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

ABSTRACT

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) U. 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. 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 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-widebasis that may involve some specialization. Success full 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 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 beutilized 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

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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 (22º 46' 28.8" S, 47º 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 21.7ºC. 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 $CaCl_2$ = 4.0; K = 1.9; Ca = 3.0; Mg = 1.0; H + Al = 44 $mmol{\cdot}dm^{-3}$; Cation exchange capacity (CEC) = 49.9 $mmol{\cdot}dm^{-3}$ 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 Piata 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]. Before sowing maize in the area, a chemical dissection of Urochloa in the area with glyphosate herbicide was to standard the dosage of 5 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 using 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) grazed pasture throughout the year, located immediately adjacent ~50 m from the area in ICLS systems.The 2.5 ha of original pasture area was divided into three portions of ~0.8 ha each to test these systems.This study was 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.

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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 soil (five per pseudoreplication) were collected using a stainless steel cylinder (100 cm^3) 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 inthe 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 H_2O_2. 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; 50 - 10; 10 - 20; 20 - 30; 30 - 40 cm).Collected soil samples were air-dried and submitted to sieve loosening (2 mm) before analyzed. 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 used the dry combustion using the Carbon Analyzer—LECO CN 2000®. 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 $CaCl_2$ 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^+ + Al^{3+} 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. SoilC stocks were calculated from C concentration sand bulk density (Equation 1) [17].

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

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 Tis 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]).

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

Where: Sc is the C stock corrected for soil mass (Mg ha^{-1}), Σn-iS is the sum of stocks of layers without the deepest layer; Mai, is soil mass in the deepest layer; ΣnMa is the sum of soil masses sampled; ΣnMr is the sum of soil mass in the reference area, and Ti is the C concentration in the deepest layer sampled.

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

The action of lime, only at one surface layer (0 - 20 cm) decrease Al values lower than 3.0 $mmol{\cdot}dm^{-3}$ (with Al saturation from 3.0 to 20.0%), values considered low and not phytotoxic to Marandu grass, and associated to pH_{CaCl2} 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 $Al(OH)_3$, 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+}, H^+ + Al^{3+} (potential acidity), calcium, magnesium and aluminium saturation (BS%) 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, at the Institute of Animal Science in the municipality of Nova Odessa (Sao Paulo State, Brazil).

Treatments	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
			Al^{3+}($mmol{\cdot}dm^{-3}$)		
ICLS - Ub Mar	2b	2b	2.7b	5a	5.4a

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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
			$H^+ + Al^{3+}$ (mmol·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. In other hand, [20] showed positive results on tillage systems for calcium disability and magnesium in deep. Among positive factors on ICL – tillage system, the drainage of calcium and magnesium on the soil are included: a) the manure and urine form 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 varies from 35 to 43 % for ICLS-Ub-Mar, from 42 to 58% for ICLS-Ur and from 21 to 33% forUCLS-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, theses 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 lime longer lasting times, 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]. Liming can disable nutrients to plants according to pH increasing values. If the system is poor and soil is degradeted (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. Theses 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. Reciclyng 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%.

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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.

Treatments	0-5	5-10 cm	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·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·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 CTC under pastures ranges from 40.0 to120.0 mmol.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 way, P values were low 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 import characteristic of soils under pasture in Brazil is that soil CEC ranges from 40 and 120 mmolc.dm^{-3}in the majority of Oxisols and Ultisols, and phosphorus is the most limiting nutrient related to

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pasture establishment and pasture sustainability.Thus, soils under pastures can be considered of 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·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 x 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 southest region in Brazil respnds for about 80 % of cation change soil capability (CEC).

Table 3.Values of cation exchange capacity (CEC), phosphorus and soil organic matter (SOM) 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.

Treatments	**0-5**	**5-10 cm**	**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	7,0
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].

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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 tolong-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] and [31].

