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Soil chemical indicators and nutrient cycling variations across sequential years of rice cultivation: A case study of floodplain conditions of the Amazon, Brazil

Luis Sanchez[1,2], Valdinar Melo[1], Taline Nunes[1], Diego Portalanza[3], Angelica Durigon[4] and Simón Farah[2]

[1]Soil Department, Federal University of Roraima, Roraima (RO), Brazil.
[2]Facultad de Ciencias Agrarias (FACIAG), Universidad Técnica de Babahoyo, Los Ríos, Ecuador.
[3]Climate Research Group, Department of Physics, Federal University of Santa Maria, Santa Maria (RS), Brazil.
[4]Agricultural Meteorology Group, Department of Crop Science, Federal University of Santa Maria, Santa Maria (RS), Brazil.

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To meet the rising food demand for next generations, soils are needed to stand biological yield and promote animal, plant and human welfare. In this logic, the aim of the study was to determine the effects of different soil uses; (a) successive irrigated rice planting and (b) different soil management practices onto soil chemical properties and nutrient cycling. The study was carried out in areas with dissimilar years of irrigated rice farming, managed with conventional tillage (CT) and minimum cultivation (MC). Having as a reference a native vegetation plot, areas with 2, 4, 9, 14 and 26 years of different management such as conventional tillage or minimum cultivation were evaluated. Soil samplings were performed in the 0 - 0.10, 0.10 - 0.20 and 0.20 - 0.30 m layers. Three sub samples per layer were collected within each replicate and then condensed to the combined sample; straw sampling was also performed. Total nitrogen (TN) and total organic carbon (TOC) were determined by dry digestion in a Vario El III elemental. Highest TOC results were obtained in Ar9 and Ar14 areas in 0-0.10 and 0.10-0.20 m layers; straw production varied from 7.61 to 8.94 Mg ha^{-1}. Ar2 presented higher value in relation to others; nevertheless these variations were not significant. Still, it was observed that the Ar9 and Ar14 areas presented a higher total biomass production (grains and straw) than those found in Ar4, Ar2 and Ar26; so, these variations did not differ. Conversion of native ecosystems to irrigated rice production areas significantly affects soil fertility.

Key words: Total organic carbon, soil management, irrigated rice.

INTRODUCTION

In order to meet the growing demand for food, upsurge production by 40% without adversely affect non-renewable natural resources available by 2030 its needed, thus requires soils that support biological

*Corresponding author. E-mail: luissjaime8@gmail.com.

productivity, maintain environmental values and provision animal, plant and human healthiness (Asmamaw, 2017). Nowadays soils are subjected to processes that guarantee or reduce crop yields and their sustainability. However, processes involved, such as fertilization and nutrient losses by crops, may induce since soil alterations, in time, to accumulation of nutrients or soil fatigue, with direct responses on crop productivity and soil biology (Moreira and Kasuya, 2016).

Consequently, depletion degree of soil organic matter content (SOM) fractions depends on the net balance between carbon inputs and outputs (Schadel and Luo, 2012). Studies have revealed that reduction of crop rotation and soil protection with harvest residues may boost carbon fractions interaction with mineral particle surfaces and develop stability and nutrient accumulation in the surface layer (Briedis et al., 2018).

In this framework, the conversion of native areas to intensive irrigated rice production fields may affect plant nutrients availability (Acton and Gregorich, 2012) due to conventional soil preparation, total or partial exclusion of crop residues and insufficient exchange of nutrients lost by erosion and gasiform emissions, leading to SOM degeneration (Dang et al., 2015), thus dropping, as the lone source of nitrogen reserve, much of the phosphorus, sulfur, cation exchange capacity (CEC), exchangeable bases, and accessibility of other nutrients, while increasing redox potential (Moreira and Kasuya, 2016; Du et al., 2019). Hence, the maintenance of rice straw at soil surface, besides supporting soil carbon increase, reduces fertilizer inputs by the use of nutrients freely available in the straw for the next harvest since the high C:N ratio and the presence of polymers such as cellulose and lignin in the straw can act as a natural barrier and retard its mineralization (de Figueiredo et al., 2015; Jeong et al., 2016). Irrigated rice crop systems with reduced cropping activities over time can increase soil fertility, increase organic matter content and total and organic phosphorus content. Based on the above, the aim of the study was to determine the effects sequential years of irrigated rice soil use and different soil management practices on chemical properties and nutrient cycling under the floodplain conditions of the Amazon.

