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Physicochemical indicators of soil with conventional rice (*Oriza sativa* L.) management under irrigation

Indicadores fisicoquímicos del suelo con manejo convencional del arroz (*Oriza sativa* L.) bajo riego

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Abstract

The research evaluated the effect of conventional management of irrigated rice on the physicochemical indicators of the soil, in the Mercedes and Pérez farms, in Yurimaguas, Peru. It is a comparative non-experimental investigation, with statistical adjustment of a completely randomized design, where the treatments are made up of the secondary forest (BS), the conventional rice management of one (A1), five (A5) and nine years (A9), evaluating physicochemical indicators of the soil in strata from 0.0 to 0.2 and 0.2 to 0.4 m. The results showed differences in the fractions, with initial reduction of sand, silt and clay increase and in time slight recovery of the sand, silt fraction and clay reduction. The chemical indicators according to treatments and strata show differences, except K; management significantly affects the beginning of the production process (A1) reducing the levels of pH, MO, N, P, K^{+}, Ca^{2+} and Mg^{2+} and increasing Al^{3+}, AC and SAl, and there is a recovery over time (A9), except in MO and N which decrease to very low levels. In conclusion, conventional management shows significant effects between treatments and indicators evaluated in both strata, negatively affecting the beginning (A1) and recovering over time (A9); however, there are long-term negative effects on OM and N levels.

Keywords: Chemical fertilization, physical indicators, chemical indicators, organic matter, crop residues, Yurimaguas, Peru.

Resumen

La investigación evaluó el efecto del manejo convencional del arroz bajo riego en indicadores fisicoquímicos del suelo, en los fundos Mercedes y Pérez, en Yurimaguas, Perú. Es una investigación no experimental comparativa, con ajuste estadístico de diseño completamente aleatorizado, donde los tratamientos lo constituyen el bosque secundario (BS), el manejo convencional del arroz de: uno (A1), cinco (A5) y nueve años (A9); evaluándose indicadores fisicoquímicos del suelo en estratos de 0,0 a 0,2 y 0,2 a 0,4 m. Los resultados mostraron diferencias en las fracciones, con reducción inicial de arena, limo e incremento de arcilla y en el tiempo ligera recuperación de la fracción arena, limo y reducción de arcilla. Los indicadores químicos según tratamientos y estratos presentan diferencias, excepto el potasio (K); el manejo afecta significativamente al inicio del proceso productivo (A1) reduciendo los niveles del potencial de hidrogeno (pH), materia orgánica (MO), nitrógeno (N), fosforo (P), potasio (K^{+}), calcio (Ca^{2+}) y magnesio (Mg^{2+}) e incrementando el aluminio (Al^{3+}), acidez cambiable (AC) y saturación de aluminio (SAl); de igual forma, se observa la recuperación en el tiempo (A9), excepto en MO y N que descienden a niveles muy bajos. En conclusión, el manejo convencional muestra efectos significativos entre tratamientos e indicadores evaluados en ambos estratos, afectando negativamente al inicio (A1) y recuperándose con el tiempo (A9); sin embargo, se observan efectos negativos a largo plazo en los niveles de MO y N.

Palabras clave: Fertilización química, indicadores físicos, indicadores químicos, materia orgánica, residuos de cosecha, Yurimaguas, Perú.

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1 Introduction

Peru has areas with great potential for irrigated rice production in different regions, which in the last 17 years (2001-2017) have had an upward trend in the national production, as the harvested area grew 2% and yields increased 0.4% on average per year. The main producing regions are San Martín with 27%, Lambayeque 13%, Piura 12%, Amazonas 10% and la Libertad with 7% (MINAGRI-DGESEP, 2018). The national average yield is 7,2t ha^{-1}, while Loreto (Yurimaguas) has an average of 2,9t ha^{-1} ranking 13th nationally. Thus, production in this region is far from the national average and the average of regions such as Arequipa (13,9t ha^{-1}), Ancash (11,9t ha^{-1}), Tumbes (8,5t ha^{-1}), and Lambayeque with 8t ha^{-1} (Contreras, 2016; MINAGRI-DGESEP, 2018; Quevedo et al., 2019). In addition, production in these areas is based on conventional crop management, with poor agricultural practices such as: pest control with agrochemicals, weed control with herbicides and intensive use of chemical fertilizers.

