60 mesh sieves (0.250 mm) and sent to the Laboratory of Environmental Biogeochemistry (CENA-USP) to determine the organic carbon content, it was done using the dry combustion LECO CN 2000 elemental analyzer. The other samples were analyzed in the Soil Analysis Laboratory of the Department of Soils and Plant Nutrition (ESALQ-USP). The soil pH was determined in CaCl₂ 0.01 mol L⁻¹. Phosphorus (P) and exchangeable cations (CEC) were extracted using the method of cation and anion exchange resin, according to literature [16]. To evaluate the total acidity of the soil, H⁺ + Al³⁺ samples were extracted with a Ca (OAc)₂ 1N solution of buffered to pH 7.0, according to the methodology described [16]. Base saturation (BS %) and aluminum saturation (m) were obtained from calculations.

Total C concentrations were determined by dry combustion using a LECO CN-2000 elemental analyzer. Soil C stocks were calculated from C concentration and bulk density (Equation 1) [17].

$$S = \delta \cdot h \cdot T \quad (1)$$

Where: S (SOC) is the C stock in soil (Mg ha⁻¹); δ is the soil bulk density (g cm⁻³); h is the soil sampled depth (cm); and T is the total C concentration (g kg⁻¹). Since the samples were collected from fixed layers, calculation of inventory was adjusted to variations in soil bulk density following changes in management practices.

Methodology described by [18] was used to adjust C stocks to a soil mass equivalent (Equation 2 – from Sisti et al. [19]).

$$Sc = \sum n \cdot iS + \{[Mai - (\sum nMa - \sum nMr)] \cdot Ti\} \quad (2)$$

Where: Sc is the C stock corrected for soil mass (Mg ha⁻¹), $\sum n \cdot iS$ is the sum of stocks of layers without the deepest layer; Mai, is soil mass in the deepest layer; $\sum nMa$ is the sum of soil masses sampled; $\sum nMr$ is the sum of soil mass in the reference area, and Ti is the C concentration in the deepest layer sampled.

The carbon stratification rate (CSR) was calculated as proposed by [11]: CSR = Sc in topsoil layer (0- 0.10 m/SOC in adjacent soil layer (0.10-0.20 m), where Sc is soil organic carbon (Sc) stocks.

2.4 Statistical Analysis

Analysis of variance (Kruskal-Wallis) was used to detect significant differences among treatments. Means were statistically separated using the Student Newman-Keuls test ($p < 0.05$).

3. RESULTS AND DISCUSSION

3.1 Chemical soil composition

Higher values of pH in CaCl_2 of 5.5 were observed in ICLS-Ur and ICLS – Ubr Pia systems in layers from 0-5 cm and from 5-10 cm (Table 1), followed by ICLS – Ub Mar, with 4.6 and lower values of 3.9 for the original soil (untreated control). The pH increase was due to the calcium (lime) addition on the surface, with the application of 2.17 ton ha^{-1} of lime, in November. For deeper layers, 20-40 cm, calcium addition did not affect soil acidity. For layers from 20-30 cm pH higher values of 4.6 to 5.2 were observed in the ICLS–Ur system. Similar results were observed by [20], with increase in the pH values with calcium application in the soil surface.

Systems managed with ICLS presented superficial layers (0-20 cm) with lower values of Al^{3+} in comparison to original soil, without calcium or fertilization. However the action of lime, only at one surface layer (0-5 cm) decrease Al for values of $2.7 \text{ mmol}\cdot\text{dm}^{-3}$, values considered low and not phytotoxic to *Urochloa* grass, and associated to pH values ranged from 4.6 to 5.5. The Al^{3+} reduction can be attributed to calcium effects and organic compounds from the organic matter decomposition in ICLS systems [21].

The highest values of potential acidity ($\text{H}^+ + \text{Al}^{3+}$) were observed in untreated control ($47 \text{ mmol}\cdot\text{dm}^{-3}$) and to ICLS - Ub Mar ($42 \text{ mmol}\cdot\text{dm}^{-3}$) on surface layer (0 – 5 cm). Lower values of potential acidity were observed to ICLS – Ur in every layer (Table 2). Presence of organic matter in ICLS – Ur system can contribute for complexation of $\text{H}^+ + \text{Al}^{3+}$. In fact, the free Al shows low concentrations in deeper layers. Similar results were obtained by [21] working with Latosol in PD system (no-tillage).

The action of lime, only at one surface layer (0 - 20 cm) decreased Al values lower than $3.0 \text{ mmol}\cdot\text{dm}^{-3}$ (with Al saturation from 3.0 to 20.0%), values considered low and not phytotoxic to Marandu grass, and associated to $\text{pH}_{\text{CaCl}_2}$ ranged from 4.5 to 5.5. There is an increase in hydroxyl concentration, reacting with H^+ from the soil solution, resulting in Al precipitation as $\text{Al}(\text{OH})_3$, which is not toxic to plants [26]. The corrective use of calcium reduced the acidity and the Al^{3+} , saturation due to the pH increase and the increase on the Ca^{2+} and Mg^{2+} levels. The Al saturation index was high in the untreated control area (without fertilization management) showing average values of 72.4% which is detrimental to the growth of *Urochloa*. Aluminum toxicity limits plant development reducing root growth and nutrient uptake.