MATERIALS AND METHODS

Area of study and experimental design

The study was carried out at the commercial plantation "O Paraiso Farm" located in Roraima state, Brazil, between 3° 19' 01.56'' N, 60° 23' 43.65'' W and 68 m altitude (Figure 1), Aw (tropical rainy) predominant climate according to Köppen's classification, an average annual air temperature of 27.2°C, a fluctuating precipitation of 1,500 to 2,000 mm and a soil type classified as Typic Fluvaquents (Batista et al., 2018). The study was conducted after the 2016 - 2017 harvest, in areas with different years of use with irrigated rice cultivation and soil management. Two-year (Ar2 - with two consecutive years of conventional tillage), 4 years (Ar4 - with two consecutive years of conventional tillage, followed by one year with minimum cultivation following with one year conventional tillage), 9 years (Ar9 - succession of three consecutive years of conventional tillage, for three years with minimum cultivation), 14 years (Ar14 - succession of three consecutive years of conventional tillage for three years with minimum cultivation), 26 years (Ar26 - succession of conventional tillage for two consecutive years, with one year with minimal cultivation) areas were evaluated. As reference, an area of native vegetation (Nat.V), located near the cultivated areas was used. Soil conventional tillage consisted of disc plowing at a depth of 0.20 m, followed by two tills, leveling with a flatten and a roller. The establishment level curves and construction plots were later done. In minimum cultivation soils, preparation operations after harvesting were reduced in relation to the conventional tillage system, plowing and leveling in areas with micro-relief imperfections was performed. The experimental design was a randomized complete block with four replications. Blocks had an area of 10,000 m^2 and the replicates 2,500 m^2. Planted cultivars, sowing dates, sowing densities and fertilization rates varied for each of the soil management systems used in the study areas (Table 1).

Concurrently with the seeding, initial fertilization 5-25-25 formula was carried out. On the other hand, urea as cover fertilization was divided into three stages of rice development, beginning of tillering (V4), maximum tillering (V8) and at the beginning of panicle development (R0).

Plant materials and soil samplings

Straw sampling was performed one day after harvesting using a 1 x 1 m wood square (Neto et al., 2015), launched at sunset at three different points per replicate. The samples were then conditioned in properly identified fiber bags and oven dried at 55°C. Rice straw chemical analysis was carried out according to EMBRAPA (2009) standard procedures. Grain production data were considered to determine harvest index according to the equation proposed by Yoshida (1981). For soil sampling, mini-trenches were opened in early straw sampled areas. Samplings were performed in the 0 - 0.10, 0.10 - 0.20 and 0.20 - 0.30 m layers. Three sub samples per layer were collected within each replicate and then condensed to the combined sample. Total Nitrogen (TN) and Total Organic Carbon (TOC) were determined by dry digestion in a Vario El III elemental analyzer (Nelson and Sommers, 1996). Available Phosphorus (P), exchangeable Potassium (K^+), Manganese (Mn^{2+}), Iron (Fe^{3+}) and Zinc (Zn^{2+}) were extracted by double acid solution (HCl 0.05 M + H_2SO_4 0.0125 M), P analyzed by UV-Visible spectrometry, Potassium (K^+) by photometry of Flame and Manganese (Mg^{2+}) and Zinc (Zn^{2+}) by Atomic Absorption Spectrometry. The exchangeable Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were extracted by Complexometric with ethyenediaminetetraacetic acid (EDTA). The exchangeable Aluminum (Al^{3+}) (KCl 1 mol L^{-1}) and Potential Acidity (H+Al) (Calcium Acetate) were determined according to methodologies proposed by Tedesco et al. (1995). Organic Phosphorus (OP), Inorganic Phosphorus (IP) and Total Phosphorus (TP) were determined according to the procedures proposed by Bowman (1989) modified by Guerra (1993).

Statistical analysis

Statistical analyzes and graphs were performed in R version 3.3.2 (R Development Core Team, 2017) (of parametric statistics) and SigmaPlot software version 11.0 (SigmaPlot, 2008). For each indicator the Shapiro-Wilk test was performed to evaluate the normality of the errors. To determine soil management effects on chemical indicators and nutrient cycling, the results were submitted