The application of conventional management is due to the low efficiency of the application of organic matter, which can affect the profitability of the crop (Alvarez et al., 2008), which has contributed in some cases to a decrease in average yield. Rice (*Oryza sativa* L.) is an essential food grain for most of citizens (Das et al., 2014; Çay, 2018; Lv et al., 2018), being a basic component in political, economic, social stability and our survival (Quevedo et al., 2019) and with important contributions in the economy. In Peru, it impacts in the generation of employment since cultivation is done manually in more than 95% of the cultivated area. The process requires on average 130 days$\cdot ha^{-1}$, generating in 2017 approximately a total of 222 thousand permanent jobs (Sanjinez, 2019). Therefore, economic stability and food security depends largely on the availability of this grain (Sanjinez, 2019; Effendi et al., 2021).

In general, agricultural practices such as monoculture, mechanization and the use of agrochemicals generally lead to changes in soil quality, degrading its structure and productive potential (Stehlíková et al., 2016; Florida and Núñez, 2020). Irrigated rice is a monoculture with special characteristics (Guzmán, 2006; Ruiz et al., 2005; Vignola et al., 2018); mechanization and fertilizer application and other activities in the development of this crop cause the degradation of soil physical properties: destruction of macropores, increased density (Çay, 2018), compaction, erosion, poor drainage, accumulation of P, K and others in the surface layer (Lv et al., 2015), hindering root growth and morphophysiological development of plants (Castillo, 2000; Pérez et al., 2002; Ruiz et al., 2005). Also, waterlogging can generate downward water circulation, causing the loss of clay and silt particles (Castillo, 2000; Alejandro, 2016) and accelerating the degradation of chemical characteristics, reducing the levels of OM, exchangeable bases and an acidification process, caused by the strong flushing (Castillo, 2000; Navarro et al., 2001; Alejandro, 2016; Ruiz et al., 2016).

In this context, it is necessary to evaluate the effects of rice cultivation on soil quality. Therefore, the aim of this research is to evaluate the effect of conventional rice (*Oryza sativa* L.) management under irrigation on the main physicochemical indicators of the soil, in the Mercedes and Pérez farms, in Yurimaguas, Alto Amazonas province-Loreto region, Peru.

2 Materials and Methods

2.1 Study area

The research was carried out in Mercedes and Pérez farms (Figure 1). Both farms are located in Suniplaya area, in the district of Yurimaguas, located in the southern part of the Alto Amazonas province in Loreto region.

2.2 Bio-climatic features

According to Holdridge (2000) classification of life zones or plant formations of the world, the area belongs to a Tropical rainforest (bh-T); according to Pulgar (2014) this area belongs to the Omagua Ecoregion or lowland rainforest. It has an equatorial, warm and humid climate with abundant rainfall, typical of the Amazon; the average temperature is $26,6°C$; the minimum relative humidity is 74.5% and the maximum is 81.5%, with an average annual rainfall of 2098 mm per year (World Climate Data, 2020). It is located on the left bank of the Huallaga River, about 100 km upstream from the confluence with the Marañon River, both belonging to the great Amazon River basin (Paredes, 2013). The soil type corresponds to Inceptisols, with a poorly developed B horizon and a medium floodable terrace.

