Revista de CIENCIAS AGRÍCOLAS

e-ISSN Online 2256-2273

Received: May 14 2024 Accepted: February 12 2025 Published: April 28 2025

Research article: Soil science

Impact of chisel plowing on soil physical properties in rice (*Oryza Sativa* L.) cultivation

Impacto del cincel en las propiedades físicas del suelo en el cultivo de arroz (*Oryza Sativa* L.)

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Cite: Castillo-Coronado, J. A.; Polania-Montiel, D.C.; Ardila-Marín, J.G. (2025). Impact of chisel plowing on soil physical properties in rice (*Oryza Sativa L.*) cultivation. *Revista de Ciencias Agrícolas*. 42(1): e1254. https://doi.org/10.22267/rcia.20254201.254

ABSTRACT

The continuous use of agricultural machinery in rice (*Oryza Sativa* L.) cultivation throughout its vegetative cycle increase in apparent density and resistance to penetration into the soil, which affects the development of the crop and its performance. Thus, seeking a more sustainable agriculture, it was proposed to evaluate the soil's physical properties and crop yield, modifying the conventional preparation with a harrow using a chisel on the USCO's Farm in Palermo (Huila, Colombia). Four experimental treatments were implemented: three with different chisel passes and a control with conventional plowing, in which real density, bulk density, and porosity were evaluated before and after tillage, and after harvest. The statistical analysis was carried out through analysis of variance, and the techno-economic analysis was carried out based on the production and operation costs between the two types of tillage. The results showed that after tillage, the bulk density decreased by 13.5% in the control and 11.5% in T3. These effects increased porosity between 23.0 and 31.6% in the area with greater tillage. After the harvest, a resilient response of the soil was found, which recovered 9.5 and 12.4% of the apparent density in T3 and T4, respectively. The use of reduced tillage with chisel did not make a significant difference in production (Control: 7.8 t ha-1, T1 and T2: 8.2 t ha-1, and T3: 8.4 t ha-1), but it was more economical and less aggressive for the soil in structural terms.

Keywords: agricultural machinery; minimum tillage; radical development; soil compaction; soil densification; soil mechanics

RESUMEN

El uso continuo de maquinaria agrícola en el cultivo del arroz (*Oryza Sativa* L.), durante todo su proceso vegetativo, genera un aumento de la densidad aparente y de la resistencia a la penetración en el suelo, lo que incide en el desarrollo del cultivo y su rendimiento. Así, buscando una agricultura más sustentable, se propuso evaluar las propiedades físicas del suelo y el rendimiento del cultivo, modificando la preparación convencional con rastra utilizando el cincel en la Finca de la USCO en Palermo (Huila, Colombia). Se implementaron cuatro tratamientos experimentales: tres con diferentes pases de cincel y un testigo con arado convencional, en los que se evaluó densidad real, densidad aparente y porosidad, antes y después de la labranza, y después de la cosecha. El análisis estadístico se realizó mediante análisis de varianza, y el análisis tecnoeconómico se llevó a cabo en función de los costos de producción y operación entre los dos tipos de labranza. Los resultados indican que después de la labranza, la densidad aparente disminuyó un 13,5% en el control y un 11,5% en el T3; efectos que provocaron un aumento en la porosidad de 23,0 y 31,6% respectivamente. Luego de la cosecha, se encontró una respuesta resiliente del suelo, el cual recuperó el 9.5% y 12.4% de la densidad aparente en T3 y T4, respectivamente. El uso de labranza reducida con cincel no marcó una diferencia significativa en la producción (Testigo: 7,8 t ha-1, T1 and T2: 8,2 t ha-1, and T3: 8,4 t ha-1), pero resultó más económica y favorable para el suelo.