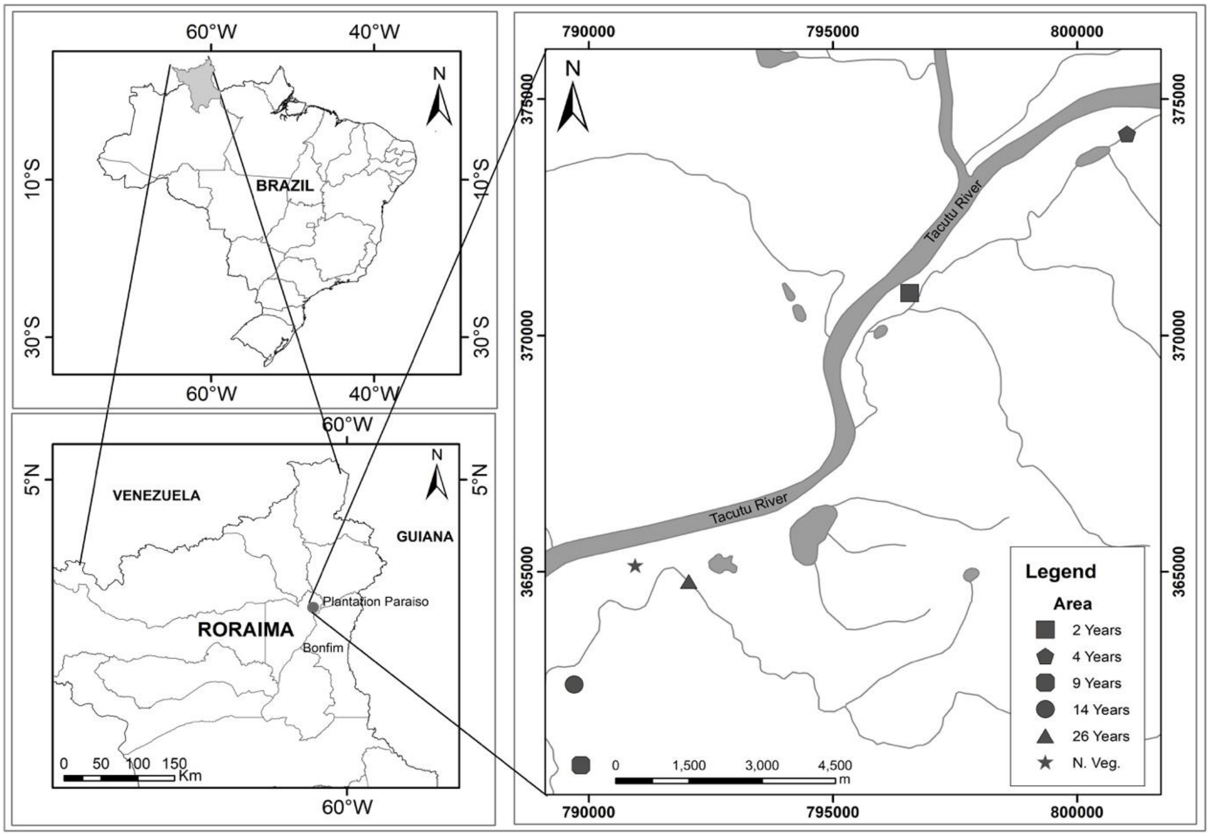

Figure 1. Location of the experimental area.

Table 1. Evaluated areas cultivars, sowing dates and densities and fertilization rates.

Area	Cultivar	Sowing date	Sowing density (kg ha^{-1})	Initial fertilization (5-25- 25) (kg ha^{-1})	Cover fertilization (urea) (kg ha^{-1})
Ar2	IRGA 429	15/12/2016	80	450	330
Ar4	IRGA 429	29/11/2016	80	450	330
Ar9	IRGA 424	16/11/2016	135	450	330
Ar14	IRGA 424	17/10/2016	142	475	340
Ar26	IRGA 424	27/09/2016	132	468	340

to variance analysis using a 5% probability Tukey test. Pearson correlation and principal component analyzes were also performed.

RESULTS AND DISCUSSION

Organic carbon

The highest TOC results (Table 2) were obtained in Ar9 and Ar14 areas in 0-0.10 and 0.10-0.20 m layers, these values differed statistically from each other, yet, significant differences were observed when compared with the values found in other areas cultivated with irrigated rice and native vegetation. In the 0.20-0.30 m layer, the highest TOC concentration was observed in Ar14 and deferred significantly from the concentrations found in other areas. TOC concentrations observed in the 9 and 14 year-old areas, alongside the evaluated profile, are due to reduced soil disturbance and superficial layer harvest residues maintenance, consequently favoring the interaction of TOC fractions with surface of colloidal particles of the soil, resulting in the formation of highly stable complexes between organic functional groups and functional groups present on the surface of minerals, which prevents or limits the access of microorganisms and enzymes to organic compounds located inside the aggregates (Yoo et al., 2011), and increases carbon

Table 2. Chemical indicators of six evaluated areas.