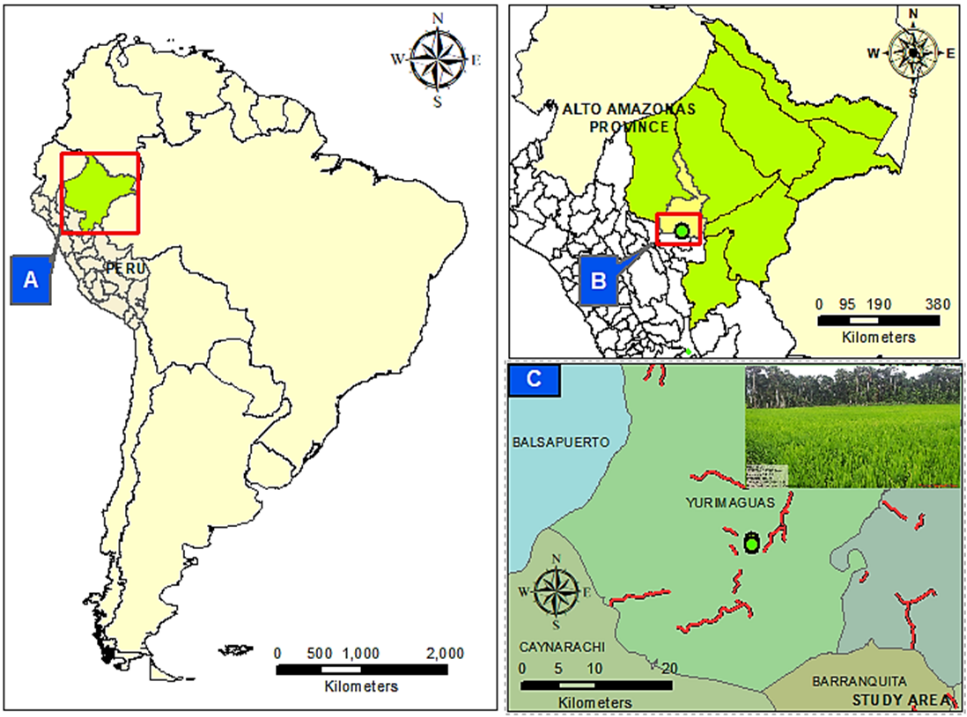

Figure 1. Geographical location of the area of study, Mercedes and Pérez farms (C), Yurimaguas in Alto Amazonas (B) Loreto-Perú (A).

2.3 Rice with conventional management

The areas with rice crops had a sequential process of intervention that is subdivided into:

(a) **First forest intervention** It was carried out on primary forest areas, using a caterpillar tractor which performed the clearing and cleaning of stumps and fallen trees in the area. Also, at this stage, the same machinery was used to level the land, build the edges, canals, access roads and drains; after this stage, the area was ready to begin the process of soil preparation and installation of the rice crop.

(b) **Soil preparation after the sow** In the dry season (June-October) the soil was harrowed with an agricultural tractor with a disc harrow, which allows the arable layer of the soil profile and the incorporation of the residues of the previous harvest. In the rainy season (between November and May), the soil is directly loosened with an agricultural tractor with a rotary plow, after flooding the land. Finally, the pits are leveled with an agricultural tractor equipped with a plow and the leveling is refined with motorized cultivators and the area is ready for rice planting.

(c) **Sowing** Once the soil is ready, in an independent space within the prepared area, the rice seedbed (variety HP 102 FL-THE VALUE) is planted for its subsequent transplanting of seedlings to the definitive field. The procedure involved soaking 80 kg of seed per hectare, the seed is sown broadcast and fertilized with urea at a dose of $8 kg\ ha^{-1}$; finally, when the seedlings from the nursery reach 25 to 30 days and about 20 cm in height, they are transplanted into the final field.

(d) **Crop management and fertilization plan at different productive stages.** Refer to Table 1.

(e) **Harvest** This stage was carried out approximately 135 days after the seedbed and crop installation, using a harvesting machine equipped with rubber tracks.

Table 1. Management plan of rice.

Description of the activity	Moment	Detail of the application
First fertilization	After the transplant	100 kg of di-ammonium phosphate and 100 kg of potassium chloride
Weed control	7 days after the transplante	Pre-emergent herbicide butachlor was applied
	10 days before the pre-sprout	Spraying was carried out with post-emergent herbicides Florpyrauxifen-benzyl (loyant), and Cyhalofop butyl (clincher) + its insecticide chlorpyrifos (typhoon).
Second fertilization	51 days after	100 kg of nitro s (ammonium nitrate) and 100 kg of potassium chloride were applied with a sheet of water.
Tilling treatment	60 days after	A biostimulant based on amino acid, fungicide carbendazin (protexin) and insecticide imidacloprid and benzoate (Agryben duo) are applied.
Third fertilization	70 days after	75 kg of ammonium nitrate (Nitro S) was applied with a water sheet.
Treatment for the formation and protection of ears	75 days after	Tebucunazole, Difeconazole, Propiconazole, imidacloprid and foliar insecticides of potassium, phosphorus, calcium, and boron were applied.
Yield	The last two harvests	A1 (7000$kg\ ha^{-1}$), A5 (8500$kg\ ha^{-1}$), A9 (8500$kg\ ha^{-1}$)

There are two harvests annually in these areas.

2.4 Secondary forest

The areas with conventional rice management were compared with secondary forest (SF), forest adjacent to these crops that present a large intervention of species with commercial value, whose current composition is based on species such as: moena (*Aniba amazónica* Meiz), pashaco blanco (*Macrolobium acaciaefolium* Benth), oje (*Ficus insípida* Willd.), Capirona (*Calycophyllum Spruceanum* (Bent.) Hook), palo lápiz (*Polyscias murrayi* F. Muel), ana caspi (*Apuleia proecox* C. Martius), bellaco caspi (*Himatanthus sucuuba* Woods), tornillo (*Cedrelinga cateniformis* D. Ducke), Cashimbo (*Cariniana periformis* Miers), setico (*Cecropia membranácea* Trécul), topa (*Ochroma pyramidale* Cav. Ex. Lamb), yarina (*Phytelephas macrocarpa* Ruiz et Pav), el huasai (*Euterpe oleracea* Mart.) and other species with low commercial value.