Palabras clave: compactación de suelos; densificación de suelos; desarrollo radical; labranza mínima; maquinaria agrícola; mecánica de suelos

INTRODUCTION

The continuous passage of agricultural machinery in a crop throughout its vegetative cycle leads to a reduction in soil macro porosity and an increase in penetration resistance and apparent density, which negatively affects crop development and subsequent yield (Gómez-Calderón *et al.*, 2018; Masola, 2020; Mwiti *et al.*, 2022; Suzuki *et al.*, 2022; Yadav & Kumar, 2024; Zabrodskyi, 2023). Knowledge of the density and porosity of the soil is key for effective production management, since the soil must have a porous condition that guarantees crop development. In this way, excessive mechanization ends up affecting the soil by interfering with root development and its drainage (Peng *et al.*, 2022; Misha *et al.*, 2024); but, on the other hand, the soil must present a structure that does not collapse under the passage of machinery or by natural processes (Azevedo *et al.*, 2023; Kumar *et al.*, 2022; Or *et al.*, 2021; Singh *et al.*, 2022).

To correct the physical properties of soils, it is necessary to adopt resource conservation technologies, such as reduced tillage or zero tillage, which are environmentally friendly and beneficial for both farmers and crop productivity. In this way, it becomes necessary to evaluate the impact of agricultural machinery on the soil to preserve its physical properties and productivity (El-Beltagi *et al.*, 2022; Hussain *et al.*, 2021; Nawaz *et al.*, 2017; Phogat *et al.*, 2020). In addition, rice (*Oryza sativa* L.) is a basic and exploited product in Colombia, with the department of Huila recording the highest grain yield (7.3 t/ha) during the first half of 2024 (Rodríguez, 2024). The physical properties of soil in this crop are closely linked to management, thus, before planting, it is essential to assess factors such as compaction, texture, structure, porosity, and infiltration capacity (Kalita *et al.*, 2020; Mairghany *et al.*, 2019; Mirzavand & Moradi-Talebbeigi, 2021; Shaheb *et al.*, 2021). Once these analyses have been carried out, corrections are made with specific plows to increase the moisture retention capacity of the soil and maintain its structure (Ajayi *et al.*, 2021; Das *et al.*, 2019; Das *et al.*, 2021; Mondal *et al.*, 2020; Tater & Vashisht, 2024). Also, for rice cultivation, the ideal effective depth is 20 cm, and the main factors that affect it are compaction, stones or rocks, water or salts, and high concentrations of certain chemical elements (Ayub *et al.*, 2020; Garbowski *et al.*, 2023).

In previous investigations on other crops and territories, they have found that, for example, in the Caribbean region, in the municipality of Majagual (locality 2) the use of the chisel plow significantly improved soil bulk density (ρa) and porosity (ϕ) compared to conventional tillage, resulting in a better yield and better profitability for rice cultivation. This implementation resulted in better conservation and internal drainage of the soil, greater moisture retention, and reduced preparation costs (Sánchez *et al.*, 1998). Likewise, in Villanueva, department of Casanare, the impact of three tillage systems on the corn crop was evaluated, for which reduced tillage with the use of the chisel decreased the ρa by 16% and the ϕ of the soil by 20% between samplings (before and after preparation). In addition, this treatment showed the most significant difference compared to direct seeding and conservation tillage (García *et al.*, 2018).

In the cotton-growing soils of Tolima, compared to conventional tillage, under deep tillage conditions, ρa decreases while the percentage of total ϕ, moisture storage, and air space increase in these soils with physical limitations. Therefore, to improve the physical characteristics of the soil, vertical tillage implements (chisels and shallow subsoiling up to 35 or 40 cm) were used to break up the soil at depth. It is recommended that when using chisels, in very settled soils, work should be started first superficially and then at greater depths; if this is not done, there is a risk of breaking the tractor or the implement (Amézquita Collazos, 1999). Similarly, a diagnosis conducted on soil compaction in the municipality of Campoalegre (Huila) showed that the average ρa of the 11,766.21-ha evaluated was classified as high, linking these issues to continuous machinery traffic and the improper use of implements (Gutiérrez-Marroquín, 2018; Perea & Cerquera, 1999).