Table 1. Values of pH in CaCl_2 , Al^{3+} , $\text{H}^+ + \text{Al}^{3+}$ (potential acidity), calcium, magnesium and aluminium saturation (BS%) in different treatments of the soil under integrated crop-livestock systems with maize and *Urochloa brizantha* cv. Marandu (ICLS-Ub-Mar), with *U.ruziziensis* (ICLS-Ur), and with *U.brizantha* cv. Piatã (ICLS-Ub-Pia) and untreated control, original soil without liming and fertilization, in five soil layers at the Institute of Animal Science in the municipality of Nova Odessa (Sao Paulo State, Brazil).

Treatments	Layers (cm)				
	0-5	5-10 cm	10 – 20	20 – 30	30-40
pH (CaCl_2)					
ICLS - Ub Mar	4.6b	4.8a	4.7ab	4.4b	4.4a
ICLS - Ur	5.5a	5.2a	5.3a	5.2a	4.6a
ICLS - Ub Pia	5.5a	5a	4.5ab	4.4b	4.4a
Untreated control	4.1c	3.9b	3.9b	4.0b	3.9a
$\text{Al}^{3+} (\text{mmol}\cdot\text{dm}^{-3})$					
ICLS - Ub Mar	2b	2b	2.7b	5a	5.4a
ICLS - Ur	1b	1b	0.8b	1.8b	3.3a
ICLS - Ub Pia	1b	2b	2.8b	6a	6.4a
Untreated control	6.9a	7.2a	6.8a	5.8a	5.7a
$\text{H}^+ + \text{Al}^{3+} (\text{mmol}\cdot\text{dm}^{-3})$					
ICLS - Ub Mar	42a	42a	38a	42a	38ab
ICLS - Ur	28c	38b	25b	28b	33b
ICLS - Ub Pia	38b	42a	42a	45a	42a

Untreated control	47a	45a	44a	45a	44a
Aluminium saturation (%)					
ICLS - Ub Mar	6b	8b	12b	36b	33b
ICLS - Ur	3b	3b	2b	6c	17c
ICLS - Ub Pia	5b	8b	20b	38b	47b
Untreated control	68a	72a	73a	75a	74a

Means (n = 5) with different lowercase letters refer to the comparison among tillage treatments within depth, differ significantly at P<0.05.

Values of changeable Ca^{2+} and Mg^{2+} in cultivated soils with ICLS, at all layers were higher than control treatment. For ICLS systems, calcium correction in superficial layer benefits the acidity correction and increased the Ca^{2+} and Mg^{2+} concentration on 0 to 20 cm layer. Therefore, on 20-40 cm layer, the calcium correction influence was lower. [21] described calcium correction, superficial or incorporated to soil did not affected acidity on sub soil layers in tillage systems. On the other hand, [20] showed positive results on tillage systems for calcium disability and magnesium in deep. Among positive factors on ICL – tillage system, system, a better distribution of the calcium and magnesium on the soil profile must include: a) the manure and urine from animals in tillage system, favoring microbiological activity; b) linkage of calcium ion and magnesium to organic acids of low molecular weight, favoring its drowning to the soil profile; c) improvement on soil aggregation by grazing development through its root system, related to the requirements of Marandu grass [16].

The Base saturation (BS) % were higher on superficial layers (0-20 cm) and varied from 35 to 43 % for ICLS-Ub-Mar, from 42 to 58% for ICLS-Ur and from 21 to 33% for UCLS-Ub-Pia (Table 2). Such results reflect the calcium correction effects over Ca^{2+} and Mg^{2+} values on cultivated areas of ICLS, highlighting the ICLS+ Ur system. For the control treatment, BS % were lower (3.3 to 4.9%). *Urochloa decumbens*, *U. ruziziensis* and *U. humidicola* are considered forages well adapted to acid and low fertility soils, these forages require values of bases saturation of 30-35 % while *Urochloa brizantha* Marandu and Piatã are classified with an intermediate adaptation to acid fertility, requiring 60% of BS [13]. It is known that lime action is temporary and its base saturation values proposed to increase the base saturation methodology are not achieved due to the buffer power of the soil associated to the organic matter and soil texture. In this aspect, higher saturation base values proposed by [13] better adjusted to grazing situations, leading to time lasting liming corrective action, providing more Ca and Mg to the system. There is increasing evidence that low base saturation levels are less limiting in soils with many years of no tillage and consequently higher SOM and residue levels [22]. The lime application can improve the availability of phosphorus releasing Ca and Mg for the root systems according to pH increasing values. If the system is poor and soil is degraded (old pastures) the response to liming can not occur but if fertility is between low and medium, liming can improve forage production in order of 1.5 t ha⁻¹ of dry matter [20].

The greatest concentrations (P<0.05) of K⁺ were always found in the surface layers with medium values. K⁺ levels were low in systems ICLS and in untreated control. These levels are considered low, related to the nutritional requirements of Marandu grass [13]. This can be explained by the low content of K in the original soil, although *Urochloa* genera shows high capability of absorption and accumulation of K, even with high entrance of animals grazing during fall and winter. Recycling nutrients were insufficient to increase the K level in superficial layers, due to decomposition of organic matter in the area. A smaller amount of residues was lost by excrement, which resulted in an insufficient cycling of nutrients.

Potassium and phosphorus seems to be the key elements and limitant for the nutrition of pastures yield ICLS system for a dystrophic soil. According to [3], more than 90% of the soils are dystrophic in the Mid-West region of Brazil, which means that soil base saturation is less than 50%.

Table 2. Values of calcium, magnesium and base saturation (BS %) of the soil Typic Acrudox cultivated with integrated crop-livestock systems with maize and *Urochloa brizantha* cv. Marandu (ICLS-Ub-Mar). with *U. ruziziensis* (ICLS-Ur). and with *U. brizantha* cv. Piatã (ICLS-Ub-Pia) and untreated control, original soil without liming and fertilization, in five soil layers.