2.5 Soil sampling and physical-chemical analysis

Two harvests annually are obtained in the areas, in which sampling was carried out before the second harvest in 2020 (August-December), in rice plots with conventional management of one year (A1), five years (A5), nine years (A9) and secondary forest (SF) as reference. In them, a subarea of 2000 m^2 was selected and sampling was performed at 5 random points in each subplot, according to the methodology of Soil Taxonomy (2014), considering strata of 0.0 - 0.2 and 0.2 to 0.4 m depth; physical (Texture) and chemical indicators were evaluated: pH, organic matter $OM, N, P, K^+, Ca^{2+}, Mg^{2+}, Mg^{2+}, Al^{3+}$, cation exchange capacity (CEC), exchangeable acidity (EA) and aluminum saturation (SAl), following the protocols described by Bazán (2017).

2.6 Experimental design and statistical analysis

It is comparative non-experimental research (Hernández et al., 2014) statistically adjusted to the completely randomized design (CRD) with four treatments: secondary forest (SF), Rice with 1 year (A1), five years (A5) and nine years of management (A9) and a sample size $n = 5$ (40 samples in total), in strata from 0.0 to 0.2 m and 0.2 to 0.4 m and each experimental unit was formed by a subarea of 1000 m^2. Similar study methodologies have been applied by Navarro et al. (2018); Florida and Núñez (2020).

The data were subjected to ANOVA variance analysis and HSD-Tukey test with a significance level of 5% ($p < 0,05$) for the comparison of means, and the free software IBM-SPSS 25 was used to measure the management effects on soil physicochemical indicators in different strata.

3 Results and discussions

3.1 Physical indicators

The only physical indicator evaluated was soil texture. Table 2 shows that the different treatments evaluated present a clayey textural class (with% clay>42%) in both strata (0.0-0.2 and 0.2-0.4 m). In addition, changes are observed in the percentage of sand and silt fractions, showing variations with a tendency to decrease in A1, A5 and slight recovery in A9; on the contrary, the clay fraction increases in A1 and tends to decrease in A5 and A9 in both strata; this fraction is the least altered. In general, there was initially a reduction in the sand and silt fractions and a significant increase in clay, and an opposite effect was observed in both strata over time.

Table 2. Fraction statistics and texture class.

Treatments	Fractions			Texture class
	Sand	Clay	Silt	
Stratum 0.0-0.2 m				
SF	$28.6{\pm}3.29^{b}$	$48.8{\pm}3.03^{a}$	$22.6{\pm}2.61^{bc}$	Clayey
A1	$7.4{\pm}0.89^{a}$	$80{\pm}4.69^{b}$	$12.6{\pm}4.56^{a}$	Clayey
A5	$9.4{\pm}6.54^{a}$	$73.6{\pm}9.94^{b}$	$17{\pm}3.46^{ab}$	Clayey
A9	$14.6{\pm}3.58^{a}$	$60{\pm}6.78^{a}$	$25.4{\pm}4.34^{c}$	Clayey
EEM	16.8	44	14.6	
Sig.	0.00**	0.00**	0.00**	
CV (%)	61.93	21.07	31.85	
Stratum 0.2-0.4 m				
SF	$21{\pm}7.21^{b}$	$48.4{\pm}6.07^{a}$	$30.6{\pm}4.98^{b}$	Clayey
A1	$7.4{\pm}1.67^{a}$	$79.6{\pm}5.18^{b}$	$13{\pm}4.24^{a}$	Clayey
A5	$7.8{\pm}1.79^{a}$	$78.4{\pm}5.55^{b}$	$13.8{\pm}4.15^{a}$	Clayey
A9	$16.6{\pm}9.21^{ab}$	$57.6{\pm}8.41^{a}$	$25.8{\pm}3.9^{b}$	Clayey
EEM	35.7	41.3	18.8	
Sig.	0.005**	0.00**	0.00**	
CV (%)	61.36	22.67	42.07	

EEM: standard error of the mean, Sig.: Significance, **: highly significant, SF: secondary forest, A1,5 and 9 area with rice cultivation of 1 year, 5 and 9 years. Means followed by the same letter in the column do not differ from each other by Tukey's test ($p = 0,05$).