Area	pH (H_2O)	TOC (gkg^{-1})	TN (gkg^{-1})	K^+ ($cmol_ckg^{-1}$)	Ca^{2+} ($cmol_ckg^{-1}$)	Mg^{2+} ($cmol_ckg^{-1}$)	Al^{3+} ($cmol_ckg^{-1}$)	H+Al ($cmol_ckg^{-1}$)
0.0-0.10 m								
Ar2	4.30	7.35^{d}	0.60^{b}	0.08^{d}	0.66^{b}	0.10^{b}	1.36^{bc}	5.90^{bc}
Ar4	4.14	11.20^{c}	0.90^{ab}	0.10^{cd}	0.40^{bc}	0.15^{b}	1.83^{b}	9.60^{a}
Ar9	4.08	14.10^{a}	1.10^{a}	0.19^{a}	1.01^{a}	0.22^{a}	1.26^{bc}	9.93^{a}
Ar14	4.15	12.48^{b}	1.00^{a}	0.14^{b}	0.99^{a}	0.25^{a}	2.84^{a}	9.08^{ab}
Ar26	4.19	10.60^{c}	0.90^{ab}	0.11^{cd}	0.65^{b}	0.10^{b}	1.16^{bc}	5.82^{c}
N.Veg	4.32	10.28^{c}	0.78^{ab}	0.12^{bc}	0.43^{c}	0.17^{b}	0.69^{c}	3.58^{c}
CV(%)	ns	4,77	16.69	9.67	12.12	18.21	19.83	21.29
0.10-0.20 m								
Ar2	4.19	5.30^{d}	0.45^{bc}	0.07^{c}	0.55^{bc}	0.07^{c}	1.80^{bc}	5.67^{b}
Ar4	4.10	7.03^{c}	0.58^{bc}	0.10^{b}	0.40^{bc}	0.14^{b}	1.96^{b}	9.32^{a}
Ar9	4.15	12.30^{a}	0.95^{a}	0.16^{a}	0.94^{a}	0.20^{a}	1.76^{bc}	9.94^{a}
Ar14	4.00	9.30^{b}	0.70^{ab}	0.17^{a}	0.91^{a}	0.17^{ab}	3.94^{a}	9.14^{a}
Ar26	4.29	6.50^{c}	0.55^{bc}	0.09^{bc}	0.63^{b}	0.15^{ab}	1.25^{c}	4.07^{bc}
N.Veg	4.35	5.18^{d}	0.35^{c}	0.11^{ab}	0.40^{c}	0.16^{b}	0.34^{d}	2.15^{c}
CV(%)	ns	5.70	22.64	8.73	16.37	17.04	16.92	22.71
0.20-0.30 m								
Ar2	4.17	4.68^{c}	0.40^{bc}	0.07^{c}	0.46^{b}	0.06^{d}	2.16^{b}	6.83^{b}
Ar4	4.00	5.38^{bc}	0.43^{bc}	0.09^{bc}	0.30^{c}	0.11^{cd}	2.36^{b}	9.35^{ab}
Ar9	4.00	5.63^{b}	0.48^{ab}	0.12^{a}	0.67^{a}	0.18^{ab}	2.63^{b}	10.50^{a}
Ar14	4.00	8.58^{a}	0.70^{a}	0.11^{ab}	0.72^{a}	0.13^{bc}	3.93^{a}	9.12^{ab}
Ar26	4.15	2.88^{d}	0.18^{c}	0.08^{c}	0.43^{bc}	0.21^{a}	0.90^{c}	2.09^{c}
N.Veg	4.19	3.05^{d}	0.23^{bc}	0.11^{ab}	0.39^{bc}	0.13^{bc}	0.30^{c}	1.28^{c}
CV(%)	ns	8.22	28,26	12,21	12.04	19.89	19.51	21.43

Means followed by the same lowercase letter in the column did not differ significantly by the Tukey's test ($p < 0.05$). Where: TOC = Total Organic Carbon, TN = Total Nitrogen, K^+ = exchangeable Potassium, Ca^{2+} = exchangeable Calcium, Mg^{2+} = exchangeable Magnesium, Al^{3+} = exchangeable Aluminum, H+Al = potential acidity, ns= Not significant.

fractions that are available and stabilized over time (Wang et al., 2014).

Adverse situation was observed in recent rice cultivated areas, as a result of the greater release of C to the atmosphere, through vegetation burning and less organic matter accumulation due to the continuous soil turning (Briedis et al., 2018). It was substantiated that the TOC values decreased in all the areas in relation to the depth, so the areas with conventional soil preparation presented a more uniform distribution in the studied profile, that is, in response to crop residues incorporation (Machado et al., 2011), aiding the reduction of more labile carbon fractions in the lowest layers (0.05 - 0.10 m), determining a potential condition of higher methane (CH_4) emissions onto the atmosphere in areas with conventional planting in relation to less disturbed soils (Nascimento et al., 2009; Qiu et al., 2018). This fact is explained by the incorporation of a soil corrector (limestone) previous to the implementation of a minimum crop system, in this process crop residues are incorporated in deeper layers.

Native vegetation did not present higher TOC contents in the superficial layer in relation to the older cultivated rice areas, though, TOC stratification was verified in the layer 0-0.10 m, as a result to surface organic matter accumulation (Leal et al., 2015). In this context, soil surface crop residues maintenance over time has benefits in fertility in terms of storage of TOC and TN (Mazzoncini et al., 2016), since these elements are the main soil organic matter components (Jia et al., 2017), so it was observed that Ar9 and Ar14 presented the highest levels of TN. Consequently, the release of mineral N depends on the recalcitrance and resistance of soil organic matter (SOM) to microbial attack, being this process dependent on soil type and management, microbial activity and environmental conditions (Mazzoncini et al., 2016).

Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Aluminum (Al^{3+})

K^+, Ca^{2+} and Mg^{2+} values found were considered low (CFSEMG, 1999), as a result of the high degree of withstanding of these soils. Therefore, Al^{3+} and H^+