The project aims to assess the impact of different conservationist mechanized schemes, like reduced tillage, on the soil at the Granja Experimental of the Universidad Surcolombiana (USCO) in El Juncal, Palermo (Huila), which shares characteristics with soils where previous studies showed good decompaction results using a chisel. Thus, it is understood that the objective of this research is aimed at establishing a tillage practice that contributes to or, at least, does not affect the optimal production conditions for rice, while representing an environmental benefit by reducing the long-term impact it has on the soil, promoting a crop with good economic performance, but more sustainable. On the other hand, the theoretical value of the project is centered on the knowledge of the relationship between tillage and soil properties, which is unknown for the region of the "Granja Experimental".

MATERIAL AND METHODS

Location and experimental design

The project was conducted at the Experimental Farm of the Surcolombiana University, located in the village of San Miguel in the municipality of Palermo (Latitude 2°53'32'' N and Longitude 75°18'24" W), 9 km from the city of Neiva (Huila). The Experimental Farm has 180,000 m2 designated for rice cultivation, of which 20,000 m2 were used for this study. This area was selected based on topography, zones of greatest impact, and the machine operator's recommendations to minimize headland turns. The experimental design was a simple factorial design in split plots, which were divided into equal parts for comparison between them, with the first factor being the type of tillage (treatments) and the second factor being the physical properties of the soil (ρa, ρ, ϕ). The limits were marked with flags and via satellite using a generic GPS (Global Positioning System) navigator, which allowed each of the treatments used to be georeferenced. The location and distribution can be seen in Figure 1.

The treatments were distributed in T1: One chisel pass, T2: Two perpendicular chisel passes, T3: Three crossed chisel passes, and T4: Control - Conventional plow, with three crossed harrow passes. The harrow used was 20 discs, and the vibratory chisel consisted of 5 bodies. Initially, the soil presented great resistance to penetration, which made it impossible to use the chisel at that time due to the risk of its fracture or damage to the tractor. This initial state of the soil, after nine months of rest, made it necessary to moisten the entire plot for prior loosening and a first harrowing pass, so all treatments were recorded in this way. A 122 hp tractor (8030, New Holland) was used for the preparation of the plots, with working depths of up to 35 cm for the vibratory chisel and no more than 20 cm for the disc plow (Dzhabborov *et al.*, 2021; Marchenko & Matvyeyeva, 2021; Wang *et al.*, 2023).