The results can be explained considering that the soil preparation system aims to prepare the soil prior to planting to create a suitable bed for plant growth and development (Vignola et al., 2018); therefore, the soil is lifted and turned from a depth of 10 to 20 cm, fractioning the aggregates, and affecting the soil-water relationship (Pérez et al., 2002; Ruiz et al., 2005). In addition, waterlogging generates downward water circulation, which causes the loss of fine particles, clay and silt (Castillo, 2000; Alejandro, 2016). These references explain why there is a reduction of the silt fraction in A1 and clay in A9 in both strata; however, they do not explain the reduction of sand and increase of clay in A1 and the recovery of the sand and silt fraction in A9; probably the initial conditioning of the plot that includes cuts and fills to flatten the terrain is responsible for the initial changes and it is only possible to observe in A5 and A9 as mentioned in the references.

3.2 Chemical indicators

Table 3 shows the means of fertility indicators; pH levels in both strata tend to decrease slightly in A1 and then increase in A5 and A9, the latter showing the highest mean. The mean *OM* and *N* in both strata tends to decrease in A1, A5 and A9 have the lowest mean; P decreases in A1 and then tends to stabilize and show recovery tendencies in A5 and A9, similar to SF. In addition, the mean levels of the superficial stratum are higher; on the contrary, in the case of K^+ the mean levels in A1, A5 and A9 are higher than SF in both strata and the highest means are in the 0.4 m stratum. In general, pH, *P* and K^+ decrease in A1 and then show recovery trends in A5 and A9, except for *OM* and *N*, which tend to decrease. In addition, significant differences were found in pH, *OM*, *N* and *P*, except for K^+, which shows no differences among the treatments and strata evaluated.

Table 3. Statistics of fertility chemical indicator.

Treatments	Indicators				
	pH	**OM (%)**	**N (%)**	**P (ppm)**	**K (ppm)**
Stratum 0.0-0.2 m					
SF	$4.74{\pm}0.14^a$	$3.82{\pm}0.68^b$	$0.19{\pm}0.03^b$	$7.04{\pm}0.48^a$	$72.37{\pm}0.99^a$
A1	$4.64{\pm}0.12^a$	$2.26{\pm}0.44^a$	$0.11{\pm}0.02^a$	$4.01{\pm}1.03^a$	$77.02{\pm}2.31^a$
A5	$4.97{\pm}0.16^b$	$2.48{\pm}0.55^b$	$0.12{\pm}0.03^a$	$6.79{\pm}2.26^{ab}$	$76.27{\pm}7.43^a$
A9	$4.76{\pm}0.08^{ab}$	$1.58{\pm}0.46^a$	$0.08{\pm}0.02^a$	$7.09{\pm}2.1^b$	$75.77{\pm}3.68^a$
EEM	16	293	1	2706	18743
Sig.	0.007**	0.00**	0.000**	0.025*	0.367ns
CV (%)	3.56	38.19	38.46	32.1	5.8
Stratum 0.2-0.4 m					
SF	$4.76{\pm}0.13^{ab}$	$1.39{\pm}0.12^{ab}$	$0.07{\pm}0.01^{ab}$	$3.21{\pm}0.78^a$	$73.26{\pm}1.06^a$
A1	$4.63{\pm}0.1^a$	$1.52{\pm}0.32^{ab}$	$0.08{\pm}0.02^{ab}$	$2.6{\pm}0.8^a$	$80.98{\pm}5.38^a$
A5	$4.97{\pm}0.07^{bc}$	$1.65{\pm}0.52^b$	$0.08{\pm}0.03^b$	$5.43{\pm}1.47^b$	$82.46{\pm}7.31^a$
A9	$5.16{\pm}0.16^c$	$0.88{\pm}0.35^a$	$0.04{\pm}0.02^a$	$3.5{\pm}1.14^{ab}$	$81.37{\pm}5.56^a$
EEM	0.01389	0.1269325	0	1178	28598
Sig.	0.00**	0.02*	0.021*	0.005**	0.056**
CV (%)	4.71	32.35	33.82	39.8	7.76

EEM: standard error of the mean, Sig.: Significance, **: highly significant, SF: secondary forest, A1,5 and 9 area with rice cultivation of 1 year, 5 and 9 years. Means followed by the same letter in the column do not differ from each other by Tukey's test ($p = 0,05$).

The behavior of the results in Table 3 can be explained considering that OM and N are indicators strongly altered by conventional management (Çay, 2018), as a consequence of being in conditions of high waterlogging (Castillo, 2000; Navarro et al., 2001; Alejandro, 2016), high transit of agricultural machinery that compacts the soil and alters the availability of oxygen (Alejandro, 2016), and the excessive use of herbicides for weed control (Ramírez et al., 2017). Therefore, the values of OM and N in A1, A5 and A9 are not ideal since Domínguez et al. (2020) consider normal values higher than 3% OM for crop development. Although, soil preparation includes the incorporation of crop residues, this does not seem to help in increasing the levels of OM and N, as pointed out by Guzmán (2006); Alvarez et al. (2008); Li et al. (2011); in addition, very low levels are observed in A9 in both strata evaluated, which could affect the absorption levels of N, P and Mg, related to the production of green matter (Aguilar, 2010). Therefore, it is necessary to determine the fertilizer application rate to optimize N use efficiency and avoid adverse effects (Zhang et al., 2009).