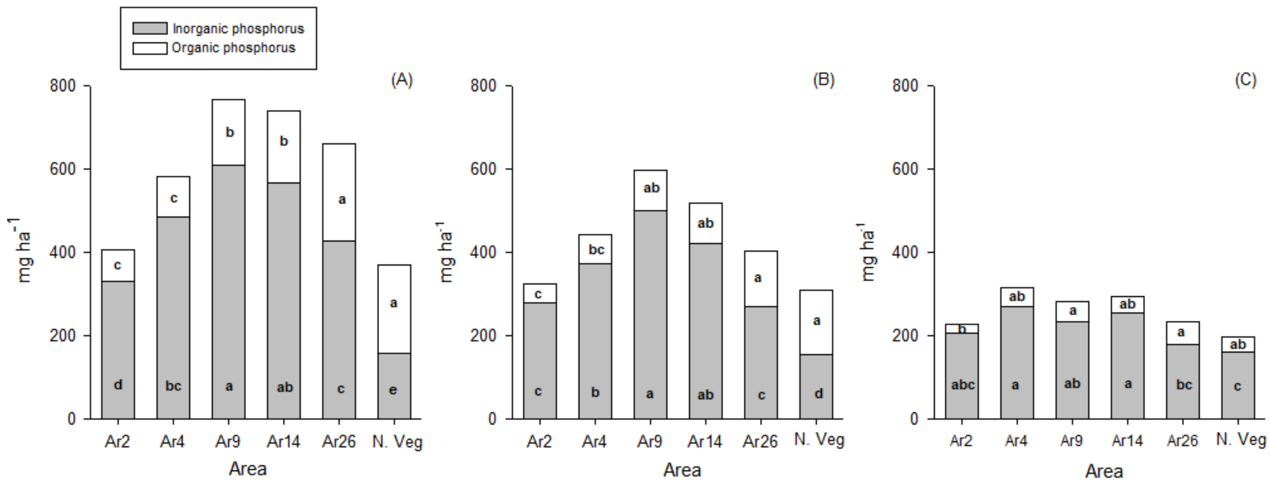

Figure 2. Phosphorus fractionation in the 0-0.10 m (A); 0.10-0.20 m (B) and 0.20-0.30 m (C) layers, in areas with different years of cultivated rice and handling. Bars followed by the same lowercase letter did not differ significantly by the Tukey's test ($p < 0.05$).

become dominant in the exchange complex. Yet, this situation is upturned hours after the soil is flooded and changes occur on the oxy-reducing system, related to these changes, there is a pH increase in values close to neutrality in acid soils due to their reduction. As a result, nutrients such as K^+, Ca^{2+} and Mg^{2+} increase their availability (Kögel-Knabner et al., 2010; Lee et al., 2011).

Organic and inorganic phosphorus

In relation to inorganic phosphorus (IP) (Figure 2), the highest levels were found in Ar9 and Ar14, being statistically equal, consequently Ar9 value differed significantly from the results observed in Ar4, Ar26, Ar2 and native vegetation. Observed amplitude in IP contents may be due to the clay content and the mineralogical constitution of the soil, since they are relevant in the adsorption of P in Fe, Al, Ca, silica clays, oxides (Chen et al., 2013; Gonzalez-Rodriguez and Fernandez-Marcos, 2018), and even with SOM, through cation bridges, among others.. Contrariwise, Ar26 presented lower values of IP in the 0-0.20 m layer, in relation to those found in Ar9 and Ar14 areas. This fact was probably due to mineral predominance of components with lower specific adsorption surface, therefore favoring the increase of IP lability as phosphate fertilizer was added due to saturation of adsorption sites (Tokura et al., 2011).

As for organic phosphorus (OP), contents increased in relation to the years of use with irrigated rice. Accordingly, the availability of P to plants depends on the transformation of OP into IP, this process involves a group of enzymes (phosphatases) produced by plants and microorganisms. Thus, this OP to IP transformation process to the plant has a reduced importance in cultivated soils, since in these soils large doses of soluble P are added. In this context, Evald (2016) found higher activity of acid phosphatase enzymes in older areas cultivated with rice, in relation to areas of up to 8 years of use, possibly being influenced by the maintenance of crop residues on the soil surface and ongoing fertilization with phosphate sources. Ar2 and Ar4 presented lower levels of OP, this fact can be related to conventional management of soil and SOM content, since in revolved soils, OP mineralization increases, and as a result, the transformation of IP is mineralized in non-labile forms, resulting in exhaustion of P in a short period of time, if phosphate fertilizers are not incorporated (Audette et al., 2016). TP contents showed significant differences between evaluated areas, probably induced by physical and chemical characteristics of soils. Therefore, rice cultivated areas presented the highest P percentages in the inorganic fraction, this may be due to the continuous phosphate fertilization, and in relation to the native vegetation, a higher value of OP was observed in relation to IP, as a result of plant residue decomposition and microbial tissue (McLaren et al., 2015).

Still, the continuous addition of phosphate fertilizers in sufficient quantities over time, increase the availability of P in the soil due to organic and inorganic fractions of P have the capacity to supply this element to the plants. Hence, the results obtained in the evaluated areas showed a linearity relation between the phosphorus availability and the years of soil use with irrigated rice (Figure 3).