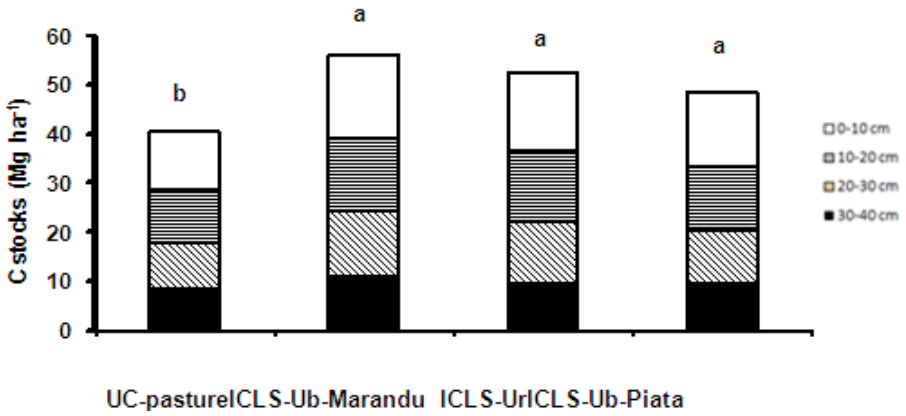

Fig.1. Soil organic C stocks in different depths under long-term pasture (UC-untreated control - pasture), integrated crop-livestock systems with maize and *Urochloa brizantha* cv. Marandu (ICLS-Ub-Marandu), with *U.ruziziensis* (ICLS-Ur), and with *U. brizantha* cv. Piata (ICLS-Ub-Piata) at the Institute 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 [32] 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 herbicies, 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

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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, phisical and biological soil conditions minimizes the effects of erosion and emergently control of weeds [33]. In Mato Grosso do Sul, had an increase of 720 kg ha^{-1} of soy bean in sequence to forage, consortiated 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 [33].

Researchers [33] verified the maintenance fertilization of pastures promoting the increase of animal production and the cultures in sequence (corn and soybean). Dry matter of straw in soil surface was from 7.2 and 11.6 Mg. ha^{-1}, for Marandu grass without fertilization and with fertilization (160 kg of N and 32 kg of P_2O_5 $ha^{-1}year^{-1}$), respectively. 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 leaves 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 were stood at limit of 70 g kg^{-1}, which is considered by [34] 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].

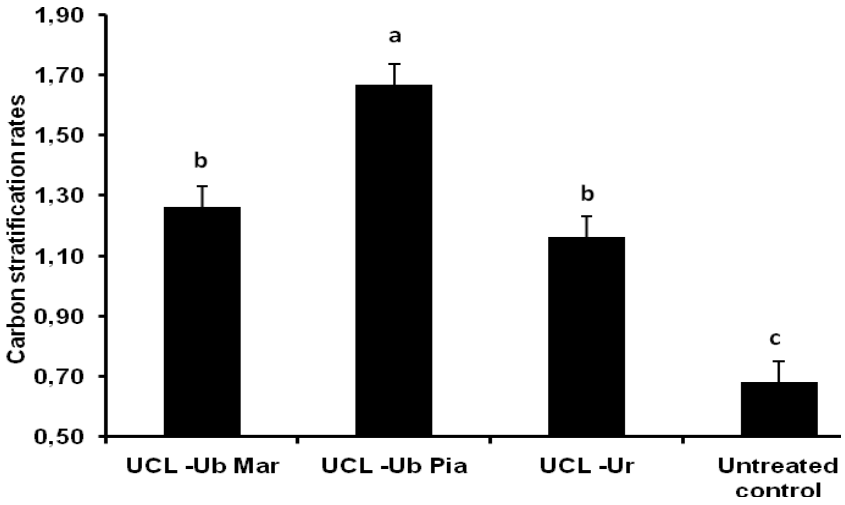

Fig 2. Carbon stratification rates (CSR) of the soil typic acrudox cultivated with integrated crop-livestock systems with maize and *Urochloa brizantha* cv. Marandu (ICLS-Ub-Mar), with *U. ruziziensis* (ICLS-Ur), with *U. brizantha* cv. Piatã (ICLS-Ub-Pia) and untreated control, original soil without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

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The CSR values were 1.3, 1.7, 1.2 and 0.7 for 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, 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 [35], [36] and [37]. According to [38], 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 media quality and while the forest system has been regardedhigh 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 [36]. 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 [39], 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.

4. CONCLUSIONS

Intercropping maize and palisade Grass (Marandu, Piata) or *U. ruziziensis* are good options to can be produced seeds or silage and cattle be able 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. 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 it promotes the higher forage accumulation and grains or silage of maize.

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