Regarding pH, the intensive use of machinery and high volumes of water cause strong washing of exchangeable bases and an accentuated acidification process (Ruiz et al., 2016); although it is possible to improve or correct with the application of calcareous matter, in this case, flooding favors their rapid incorporation, raising pH levels (Morales, 2004). However, the results do not show this acidification process and according to Sanjinez (2019) are very close to the optimum levels for this crop (5.5 to 6.5 pH). Regarding K^+, no differences are observed and it tends to increase with time, which can be explained considering (Table 1) that 100 kg of potassium chloride is applied before transplanting, 100 kg more at 51 days after transplanting and foliar based on K, P, Ca^{2+} and B at 75 days, generating an accumulation that can alter the relationship that this element maintains with the cations Ca, Mg and with the nutrients N and P, and negatively influencing their absorption and limit production (Aguilar, 2010; Das et al., 2014), since the amount applied to the areas exceeds what is recommended by Alejandro (2016), doses between $80-150$ kg of K_2O ha^{-1} and by Paredes and Becerra (2015), who suggest using no more than 60 units of K^+ before transplanting. Therefore, it is necessary to consider the absorption curves of the crop to provide the necessary nutrients at each phenological stage of the crop (Tinoco and Acuña, 2009; Zhang et al., 2009). If the trend of K imbalance is not reversed, the potential for improving N and P fertilizer use efficiency and crop yield will be limited.

Table 4. Statistics of exchangeable chemical indicators.

Treatments	Indicators			
	Ca	**Mg**	**Al**	**CICe**
	Cmol(+)/kg			
	Horizon 0.0-0.2 m			
SF	4.41±0.78^a	0.65±0.09^a	7.42±1.16^{ab}	12.61±1.22^a
A1	4.04±0.82^a	0.61±0.11^a	13.1±1.57^c	18.36±2.58^b
A5	5.97±0.45^b	0.87±0.09^b	5.14±1.58^a	12.17±1.92^a
A9	4.95±0.59^{ab}	0.74±0.06^{ab}	7.94±1.09^b	13.93±1.56^a
EEM	459	8	1870	3561
Sig.	0.002**	0.001**	0.00**	0.00**
CV (%)	20.04	18.31	38.54	21.37
	Horizonte 0.2-0.4 m			
SF	4.59±0.73^{ab}	0.66±0.08^a	8.55±1.59^b	14.33±1.87^a
A1	4.05±0.69^a	0.61±0.09^a	12.26±2.13^c	18.15±2.2^b
A5	6.4±0.91^c	0.91±0.08^b	4.63±1.67^a	12.66±1.31^a
A9	5.85±0.58^{bc}	0.83±0.05^b	5.75±0.44^{ab}	12.91±0.76^a
EEM	539	6	2517	2652
Sig.	0.00**	0.00**	0.00**	0.00**
CV (%)	22.56	19.28	42.97	18.61

EEM: standard error of the mean, Sig.: Significance, **: highly significant, SF: secondary forest, A1,5 and 9 area with rice cultivation of 1 year, 5 and 9 years. Means followed by the same letter in the column do not differ from each other by Tukey's test ($p = 0,05$).

Table 4 shows that the means of Ca^{2+} and Mg^{2+} levels in both strata tend to decrease slightly in A1 and then increase in A5 and A9; on the contrary, Al^{3+}, AC and SAL levels increase in A1 and then decrease in A5 and A9. In general, all exchangeable indicators present highly significant differences according to treatment and stratum evaluated in comparison to the secondary forest soil.

The behavior of the exchangeable indicators (Table 4) can be explained by considering that rice soils lead to the establishment of a compact illuvial horizon, poorly permeable and enriched in iron and manganese, and an impoverished eluvial horizon, which is seen by an intense washout of bases (Castillo, 2000; Navarro et al., 2001); in addition, NH^{+4}, Fe^{2+} and Mn^{2+} ions released after flooding can displace considerable amounts of Mg^{2+} from exchange sites by strong scouring (Bacha, 2002; Ruiz et al., 2016). This explains the reduction of Ca^{2+}, Mg^{2+} and the increase of Al^{3+}, AC and SAl in A1; however, these references do not explain the recovery of Ca^{2+}, Mg^{2+} and the reduction of Al^{3+}, EA and SAl in A5 and A9, but may be due to the incorporation of crop residues and the contribution of fertilizers, in some cases in excess such as K^+ (Table 1) in the production process.