Treatments	Layers (cm)				
	0-5	5-10	10 – 20	20 – 30	30-40
Ca^{2+} (mmol·dm ⁻³)					
ICLS - Ub Mar	21a	16a	13.0a	5.0b	6.0a
ICLS - Ur	25a	22a	26.0a	19.0a	9.0a
ICLS - Ub Pia	9b	11b	6.0b	5.0b	3.0b
Untreated control	2b	1b	1c	1b	1b
Mg^{2+} (mmol·dm ⁻³)					
ICLS - Ub Mar	8a	7a	6.0a	3.0b	4.0a

ICLS - Ur	9a	8a	8.0a	7.0a	6.0a
ICLS - Ub Pia	5a	8a	4.0a	4.0b	3.0a
Untreated control	1b	0.9b	0.9b	0.9c	0.9b
$K^+ (mmol \cdot dm^{-3})$					
ICLS - Ub Mar	2.1a	1.1a	1.3a	1.3a	1.2a
ICLS - Ur	2.2a	1.4a	0.9a	0.8a	0.7a
ICLS - Ub Pia	4.8a	2.9a	0.9a	0.7a	0.7a
Untreated control	2.1a	1.4a	1.1a	0.9a	0.9a
BS (%)					
ICLS - Ub Mar	43a	32a	34.0a	18.0b	22.0b
ICLS - Ur	56a	42a	58.0a	49.0a	33.0a
ICLS - Ub Pia	33a	28a	21.0ab	18.0b	14.0b
Untreated control	4.9b	4b	3.3b	3.4c	3.7c

Means ($n = 5$) with different lowercase letters refer to the comparison among tillage treatments within depth, differ significantly at $P < 0.05$.

The CEC had variation with the soil depth (0 - 30 cm) varying from 47.48 to 79.9 $mmol \cdot dm^{-3}$ of soil but decreased in the deeper layers (30 to 40 cm) varying from 46.8 to 49.0 (Table 3). The statistical analyses showed the differences between the untreated control and CEC soil average 48.9 that were lower than the other treatments ICLS-Ub M; ICLS-Ur; ICLS-Ub Pia that averaged 61.4, 60.2, 58.7 and 66.4, respectively. Soil CEC under pastures ranges from 40.0 to 120.0 $mmol \cdot dm^{-3}$ in the majority of Oxisols and Ultisols [3].

In ICLS system, percent contributions of Mg into cultivated soil CTC are between 8.8 and 14.0 %, in a recommended range according to [23], from 6 to 12% for Mg. For Ca, % values were from 13.8 to 38.9 %, low than recommendation (from 65 to 85 %). For K, in the 5 to 10 cm layer, for *U. ruziziensis* and for Marandu grass, the % contribution on CTC was 1.2 to 1.4, low than recommended (from 2 to 5%), reflecting the nutritional limitation of this element. For Piatã grass, relation of K/CTC indicates nutritional equilibrium related to K.

In a general, P values were lower and lower for control treatments. For ICLS- Ub Pia system, P value was higher in deeper layers (table 3). The organic P addition (from vegetal dry material after herbicide application), added with corn as fertilizer, higher P values were found in 0-5 cm layer, reducing as going deeper. Such result is due to the less absorption of P by the forage as result of less oxidation of organic matter. [3] verified that phosphorus is the most limiting nutrient related to pasture establishment and pasture sustainability. These observations can be extrapolated to the Southwest, Mid-West and North, where more than 70% of the herds and cultivated pasture of Brazil are concentrated. [3] verified that tropical forage use more efficiently soil nutrients and the P recovering was from 62 to 85% in integrated crop-livestock system with annual cultures and grazing in comparison to 35 to 44% on systems with only annual cultures.

An important characteristic of soils under pasture in Brazil is that soil CEC ranges from 40 and 120 $mmol \cdot c \cdot dm^{-3}$ in the majority of Oxisols and Ultisols, and phosphorus is the most limiting nutrient related to pasture establishment and pasture sustainability. Thus, soils under pastures can be considered to be the low and intermediate fertility.

3.2 Organic matter and carbon stocks

There was a greater accumulation of surface organic matter (0-10cm). The contents of organic matter in this layer were similar between the different ICL systems. Without the management strategies and fertilization, the accumulation of organic matter was lower in the untreated control ($< 30.0 g \cdot dm^{-3}$), a level below those viewed as critical. For all the treatments, deeper soil layers showed lower concentrations of total organic matter ($SOM = C \times 1.72$). The ICLS system with the forage inclusion showed to be efficient to increase organic matter levels in soil (Table 3) leading to higher production of dry matter of aerial parts and roots and organic matter accumulation. This observation was similar to the organic matter soil reported by [6]. Higher levels of organic matter in soil are desirable to disable nutrients and in southeast region in Brazil is responsible for about 80 % of cation change soil capability (CEC).

Table 3. Values of cation exchange capacity (CEC), phosphorus and soil organic matter (SOM) in the different treatments of the soil under integrated crop-livestock systems with maize plus *Urochloa brizantha* cv. Marandu (ICLS-Ub-Mar), with *U. ruziziensis* (ICLS-Ur), and with *U. brizantha* cv. Piatã (ICLS-Ub-Pia) and untreated control, original soil without liming and fertilization, in five soil layers.