Micronutrients

In relation to Zinc (Zn^{2+}) (Figure 4A), in the 0-0.10 and

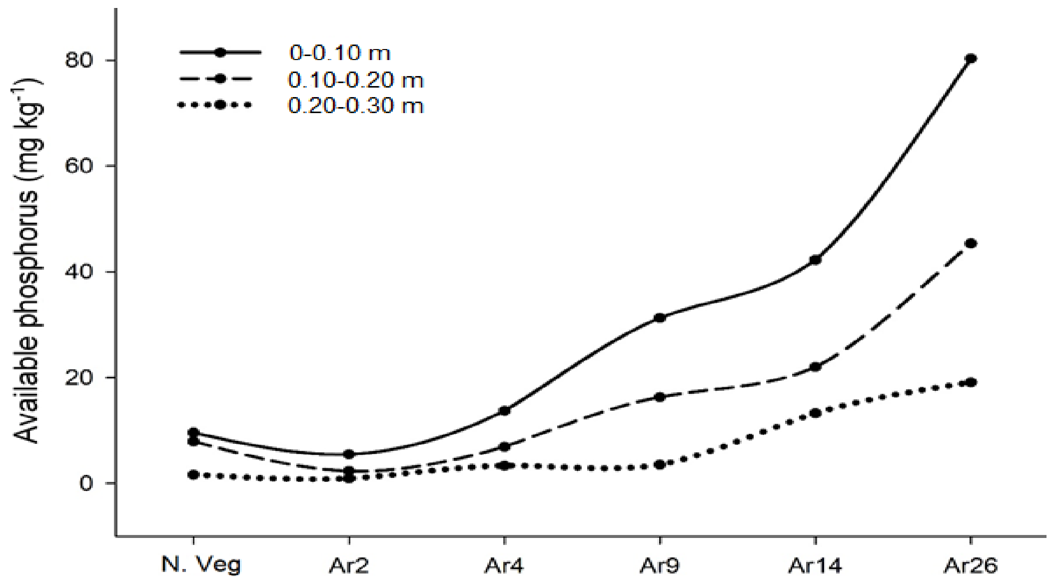

Figure 3. Phosphorus availability in 0-0.10, 0.10-0.20 and 0.20-0.30 m layers, in areas with different years with cultivated rice and soil management.

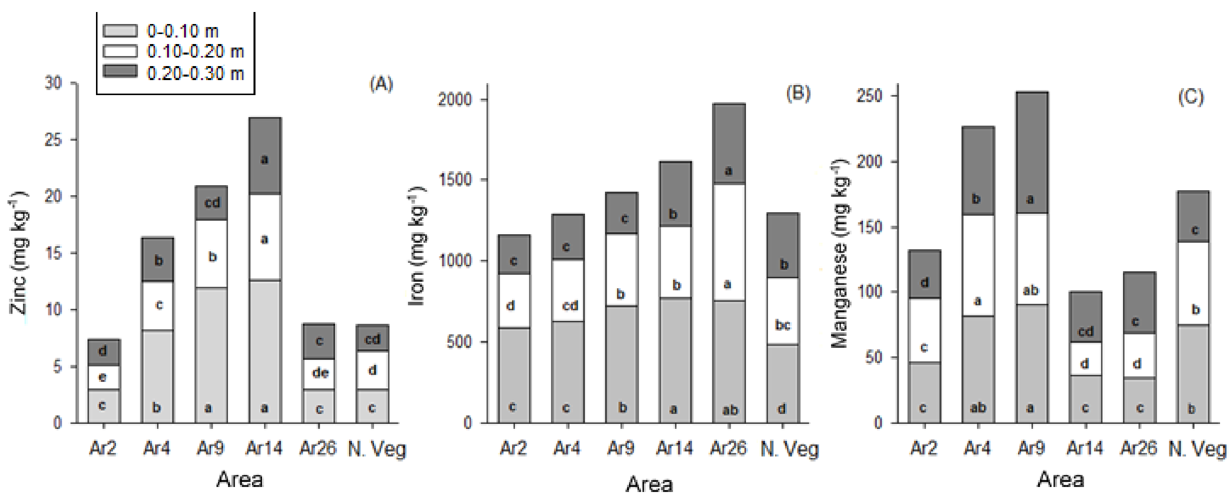

Figure 4. Zinc (A), Iron (B) and Manganese (C) values in 0-0.10 m, 0.10-0.20 m and 0.20-0.30 m layers. Bars followed by the same lowercase letter in the layer do not differ significantly by the Tukey's test (p <0.05).

0.10-0.20 m layers, the highest values were observed in the Ar14 and Ar9 areas, being different from the others. The 0.20-0.30 m Ar14 layer presented the highest value along the profile studied. However, the high values of Zn^{2+} found are due to pH < 5.0 (Havlin et al., 2005). Inversely, flooded soils periodically exhibit changes in the redox potential (Eh) and consequently changes in soil pH may decree the labile Zn fractions at less labile fractions (Kashem and Singh, 2001) and affect normal plant development (Dobermann and Fairhurst, 2000; Impa et al., 2012). In this scenario, the amplitude of the Zn^{2+} contents, in addition to the changes in Eh, may be related to SOM content, microbial activity in the rhizosphere, concentrations of macro nutrients (especially P), soil moisture, and other factors that control Zn^{2+} availability for plants (Alloway, 2009).