3.3 Multiple comparisons of physical indicators

All the fractions evaluated in the different treatments show significant differences (Table 3) and the HSD-Tukey multiple comparisons (Table 5) show that the sand fraction in treatments A1, A5 and A9 are different from SF, except A9 at 40 cm depth. In the case of the clay fraction, A1 and A5 present differences with SF in both strata and in the silt fraction A1 is different from SF in the superficial stratum, in the 40 cm stratum both A1 and A5 are different from SF.

Table 5. Tukey-HSD Test for physical indicators.

Dependent variable	Treatments		Mean differences (I-J)	Desv. Error	Sig.
Sand	SF20	A1	21.2*	2.59	0.000
		A5	19.2*	2.59	0.000
		A9	14*	2.59	0.000
	SF40	A1	13.6*	3.78	0.012
		A5	13.2*	3.78	0.014
		A9	4.4	3.78	0.657
Clay	SF20	A1	-31.2*	4.2	0.000
		A5	-24.8*	4.2	0.000
		A9	-11.2	4.2	0.072
	SF40	A1	-31.2*	4.06	0.000
		A5	-30*	4.06	0.000
		A9	-9.2	4.06	0.149
Silt	SF20	A1	10*	2.42	0.004
		A5	5.6	2.42	0.135
		A9	-2.8	2.42	0.660
	SF40	A1	17.6*	2.74	0.000
		A5	16.8*	2.74	0.000
		A9	4.8	2.74	0.332

*, Mean difference is significant at 0.05.

Multiple comparisons show differences between treatments and physical and chemical indicators evaluated in both strata. This result shows that the time of crop management, mainly mechanization and irrigation, has effects on the different soil fractions in both strata, compared to the secondary forest used as reference, being the affectation in the following order: sand>clay>silt.

3.4 Multiple comparisons of chemical indicators

The chemical indicators evaluated in the different treatments and strata also show significant differences (Table 4), except for K. The HSD-Tukey multiple comparisons (Table 6) show that pH in treatment A1 at 0.2 m and A9 at 0.4 m are different from SF; *OM* and *N* in treatments A1, A5 and A9 at 0.2 m; P in treatments A1 in surface stratum and A5 at 0.4 m and K^{+} do not show differences compared to secondary forest SF.

Table 6. HSD-Tukey test for chemical fertility indicators.

Dependent variable	Treatments		Mean diffenrences (I-J)	Desv. Error	Sig.
pH	SF20	A1	0.09400	0.07977	0.648
		A5	-.23000*	0.07977	0.048
		A9	-0.02400	0.07977	0.990
	SF40	A1	0.13200	0.07454	0.322
		A5	-0.21000	0.07454	0.054
		A9	-.39200*	0.07454	0.000
OM	SF20	A1	1.56200*	0.34219	0.002
		A5	1.34000*	0.34219	0.006
		A9	2.24000*	0.34219	0.000
	SF40	A1	-0.13400	0.22533	0.932
		A5	-0.25800	0.22533	0.668
		A9	0.50600	0.22533	0.153
N	SF20	A1	0.08200*	0.01769	0.001
		A5	0.07000*	0.01769	0.006
		A9	0.11400*	0.01769	0.000
	SF40	A1	-0.00600	0.01179	0.956
		A5	-0.01400	0.01179	0.643
		A9	0.02600	0.01179	0.164
P	SF20	A1	3.03000*	1.04036	0.045
		A5	0.25000	1.04036	0.995
		A9	-0.05400	1.04036	1.000
	SF40	A1	0.61200	0.68649	0.809
		A5	-2.22200*	0.68649	0.024
		A9	-0.28600	0.68649	0.975
K^+	SF20	A1	-4.65200	2.73811	0.356
		A5	-3.89800	2.73811	0.504
		A9	-3.40000	2.73811	0.611
	SF40	A1	-7.72400	3.38217	0.144
		A5	-9.20600	3.38217	0.065
		A9	-8.11000	3.38217	0.118

*, Mean difference is significant at 0.05.