Layers (cm)

Treatments	0-5	5-10	10 – 20	20 – 30	30-40
CEC (mmol·dm ⁻³)					
ICLS - Ub Mar	73.1a	76.1a	58.0a	51.0a	49.0a
ICLS - Ur	64.2a	72.9a	60.0a	55.0a	49.0a
ICLS - Ub Pia	56.8a	79.9a	53.0a	55.0a	49.0a
Untreated control	53.7b	48.5b	47.4b	48.0b	46.8b
Available P (mg·dm ⁻³)					
ICLS - Ub Mar	6.2	5	7.6	7.3	6.7
ICLS - Ur	10	7	7.8	6.7	6.1
ICLS - Ub Pia	8	6.7	13.0	10.8	10.8
Untreated control	3.1	2.9	2.5	2.1	2.1
SOM (g·dm ⁻³)					
ICLS - Ub Mar	31a	33a	9,0a	8,0a	7,0a
ICLS - Ur	37a	29a	11,0a	7,0a	7,0a
ICLS - Ub Pia	30a	30a	9,0a	7,0	7,0a
Untreated control	21b	17b	11,0a	10a	7,0a

Means (n = 5) with different lowercase letters refer to the comparison among tillage treatments within depth, differ significantly at P<0.05.

The use of ICLS system under tillage can be an option to increase soil fertility and recovering degraded pasture areas. Data in the southeastern USA demonstrated that no-tillage management preserved the long-term accumulation of organic matter from a perennial pasture when the land was converted to an integrated crop–livestock grazing system [24]. [25] verified that in humid tropical zone no tillage increased the soil organic carbon (SOC) stocks and corresponded at higher SOC resilience that indicates a considerable potential to reverse the process of soil degradation. The results support the hypothesis that SOC restoration is determined by the intensification of the no-tillage cropping systems through the continuous input of biomass-C to maintain the C flow in the soil supplying the process of soil C transformations and driving the production systems. Some authors [25] related C concentration in the crop residues (i.e., g C kg⁻¹ of dry matter) was 455 for maize and 443 g kg⁻¹ for *B. ruziziensis*. More researcher are necessary to identify cropping systems that improve the SOC stock, advance soil fertility, develop the diversity and wealth of microflora and fauna communities [26], improve porosity and soil conductivity [27], raise aggregation and assemble up nutrient cycling [28] and the interaction between clay + silt content and SOC [29].

Success of ICLS under no-tillage practices are being developed in southern South America [3]. Thus, ICLS became one important alternative to pasture recuperation and improvement for sustainability not just of annual crops but also one of the most important practices nowadays for animal production systems in Brazil. Forages in ICLS produce straw and soil cover for minimum tillage systems, improve soil chemical, physical and biological properties, lead to better use of equipment, improve farmers income, and multiply jobs in rural areas [3].

Highest soil C stocks (Mg·ha⁻¹) were obtained under ICLS-Ub-Mar (56.2) and ICLS-Ur (52.6) followed by ICLS-Ub-Pia (48.5), and the lower to long-term pasture – untreated control (40.3), Figure 1. Some authors have reported that Cerrado soils managed by zero-tillage methods and by reposition fertilized pastures [44] have increased SOC contents compared with conventionally tilled soils. However, in conventional pastures with low levels of fertility and deterioration in soil physical properties, the low production of biomass reduces carbon contents. The SOC stocks found in this study (ranging between 40–56 Mg·ha⁻¹) were similar to those reported in other studies on Cerrado soils or Atlantic biome by [30], [31], [32] and [33].

Several studies have compared the SOC stocks and verified that conservation tillage systems, as zero-tillage, no-tillage or minimal tillage, with minimum soil disturbance, crop rotation and mulching with crop residues also maintained a high level of SOM [34] and therefore improves soil quality [35]. Soil C accumulation under conservation tillage systems was correlated with contents and types of clay and attributed to two main factors: i) physical protection of organic compounds against microbial decomposition, favored by the C occlusion in soil aggregates; and ii) chemical protection of organic compounds through their interaction with minerals and cations hindering their decomposition [36].

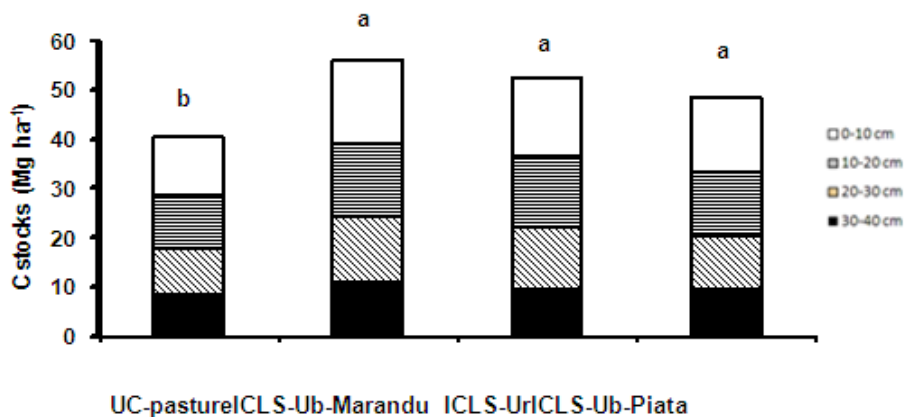


Fig.1. Soil organic C stocks in different depths under long-term pasture (UC-untreated control - pasture), integrated crop-livestock systems with maize and *Urochloa brizantha* cv. Marandu (ICLS-Ub-Marandu), with *U. ruziziensis* (ICLS-Ur), and with *U. brizantha* cv. Piata (ICLS-Ub-Piata) at the Institute of Animal Science in the municipality of Nova Odessa (São Paulo State, Brazil). Student Newman-Keuls test * $P < 0.05$).