For iron (Fe^{3+}) (Figure 4B), highest contents were observed in Ar14 and Ar26 areas in 0-0.10 m layer, though, in 0.10-0.20 and 0.20-0.30 m layers, the oldest cultivated area had the highest value with 724.66 and 492.08 mg kg^{-1} respectively and presented a significant difference when compared with others. In this sense, the values obtained in studied areas were higher than the rice critical limit (300 mg kg^{-1} Fe^{3+}), and under flooded

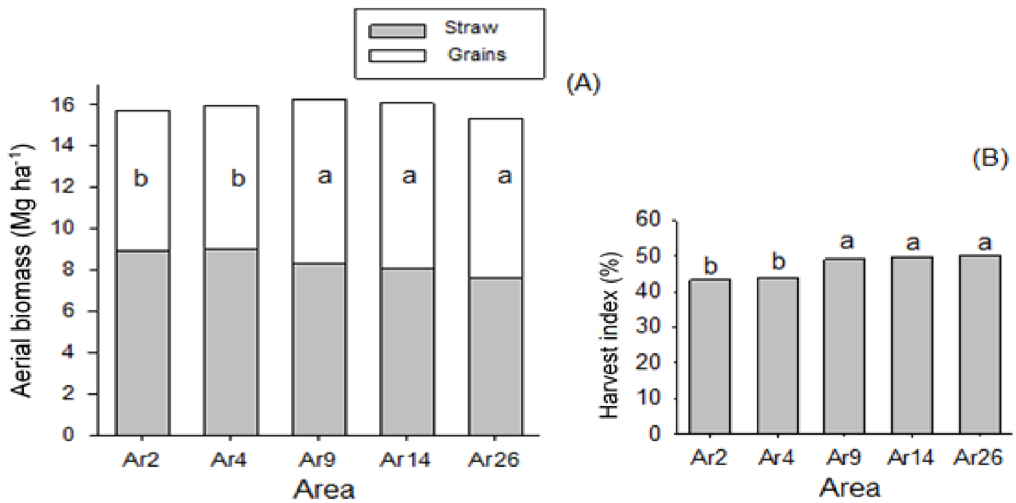

Figure 5. Aerial biomass production (A) and harvest index (B) in areas with different years of land use and management. Bars followed by the same lowercase letter did not differ significantly by the Tukey's test ($p<0.05$).

conditions the availability of this element increases and subsequently affects the approachability of other nutrients (Mn^{2+}, Zn^{2+} and K^{+}) by antagonistic interactions or by Fe^{2+} accumulation in the root system, as well as by the excessive absorption by the plant, affecting normal development (Becker and Asch, 2005). Thus, rice plants Fe^{3+} toxicity expression severity has been related different factors such as: Material source, Fe^{3+} contents, soil pH, SOM and others. Amongst these factors, the material source plays a fundamental role in minerals surface Fe^{3+} retention, which explains why, in soils with predominantly kaolinite, toxicity symptoms occur more commonly than soils with a clay smectite predominance (Favre et al., 2002; Becker and Asch, 2005).

However, rice plants developed mechanisms (rhizosphere oxidation via aerenchyma, selectivity and root and stem membrane retention) to survive in soils with high Fe^{2+} concentrations (Nava and Bohnen, 2002; Becker and Asch, 2005). In relation to the Manganese (Mn^{2+}) (Figure 4C) Ar9 showed the highest value along the evaluated profile, then, Mn availability depends on OM contents, while sometimes soils with high OM content present less availability of this element, as observed in Ar14. However, soils under flooded conditions some Mn minerals dissolve and become available to plants (Jones and Jacobsen, 2009).

Aerial biomass production and nutrient cycling

Straw production varied from 7.61 to 8.94 Mg ha^{-1} (Figure 5). Ar2 presented higher value in relation to others; formerly these variations were not significant. Though, it was observed that the Ar9 and Ar14 areas presented a higher total biomass production (grains and straw) than those found in Ar4, Ar2 and Ar26, so, these variations did not differ ($p> 0.05$).

The grain-straw ratio varied from 43.20 to 50.29%, with Ar26 being the one with the highest harvest index (HI), that is, 50% of the total aerial biomass corresponded to grain yield and 50% of straw (Khush, 2005). However, this value did not differ from the HI obtained in Ar14 and Ar9. New rice cultivated areas presented a lower HI, probably due to the different sowing dates, since rice productivity is influenced by factors such as meteorological variables and soil management (Ntanos and Koutroubas, 2002; Katsura et al., 2008; Huang et al., 2013). Therefore, to evaluate varieties responses to climatic factors can lead to an improvement of applied nutrients utilization by plants in early stages, thus improving the potential of high yield cultivars (Ohsumi et al., 2014; Rabaioli et al, 2008). In this context, Ar14 presented higher N translocation in the anthesis phase for grain formation in relation to Ar2 (Table 3). In this scenario, the upkeep of crop residues, in addition to soil quality improving, is a source of nutrients for the next harvest, since many of the minerals absorbed by plants remain in the straw after harvest, recovering around 35% of N, 30% of P, 85% of K and 45% of sulfur (S). Much of these elements can be recycled by plants after decomposition (Byous et al., 2004).