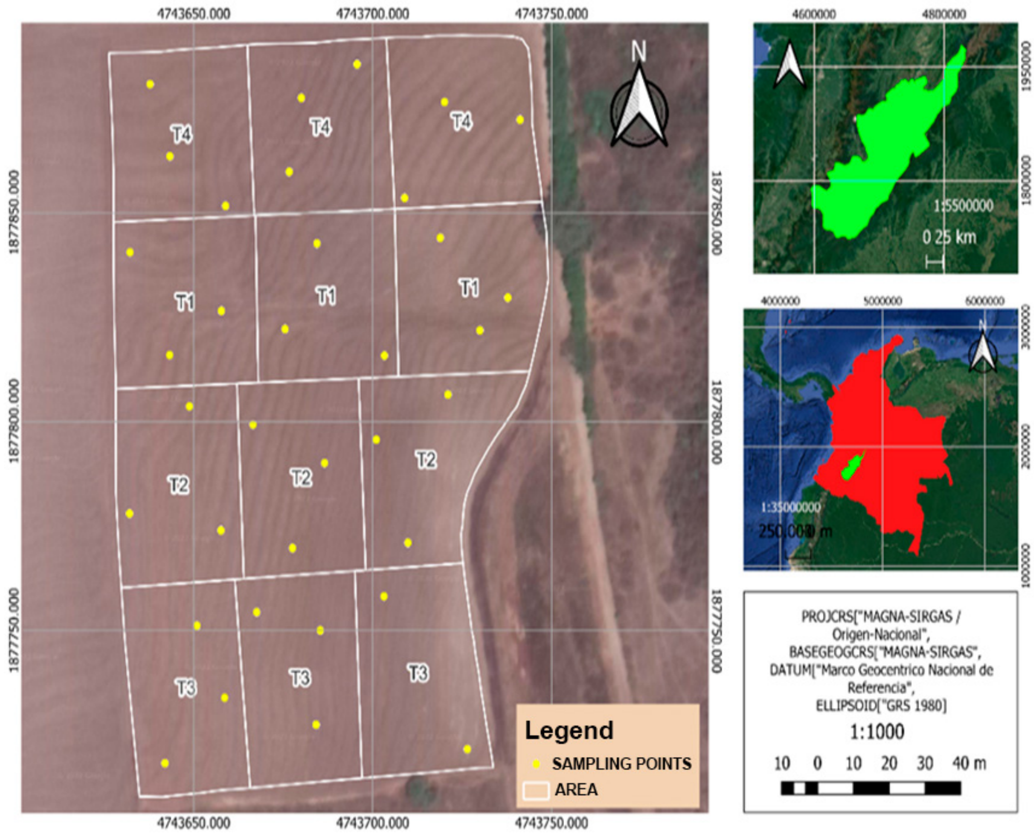

Figure 1. *Location of the work area.*

The sampling points were 9 per treatment (per plot) and 3 per subplot, established randomly using the conditional Latin hypercube (cHL) method (Carvalho-Junior *et al.*, 2014; Liu *et al.*, 2015; Puerres-Tipas *et al.*, 2021). To implement this method, the Geographic Information Program QGIS® was used, and the algorithm (cHL) was programmed using the RStudio® package. With QGIS®, a grid of points equidistant from 2 m was generated, while the algorithm programmed in RStudio® selected the random sites where to take the samples, avoiding the edge effect. Once the points were located, they were taken to the GPS to be later georeferenced and marked with flags in the field. The distribution of the sampling points is shown in Figure 1.

Characterization

The studied soil corresponds to the order Entisols, suborder Fluvents, and great group Ustifluvent with a sandy loam texture, which taxonomically classifies it as an Entic Ustifluvent (Rivera-Montilla & Cortes-Bernal, 2016). The physical properties of the soil were monitored before and after machining as well as after cultivation. Thus, three samples were taken per subplot in each monitoring, taking into account the recommendations of Karlen *et al.* (2019); Lehmann *et al.* (2020). A total of 36 samples were taken in each of the three monitoring periods. Each sample was taken between 15 and 20 cm deep using a shovel, taking between 0.5 and 1.0 kg of soil, and then transported in airtight bags to the Geoagro Environmental Resources Laboratory - LABGAA of the Universidad Surcolombiana. There, the samples were duly treated, dried, and processed, and the results were compiled to carry out the analysis and obtain the results of the properties.

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The true density (ρ) was measured using the pycnometer method, which expresses the ratio of dry soil mass per unit volume of soil (without voids), as shown in Equation 1.

$$\rho = \frac{(MPDS - MPV) * Dw}{(MPW - MPV) - (MPSW - MPDS)} \quad (1)$$

Where: ρ is the true density (g cm-3); MPDS is the mass of the pycnometer with dry soil (g); MPV is the mass of the pycnometer without voids (g); MPW is the mass of the pycnometer with water (g); MPSW is the mass of the pycnometer with soil and water (g); and Dw is the density of water (g cm -3).

The ρa was measured by the known cylinder method, which expresses the ratio of dry soil mass per unit of total volume (volume occupied by solids and voids), as indicated in Eq. (2).

$$\rho_a = \frac{MDS}{Vt} \quad (2)$$

Where: ρa is the bulk density (g cm-3); MDS is the mass of dry soil (g); and Vt is the total volume of the cylinder (cm3).

Soil ϕ is obtained by the ratio of ρ to ρa, according to Eq. (3) (Gutiérrez-Marroquín, 2018).

$$\phi = 1 - \frac{\rho_a}{\rho} \quad (3)$$

Where: is the porosity (Unitless).