The increase in SOC stocks for the 0–40 cm layer was approximately 15.9; 12.3 and 8.2 Mg ha^{-1} , or 39, 30 and 20% for ICLS Ub-Mar, ICLS-Ur and ICLS-Ub-Pia, respectively, in comparison to untreated control – pasture, without fertilization had lowest values.

3.3 Forage Dry Production and Crude Protein

Forage dry matter production (56 days after the harvest of off-season maize) obtained for Marandu, Piata and *U. ruziziensis* were similar 2.2, 2.1 and 1.7 Mg ha^{-1} , respectively, however for untreated control pasture was 0.9 Mg ha^{-1} for the forages growing in autumn (April to June). Values of forage dry matter, in this experiment were lower in comparison to those described [5], varying from 3.7 to 13.8 Mg ha^{-1} and similar to those found by [37] ranging from 1.5 to 2.4 Mg ha^{-1} . Such lower yield is consequence of the system adopted. The herbicide application for the corn plantation paralyzes and retards the grass growth. The light competition and photosynthesis favored by the corn. Only after harvest, the grass has access to the light and grows normally. Although productivity are low, can be considered normal for this season of the year. When, in mid-April-May-June (autumn), the rainfall (42 mm) and the low temperature (18°C) limited dry mass accumulation. The use of suppressive herbicides, in tillage systems has helping the maintenance and pastures recovering but the dosages must be well recommended to maintain the environment sustainability and the system productivity. It was verified the use of herbicide in tillage systems with corn and grass reduced the forage yield. Another fact in this system was the implementation of corn into a grass pasture already established, getting the best results on forage and nutrient advantages, added to soil tickler. Tropical forage can grow even in hydric deficit and low temperatures. *U. brizantha* and species from species of *Panicum* genera, with vigorous and deep root systems, present high tolerance to hydric deficiency and good absorption of nutrients in deep layers, disabling their development in conditions where the majority of grains can not grow. Despite that, the entrance of light during corn harvest and the first rains are essentials for a vigorous growth. Besides the forage development, physical and biological soil conditions minimize the effects of erosion and controls the emergence of weeds [38]. In Mato Grosso do Sul, had an increase of 720 kg ha^{-1} of soybean in sequence to forage, consorciated with corn, in comparison to corn only indicating the importance of technology of forage production in fall-winter season to improve the straw production and grains of 9.0, 8.0 and 8.9 kg/ha of dry matter for Piata, Ruziziensis and Marandu [38]. [39] showed that management of pasture with N-fertilizer application (50 to 100 $\text{kg N ha}^{-1} \text{yr}^{-1}$) provided increases in animal production but also in the following crops production in succession. In areas previously planted with fodder that received N-fertilizer increased yields of maize. It is noteworthy that the dry mass of crop residue on the soil surface and dry mass of roots to 60 cm depth were: 7.200 and 7.800 kg ha^{-1} , respectively, at unfertilized pasture, and 11.600 and 14.500 kg ha^{-1} , respectively, in the pasture that received fertilizer (160 kg of N and 32 kg of $\text{P}_2\text{O}_5 \text{ ha}^{-1} \text{year}^{-1}$), which provided better soil cover and resulted in greater nutrient cycling, favoring crops [39]. In this way, fertilized pastures gave a best soil cover and nutrient recycling, improving the following cultures.

Once recovered, pastures present better nutritive values in fall-winter season, relieving the effect of these seasons on the animal production and grazing. The crude protein concentration in grasses did not differ significantly among all cropping systems (Marandu = 75, Piata = 69 and Ruziziensis = 86 g kg^{-1}), but for untreated control was lower (CP = 51.9 g kg^{-1}). For ICLS systems, the crude protein values of grass stood at limit of 70 g kg^{-1} , which is considered by [40] to be the minimum amount necessary to maintain a microorganism population in the rumen of cattle.

3.4 Carbon Stratification Rates

The carbon stratification ratio (CSR) is the ratio between the soil organic carbon (SOC) stocks from two distinct soil layers, usually the topsoil with strong influence from soil management practices, such as tillage and cropping system, and the adjacent soil layer, which is less affected by farming operations [11].

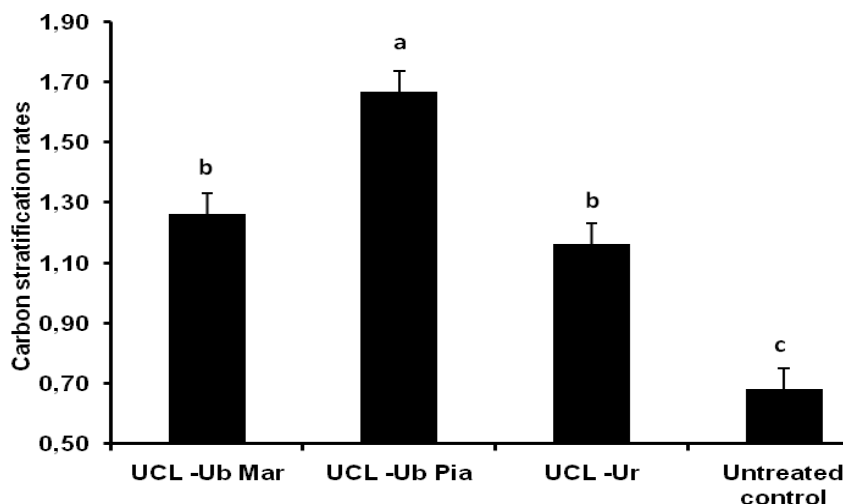


Fig 2. Carbon stratification rates (CSR) of the soil type acruox cultivated with integrated crop-livestock systems with maize and *Urochloa brizantha* cv. Marandu (ICLS-Ub-Mar), with *U. ruziziensis* (ICLS-Ur), with *U. brizantha* cv. Piatã (ICLS-Ub-Pia) and untreated control, original soil without liming and fertilization. Error bars indicate standard errors of the means. Lowercase letters indicate difference among no tillage treatments and untreated control.