Table 7 shows the multiple comparisons according to the HSD-Tukey test, where Ca^{2+} in treatment A5 at 0.2 and 0.4 m shows differences with respect to the control treatment (SF); also, Mg^{2+} in A5 at 0.2 m and A5 and A9 at 0.4 m are different from SF; in the case of Al^{3+} in A1 at 0.2 m and A1 and A5 at 0.4 m shows differences with respect to SF and CICe in A1 at 0.2 and 0.4 m are different from SF. This multiple comparison test demonstrates that more than one treatment showed differences with respect to the control treatment (SF) in the different indicators and strata evaluated and negative effects are evidenced according to the treatments in the following order: A1>A5 >A9.

In general, the chemical indicators according to the treatments are severely affected at the beginning of the management (A1) and in most of them a recovery with time is observed, due to crop residues during soil preparation and the lack of precision in the management plan that so far (A9) seems a recovery process; however, negative effects are observed with time, as mentioned by Castillo (2000); Federación Nacional de Arroceros de Colombia (2001); Navarro et al. (2001); Ruiz et al. (2005); Alejandro (2016); Ruiz et al. (2016); Vignola et al. (2018); Domínguez et al. (2020).

Table 7. HSD-Tukey test for exchangeable chemical indicators.

Dependent variable	Treatments		Mean differences (I-J)	Desv. Error	Sig.
Ca^{2+}	SF20	A1	0.36600	0.42868	0.828
		A5	-1.56000*	0.42868	0.011
		A9	-0.54000	0.42868	0.600
	SF40	A1	0.54000	0.46432	0.658
		A5	-1.81000*	0.46432	0.006
		A9	-1.25600	0.46432	0.067
Mg^{2+}	SF20	A1	0.04000	0.05638	0.892
		A5	-.22000*	0.05638	0.006
		A9	-0.09400	0.05638	0.372
	SF40	A1	0.04600	0.04868	0.782
		A5	-.25600*	0.04868	0.000
		A9	-.17400*	0.04868	0.012
Al^{3+}	SF20	A1	-5.67400*	0.86488	0.000
		A5	2.28400	0.86488	0.076
		A9	-0.51600	0.86488	0.932
	SF40	A1	-3.70800*	1.00345	0.010
		A5	3.92000*	1.00345	0.006
		A9	2.80000	1.00345	0.057
CICe	SF20	A1	-5.74400*	1.19345	0.001
		A5	0.44200	1.19345	0.982
		A9	-1.31600	1.19345	0.693
	SF40	A1	-3.82200*	1.02998	0.009
		A5	1.66800	1.02998	0.396
		A9	1.41400	1.02998	0.533

*, Mean difference is significant at 0.05.

Finally, based on the yield background of the areas (Table 1) there is an average yield in the last two seasons of 7t ha^{-1} in A1 and 8,5t ha^{-1} in A5 and A9, the latter higher than the national average of 7,19t ha^{-1} (MINAGRI-DGESEP, 2018), to the 7,72t ha^{-1} reported by Gabriel (2014) combining biol and 20t ha^{-1} of bocashi, to the 6,88t ha^{-1} obtained by Jara (2003) with the Biflor variety in Tulumayo, Leoncio Prado and to the 5,5 and 5,3t ha^{-1}, respectively obtained by Barahona et al. (2019) in an Inceptisols soil in Coclé, Panama. However, they are slightly lower than the 9,5t ha^{-1} reported by Quevedo et al. (2019) and the 10,346t ha^{-1} reported by Contreras (2016), with the application of phosphorus and micronutrients in Tinajones Jequetepeque. According to Sanjinez (2019), the optimum temperature for germination varies between 10 and 35°C, and for stem, leaf and root growth it varies between 7 and 23°C; the area under study has an average of 26.6°C (World Climate Data, 2020). Secondly, the yields are due to the very disciplined fertilizer plan applied (Table 1) and thirdly to the crop residues incorporated in each soil preparation cycle.

4 Conclusions

Differences were found in the sand, silt and clay fractions in the different treatments evaluated (SF, A1, A5 and A9) and they correspond to a clayey textural class. Initially, a reduction was found in the mean values of the sand and silt fractions and an increase in clay, and over time the sand, silt and clay fractions tended to decrease.

The chemical indicators determine that the soils have an acid to slightly acid pH, with OM, N, P and Ca levels that vary from low to medium; K, Mg and CEC have low levels and Al has high levels, with significant differences between the treatments and strata evaluated, except for K, which shows no differences.

The analysis of variance and multiple comparisons show differences between treatments in the different physical and chemical indicators evaluated in both strata; the time of irrigated rice management has effects on the different soil fractions and on the chemical indicators in both strata, affecting severely at the beginning of management (A1) and a recovery is observed over time (A9), due to the incorporation of crop residues and a strict fertilization plan that has maintained yields above the national average; however, negative effects are observed in the long term.

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