Cultivation

After land preparation, the soil was prepared by micro-leveling with Landplane, and ridges were made with Taipa on contour lines to enable flood irrigation. The variety Fedearroz 2020 was sown using a fine-grain mechanical seeder (SSM-23, Semeato) on December 29, 2021, at a density of 0.015 kg m-2, equivalent to approximately 500 seeds m-2. The fertilization and pest control plan as recommended by the agronomist, was implemented uniformly across the entire experimental area. Four soil fertilizations were carried out. In the first application, 49.68 kg ha-1 of nitrogen (N) and 12.3 kg ha-1 of phosphate (P2O5) were applied. The second fertilization included 46.0 kg ha-1 of N, 12.4 kg ha-1 of P2O5, and 30.0 kg ha-1 of potassium (K). In the third application, 30.0 kg ha-1 of N, 46.0 kg ha-1 of P2O5, and 60.0 kg ha-1 of K were used. Finally, the fourth fertilization involved 56.5 kg ha-1 of N and 90.0 kg ha-1 of K. Two weed control treatments were also carried out before sowing, along with one panicle protection treatment during the maturation stage. Regarding crop growth monitoring, 50 × 50 cm gauges were installed near the sampling points, and a tape measure was used to measure the height from the soil to the apex of the central leaf; the same amount and height measurements were taken at the moments of maximum tillering, maximum lodging, and maturity; before harvest, the cutting and threshing of the spikelets were carried out when the grain had a moisture content of 26% to establish the yield parameter of mass production per unit area [kg m-2] (Scott-Suarez, 2022). Finally, the harvest was carried out on April 22, 2022, with a fine grain harvester (5650, Massey Ferguson).

Statistical analysis

The assumptions of normal distribution (Shapiro-Wilk test) and homoscedasticity (Levene's test) were first verified (Gutierrez & de la Vara, 2008); then, through Analysis of variance (ANOVA) was performed using the Fisher Least Significant Difference (LSD) method to identify and quantify significant differences in each of the analysis parameters, both within subplot and between plots (between treatments) using the Microsoft Office Excel® statistical package. Finally, for property mapping, the IDW Interpolation function of the QGIS® Geographic Information System was used with the characteristic data after the statistical analysis (Kaya-Altop *et al.*, 2019; Pattanayak *et al.*, 2022; Santiago-Arenas *et al.*, 2020).

RESULTS AND DISCUSSION

Evaluation of physical properties

When studying spatiotemporally the ρ of the soil, it was taken into account that the average value of the ρ of the soil is 2.65 g cm-3. High values would indicate high water retention that would produce waterlogging (Abdallah *et al.*, 2021; Kaur *et al.*, 2020; Manik *et al.*, 2019), and low values are associated with water losses due to increased infiltration (Cui *et al.*, 2019; He *et al.*, 2020; Ngo-Cong *et al.*, 2021). In the first sampling, it was shown that the soil had a high true density, which was homogeneous since no significant differences (p-value=0.08; F-value=3.12; F-critic=4.07) were found between the averages of the subplots of each treatment, the results can be seen in Table 1, which reports the average of each of the 12 subplots, summarizing a total of 108 data points established in the pycnometer sample (9 for each subplot) after excluding outliers and confirming the absence of significant variation.

Table 1. *True density in space and time*

gr cm^{-3} / Samplings	Treatments	Average	Standard deviation	Standard error	Coefficient variation (%)
S1	Control^{D}	2.708^{a}	0.019	0.011	0.023
S1	T1^{D}	2.739^{a}	0.051	0.029	0.170
S1	T2^{D}	2.693^{a}	0.054	0.031	0.192
S1	T3^{D}	2.756^{a}	0.002	0.005	0.008
S2	Control^{D}	2.728^{b}	0.013	0.020	0.118
S2	T1^{D}	2.729^{b}	0.127	0.075	1.404
S2	T2^{D}	2.708^{b}	0.019	0.011	0.024
S2	T3^{D}	2.732^{b}	0.078	0.045	0.406
S3	Control^{D}	2.786^{c}	0.024	0.014	0.029
S3	T1^{D}	2.793^{c}	0.085	0.049	0.360
S3	T2^{D}	2.750^{c}	0.119	0.069	0.943
S3	T3^{D}	2.748^{c}	0.019	0.011	0.006

Different uppercase letters denote significantly different means between samples. Different lowercase letters denote significantly different means between treatments. (p-value<0.05).