Significant differences among ICLS were found in CSR (calculated by dividing the SOC on 0 -10 cm layer by those in 10 - 20 cm layer). Highest CSR corresponded to ICLS-Ub-Ur, and lowest to untreated control, and intermediate to ICLS-Ub-Mar and ICLS-Ub-Pia. The CSR values were 1.7, 1.3, 1.2 and 0.7 for ICLS-Ur, ICLS-Ub-Mar, ICLS-Ub-Pia and untreated control, respectively (Figure 2). The critical CSR value for tropical and subtropical soils is still unknown, but a CSR value of 1.5 has been previously proposed for subtropical soils [41], [42] and [43]. According to [44], the highest values of CSR have been found in forest system (1.98), and the lowest in pasture with beginning of degradation and conventional maize (1.10) - are considered reasonable quality, while the improved pasture – Marandu palisade grass (1.28) and the area of hay (1.23) of medium quality and while the forest system has been regarded high quality.

In addition, a previous study, which evaluated the quality of no-tillage (NT) management, suggested that systems with poor quality management would typically have CSR < 1.0, soils transitioning from conventional-tillage to NT would have CSR ranging from 1.0 to 1.2, good quality NT systems would have CSR ranging from 1.2 to 1.5, and a high quality NT soil would reach CSR > 1.5 [45]. Based on that classification, treatments with ICLS + *Urochloa* genera in the Oxisol could be considered high quality, in the long term. These results suggest that this classification could fit well as a limit for high quality soil management (>1.5). Untreated control (without management practices, no liming and no fertilization) pasture of Marandu palisade grass showed the lowest and above critical CSR=0.7.

According to [45], the stocks of SOC were significantly and linearly related with the indexes of soil quality. The higher values of CSR were found in the treatment with moderate intensity grazing (20 cm) compared with grazing intensity (10, 30 or 40 cm). CSR was an efficient indicator of soil quality for subtropical soils under integrated crop-livestock system. A critical CSR value of 1.5 is suggested to maintain soil quality in subtropical soils under integrated crop-livestock system.

Significant soil C sequestration occurred with ICLS that indicates the potencial of this system when compared with continuous pasture without fertilizer and lime inputs. ICLS favored shoot and root biomass accumulation from *Urochloa* and maize above and inside the soil. In general, carbon losses or gains are affected by management systems [32]. For instance, poor-managed pastures decreased carbon soil stocks, while well-managed pastures have the capability of increasing carbon soil stocks [33]. In addition, ICLS sampled in this work were well-managed agriculture system, which may help to accumulate carbon in soil surface. However, SOC stocks concentrations decreased with soil depth, o que resulta aumentos na CSR with soil depths. Based in [11] and [45] in this study was made the comparison between the

surface and lower depth ratios (i.e., 0-10; 10-20 cm) and SOC stocks were calculated based on equivalent soil mass [46], and not yet just only organic carbon concentration, resultando valores de CSR menores que os encontrados por [41] e similares aos encontrados por [45].

Another important factor is that the maize crop in ICLS treatments was harvested for silage, meaning, that total above-ground biomass was exported at harvest. Thus, we estimated that maximum above ground biomass of crop residues did not exceed 5% of the total quantity produced. Thus, for soil C formation, root biomass was the major contributor.

4. CONCLUSIONS

Intercropping maize and palisade Grass (Marandu, Piata) or *U.ruziziensis* are good options for those who produce seeds or silage, in the case of maize, as well as for cattle to graze in the same area subsequently, which increases returns per area. In Brazil is recognized the economic and biological synergies possible through integration of crops and livestock, which help increase efficiency and sustainability of their production systems.

ICLS increased the C stocks and CSR that are good quality indicators of the sustainability of an agricultural system. In our study, higher values of CSR 1.7 were found in the integrated crop-livestock systems with maize and *U. ruziziensis* (ICLS-Ur). The CSR values for ICLS-Ub-Mar, ICLS-Ub-Pia, ranging from 1.2 to 1.5, classifies these systems, as good quality. On the other hand, without integrated-crop-livestock and no liming, no fertilization pasture of Marandu palisade grass showed the lowest and above critical CSR=0.7. It is interesting to highlight that the liming and fertilization in crops can influence the soil chemical properties and improve the soil fertility (reduce high acidity, aluminium saturation and increase exchangeable bases and carbon stocks), and it promotes the higher forage accumulation and grains or silage of maize.