In relation to P, the highest levels of this element in rice straw were observed in Ar9 and Ar26 (Table 4). However, accumulations of P in crop residues depend on the opportune availability of P and the initial development of the plants (Dobermann and Fairhurst, 2000). For K^{+}, was observed that Ar4 and Ar14 presented the highest accumulations in the straw, however, the highest return rate in relation to the amount of fertilizer applied varied from 76% found in Ar26 to 137% presented in Ar4. This fact may be related to K increased availability or increased solution diffusivity (mobility) under flooded

Table 3. Rice straw nutrient content in areas with different years of use and management.

Area	N	P	K	Ca	Mg	Fe	Mn	Zn	C/N
Ar2	7.82[a]	0.72[d]	11.60[b]	0.15[b]	0.03	110.00	52.50	20.93	60.78[c]
Ar4	5.85[bc]	0.97[b]	17.18[a]	0.09[c]	0.03	97.50	47.50	20.49	81.77[b]
Ar9	6.57[b]	1.19[a]	11.58[b]	0.15[b]	0.03	120.00	60.00	20.97	72.41[b]
Ar14	5.25[c]	0.85[c]	15.78[a]	0.13[b]	0.04	137.50	55.00	20.78	96.02[a]
Ar26	6.18[b]	1.14[a]	11.83[b]	0.18[a]	0.03	102.50	55.00	21.11	81.77[b]
CV (%)	5.22	5.47	8.81	6.70	Ns	ns	ns	ns	5.80

Means followed by the same lowercase letter in the column did not differ significantly by the Tukey's test ($p < 0.05$). ns= Not significant

Table 4. Rice straw soil incorporated fertilizer dose and nutrient return in different years of use and management areas.

Area	Mineral fertilization (kg ha^{-1})			Return of nutrients to straw (kg ha^{-1})							
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	CaO	MgO	Fe_2O_3	MnO	ZnO
Ar2	174.60	112.50	112.50	69.91	6.44	103.70	1.34	0.27	0.98	0.45	0.18
Ar4	174.60	112.50	112.50	52.53	8.71	154.28	0.81	0.27	0.81	0.45	0.18
Ar9	174.60	112.50	112.50	54.40	9.85	95.88	1.24	0.25	0.99	0.50	0.17
Ar14	180.15	118.75	118.75	42.42	6.87	127.50	1.05	0.32	1.13	0.48	0.16
Ar26	179.80	117.00	117.00	47.03	8.68	90.03	1.37	0.23	0.76	0.46	0.15

conditions (Kögel-Knabner et al., 2010). Although K trade for grain formation is small, the demand for the plant is great (Yamada and Roberts, 2005), and around 85% of the absorbed K remains in the vegetative parts (Byous et al., 2004). Thus, maintenance of crop residues results in a long-term source of nutrients (Behera and Shukla, 2015), and can substitute significant amounts of nitrogen and potassium fertilizers without negative effects on productivity (Huang et al., 2013).

A negative effect of residue retention on crop yield is the microbial immobilization of N during the establishment of the crop (before tillering), which can reduce N uptake and affect crop growth. However, the immobilization of N can be avoided when nitrogen fertilizers are applied in sufficient doses (Huang et al., 2013), or in some cases, the early application of nitrogen fertilizers may result in a more efficient increase in rice crop productivity. In general terms, efficient soil management, water regime, crop residues and fertilizers, contribute to the production of dry mass and support soil microbial activity, resulting in increased carbon stocks (Briedis et al., 2018; Wang et al., 2018) and soil nutrients (Mazzoncini et al., 2016). Positive correlations ($p \leq 0.01$) were observed between SOC with TN, TP and IP, for the 0-0.10, 0.10-0.20 and 0.20-0.30 m layers, however, the SOC and OP were correlated ($p \leq 0.05$) only in the 0-0.10 m layer. Positive significant relationships ($p \leq 0.01$) between SOC with Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Zn (Zn^{2+}) were also presented in the 0-0.10 and 0.10-0.20 m layers. The 0.20-0.30 m layer was only correlated with Ca^{2+} and Zn^{2+}. This is due to SOC interaction with the soil mineral particles, allowing it to function as nutrient reservoir and energy for the plants (Bandyopadhyay et al., 2010, Yu et al., 2017). Principal component analyzes (PCA) showed that new cultivated areas had a decline in soil fertility, due to the constant turning of the arable layer and the rapid mineralization of SOM. However, in Ar9 and Ar14, that were managed with minimal cultivation, a close relation with the evaluated indicators was shown, thus demonstrating that the reduction of the disturbance of the arable layer and the conservation of the harvest residues at the soil surface contribute to the fertility of the soil (Yang et al., 2005, Wang et al., 2014, Qiu et al., 2018).

Conclusion

Conversion of native ecosystems to irrigated rice production areas significantly affects soil fertility. Nevertheless, the less disturbed rice production and the maintenance of the straw in the superficial layers result in an effective strategy to promote the increase SOC stocks, therefore improving the soil quality over time.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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