REFERENCES

1. FAO. An international consultation on integrated crop-livestock systems for development: The way forward for sustainable production intensification. Integrated Crop Management. 2010;13:64.
2. Ryan J, Sommer R, Ibrikci H. Fertilizer best management practices: a perspective from the Dryland west Asia-North Africa Region. J. Agron. Crop Sci. 2012;198:57–67.
3. Macedo MCM. Crop and livestock integration: the state of the art and the near future. Revista Brasileira de Zootecnia. 2009;38:133-146. English abstract. Accessed 22 March 2012. Available <http://www.scielo.br/pdf/rbz/v38nspe/v38nspea15.pdf>.
4. Takin FO. Advantages of maize-cowpea intercropping over sole cropping through competition indices. J. Agric. Biodivers. Res. 2012;1:53–59.
5. Crusciol CAC, Nascenteb AS, Mateus GP, Parizd CM, Martinsa PO, Borghi E. Intercropping soybean and palisade grass for enhanced land use efficiency and revenue in a no till system. European Journal of Agronomy. 2014;58:53-62.
6. Franzluebbers AJ, Stuedemann JA. Early response of soil organic fractions to tillage and integrated crop-livestock production. Soil Sci. Soc. Am. J. 2008;72:613-625.
7. Allard V, Soussana JF, Falcimagne R, Berbigier P, Bonnefome JM, Ceschia E. et al. The role of grazing management for the net biome productivity and greenhouse gasbudget (CO₂, N₂O and CH₄) of semi-natural grasslands. Agriculture, Ecosystems and Environment, 2007;121:47-58.
8. Carvalho JLN, Raucci GS, Cerri CEP, Bernoux M, Feigl BJ, Wruck FJ et al. Impact of pasture, agriculture and crop-livestock systems on soil C stocks in Brazil. Soil and Tillage Research, 2010;110:175–186.
9. Silva JE, Resck DVS, Corazza EJ, Vivaldi L. Carbon storage in clayey oxisol cultivated pastures in the Cerrado region, Brazil. Agriculture Ecosystems and Enviroment, 2004; 103:357-363.
10. Maia SMF, Ogle SM, Cerri CC, Cerri, CEP. Changes in soil organic carbon storage under different agricultural management systems in the Southwest Amazon Region of Brazil. Soil and Tillage Research, 2010;106:177-184.
11. Franzluebbers AJ. Soil organic matter stratification ratio as an indicador of soil quality. Soil and Tillage Research 2002;66:95-106.
12. Soil Survey Staff. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd edition. Natural Resources Conservation Service. U.S. Department of Agriculture Handbook 1999; 436.
13. Werner JC, Paulino VT, Cantarella H, Andrade NO, Quaggio JA. Forrageiras. In: Van Raij B, Cantarella H, Quaggio JA, Furlani AMC, Eds., Recomendações de adubação e calagem para o Estado de São Paulo, 2nd Edition, Instituto Agronomico, Campinas, 1996;263-273. Portuguese.
14. Hulbert SH. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 1984;54(2):187-211.

15. Blake GR, Hartge KH. Bulk density. In: Klute, A.(Ed.). Method soil analysis. 2.ed. Madison, ASA, Pt. 1986;1: 364-367 (Agronomy, 9).
16. Van Raij B, Andrade JC, Cantarella H, Quaggio JA. Análise química para avaliação da fertilidade de solos tropicais. Instituto Agronômico, Campinas, 2001.285p. Portuguese.
17. Paul EA, Clark FE. Soil Microbiology and Biochemistry. Academic Press, San Diego, 1989;272p.
18. Siqueira Neto M, Scope E, Corbeels M, Cardoso AN, Douzet JM, Feller C. et al. Soil Carbon Stocks under No-Tillage Mulch-Based Cropping Systems in the Brazilian Cerrado: An On-Farm Synchronic Assessment. Soil Tillage Research. 2010;110:187-195. Accessed 15 March 2012. Available: <http://www.sciencedirect.com/science/article/pii/S0167198710001352>
19. Sisti CJ, Santos H P, Kohhann R, Alves BJR, Urquiaga S, Boddey RM. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil and Tillage Research. 2004;76:39-58.
20. Oliveira PPA, Boaretto AE, Trivelin PCO. Liming and fertilization to restore degraded *Brachiaria decumbens* pastures grown on an entisol. Science and Agriculture, 2003;60(1)125-131.
21. Zambrosi FCB, Alleoni LRF, Caires EF. Liming and ionic speciation of an Oxisol under no-till system. Scientia Agricola, 2008;65:190-203.
22. Séguy L, Bouzinac S, Scopel E, Ribeiro F. New concepts for sustainable management of cultivated soils through direct seeding mulch based cropping systems: the CIRAD experience, partnership and networks. In: 2001-2005 Cirad's contribution to the World Congress on Conservation Agriculture.2006.Available at www.agroecologie.cirad.fr/congres/index.php?lang=en&rub=1.
23. Graham, ER. An explanation of theory and methods of soil testing. Mo. Agric. Exp. Stn. Bull.1959;737.
24. Sulc RM, Tracy BF. Integrated crop-livestock systems in U.S. Corn Belt. Agron. J., 99: 335-345, 2007.
25. Sá JCM, Séguy L, Tivet F, Lal R, Bouzinac S, Borszowski PR. et al. Carbon depletion by plowing and its restoration by no-till cropping systems in oxisols of subtropical and tropical agroecoregions in Brazil. Land Degrad. Develop. 2013;1-13.
26. Hungria M, Franchini JC, Brandao-Junior O, Kaschuk G, Souza RA. Soil microbial activity and crop sustainability in a long-term experiment with three soil-tillage and two crop-rotation systems. Applied Soil Ecology. 2009;42:288–296.
27. Cassaro FAM, Borkowski AK, Pires LF, Rosa JA, Saab SD. Characterization of a Brazilian clayey soil submitted to onventional and no-tillage management practices using pore size distribution analysis. Soil and Tillage Research. 2011;111:175–179.
28. Chapuis-Lardy L, Brossard M, Assad MLL, Laurent JY. Carbon and phosphorus stocks of clayey Ferralsols in Cerrado native and agroecosystems, Brazil. Agriculture, Ecosystems and Environment. 2002;92:147–158.
29. Zinn YL, Lal R, Resck DVS. Texture and organic carbon relations described by a profile pedotransfer function for Brazilian Cerrado soils. Geoderma 2005b;127:168–173.
30. Carvalho JLN, Raucci GS, Cerri CEP, Bernoux M, Feigl BJ, Wruck FJ. et al. Impact of pasture, agriculture and crop-livestock systems on soil C stocks in Brazil. Soil and Tillage Research. 2010;110:175–186.
31. Marchão RL, Becquer T, Brunet D, Balbino LC, Vilela L, Brossard M. Carbon and nitrogen stocks in a Brazilian clayey Oxisol: 13-year effects of integrated crop–livestock management systems. Soil and Tillage Research. 2009;103:442-450.
32. Carvalho JLN, Raucci G S, Cerri CEP, Bernoux M, Feigl BJ, Wruck FJ, Cerri CC.,. Impact of pasture, agriculture and crop-livestock systems on soil C stocks in Brazil. Soil and Tillage Research, 2010; 110, 175–186.
33. Maia SMF, Ogle SM, Cerri CC, Cerri CEP. Changes in soil organic carbon storage under different agricultural management systems in the Southwest Amazon Region of Brazil. Soil & Tillage Research, 2010;106, 177-184.
34. Blake GR, Hartge KH. Bulk density. In: KLUTE, A. (Ed.). Method soil analysis. 2.ed. Madison, ASA, Pt. 1,1986; 364-367 (Agronomy, 9).
35. Sommer R, Ryan J, Masri S, Singh M, Diekmann J. Effect of shallow tillage, moldboard plowing, straw management and compost addition on soil organic matter and nitrogen in a dryland barley/wheat-vetch rotation. Soil and Tillage Research, 2011; 115-116, 39-46.
36. Roesch LF, Camargo F, Selbach P, Sá ES, Passaglia L. Identificação de cultivares de milhos eficientes na absorção de nitrogênio e na associação com bactérias diazotróficas. Ciência Rural, 2005;35, 924-927.
37. Batista K, Duarte AP, Ceccon G, DeMaria IC, Cantarella H. Acúmulo de matéria seca e nutrientes em forrageiras consorciadas com milho safrinha em função da adubação nitrogenada. Pesq. agropec. bras., Brasília. 2011;46(10):1154-1160. English abstract.
38. Kichel AN, Almeida RG, Costa JAA. Integração lavoura-pecuária-floresta e a sustentabilidade na produção de soja. In: CONGRESSO BRASILEIRO DE SOJA, 6, 2012, Cuiabá, MT. Anais... Cuiabá, MT: Embrapa; Aprosoja, 2012. 3p. 1 CD-ROM.
39. Kichel AN, Miranda CHB. Integração lavoura-pecuária: sustentabilidade da agropecuária. Campo Grande: Embrapa Gado de Corte, 2006.
40. Van Soest, P.J., Nutritional Ecology of the Ruminant, 2nd ed. Cornell University New York; 1994.

41. Sá, JCM, Lal R. Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol. *Soil and Tillage Research*. 2009;103:46-56.
42. Ferreira AO, Sá JCM, Harms MG, Miara S, Briedis C, Quadros Netto C et al. Stratification ratio as soil carbon sequestration indicator in macroaggregates of Oxisol under no-tillage. *Ciência Rural*. 2012;42:645-652.
43. Canalli LBS, Sá JCM, Santos JB, Ferreira AO, Briedis C, Tivet F. Proposal of a protocol for the validation and certification of no-till system quality for reduction of CO₂ emissions. In: 12º Encontro Nacional de Plantio Direto na Palha - Tecnologia que mudou a visão do produtor, Foz do Iguaçu, Anais. Ponta Grossa, Federação Brasileira de Plantio Direto na Palha (FEBRAPDP). 2010;85-94. English abstract.
44. Paulino VT, Teixeira EMC, Lucena MAC. Qualidade do solo, estratificação do carbono em diferentes sistemas de manejo. In: XXIII Congresso Brasileiro de Zootecnia, Foz do Iguaçu, PR, Brasil, 1-3p. 2013. English abstract.
45. Silva FD, Ferreira AO, Assmann JM, Menefee D, Amado TJC, Anghinoni I. et al. Soil quality and carbon stratification as affected by different grazing intensities under integrated crop-livestock systems. In: II International symposium on Integrated Crop Livestock System, Porto Alegre, RS, Brazil. 2012.
46. Ellert, BH, Bettany, JR Calculation of organic matter and nutrients stored in soils under contrasting management regimes. *Canadian Journal of Soil Science*, 1995, 75, 529-538.

COMPETING INTERESTS-

"Authors have declared that no competing interests exist."

AUTHORS' CONTRIBUTIONS

VALDINEI TADEU PAULINO, Scientific Researcher, was the advisor for the Master students and designed the study, managed the analyses and performed the statistical analysis.

JOÃO BATISTA DE ANDRADE, Scientific Researcher: managed the analyses of the study and the field experiments; ERIKA MARIA CELEGATO TEIXEIRA AND MÁRCIA ATAURI CARDELLI DE LUCENA were Master Science students and conducted the experiments; and KEILA MARIA RONCATO DUARTE, Scientific Researcher: wrote the first draft of the manuscript and managed the literature searches

"All authors read and approved the final manuscript."

CONSENT (WHERE EVER APPLICABLE)

ETHICAL APPROVAL (WHERE EVER APPLICABLE)