Since this property is a function of the soil's mineralogical composition, it was expected to remain more or less constant over time, regardless of treatment and use. Thus, it can be concluded that there is no spatial difference between treatments nor temporal difference as an effect of tillage and cultivation, indicating no significant change in soil composition. Small changes in space could be due to slight compositional changes from one site to another. Small changes in time, for the same site, may be associated with sampling problems and sample handling in transport or the laboratory.

In the case of ρa, this is linked to the soil texture and structure, predominantly sandy loam soil throughout the experimental area. This parameter indicates whether the soil is settled or not (Leonard *et al.*, 2019; Stošić *et al.*, 2020), A high ρa (>1.8 g cm-3) is not good, as it does not favor plant root development (Kalita *et al.*, 2020).

For the first sampling, the results reported in Table 2 show that the soil exhibited a high ρa, which inhibits plant growth. This condition was relatively homogeneous across the entire experimental plot, as all averages exceeded the recommended threshold value of 1.6 g cm-3 for the crop. As for homogeneity, the ANOVA does not show a significant difference (p-value=0.89; F-value=0.20; F-critic=4.07) between the measured values. The high densification value is related to the nine months during which the experimental area remained fallow. In general, there was evidence of the formation of weed cover whose rooting led to densification, decreasing aeration, and causing water retention or waterlogging due to poor drainage (low infiltration capacity) which at the USCO Experimental Farm has been caused by plough foot due to repetitive use of disc plough at the same depth, frequent tractor and farm equipment traffic, and the continuous cultivation of rice without rotation. This compacted layer acts as a barrier, restricting water movement and significantly reducing infiltration (Van Loon & Flores Rojas, 2022).

Table 2. *Bulk density in space and time*

[g cm^{-3}]		Average	Standard deviation	Standard error	Coefficient variation (%)
Samplings	Treatments				
S1^{D}	Control	1.897^{a}	0.020	0.012	0.027
S1^{D}	T1	1.862^{a}	0.011	0.006	0.009
S1^{D}	T2	1.796^{a}	0.023	0.013	0.036
S1^{D}	T3	1.866^{a}	0.022	0.013	0.032
S2^{E}	Control	1.641^{b}	0.024	0.014	0.038
S2^{D}	T1	1.736^{a}	0.043	0.025	0.121
S2^{D}	T2	1.769^{a}	0.025	0.014	0.040
S2^{E}	T3	1.651^{b}	0.027	0.016	0.931
S3^{D}	Control	1.844^{a}	0.025	0.014	0.042
S3^{D}	T1	1.893^{a}	0.021	0.012	0.030
S3^{D}	T2	1.920^{a}	0.030	0.017	0.061
S3^{D}	T3	1.808^{a}	0.030	0.017	0.060

Different uppercase letters denote significantly different means between samples. Different lowercase letters denote significantly different means between treatments. (p-value<0.05).

Table 2 and Figure 2 also show the results of the evaluation of the ρa in the second sampling, that is, after tillage with the different schemes, which showed a decrease in the ρa of the soil. This is possible up to the depth at which it was mechanized, in which, for the harrow, it was 20 cm and for the chisel, 30 – 35 cm (Ruiz *et al.*, 2001). The soil finally showed a lower ρa value in all treatments, which was predictable, although the decrease did not occur uniformly; in this case, it decreased 13.5% in the control, 6.8% in T1 with minimum tillage, 1.5% in T2, and 11.5% in T3. In the T3 and control areas, as they were subjected to greater tillage and their structures were exposed, less dense soils were observed; the opposite was the case for the T1 and T2 areas, where, curiously, a single chisel pass caused a greater decrease in density than the two perpendicular passes. In this opportunity, a significant spatial difference was demonstrated between the ρa of higher tillage and lower tillage (p-value=0.04; F-value=5.51; F-critic=5.14), but there was statistical similarity between T3 and the control, and between T1 and T2, respectively. In this way, a soil that was initially homogeneous in this property ended up showing differences by areas due to the effect of the treatments, which affects the subsequent results of the project when analyzing the impact of mechanized tillage.

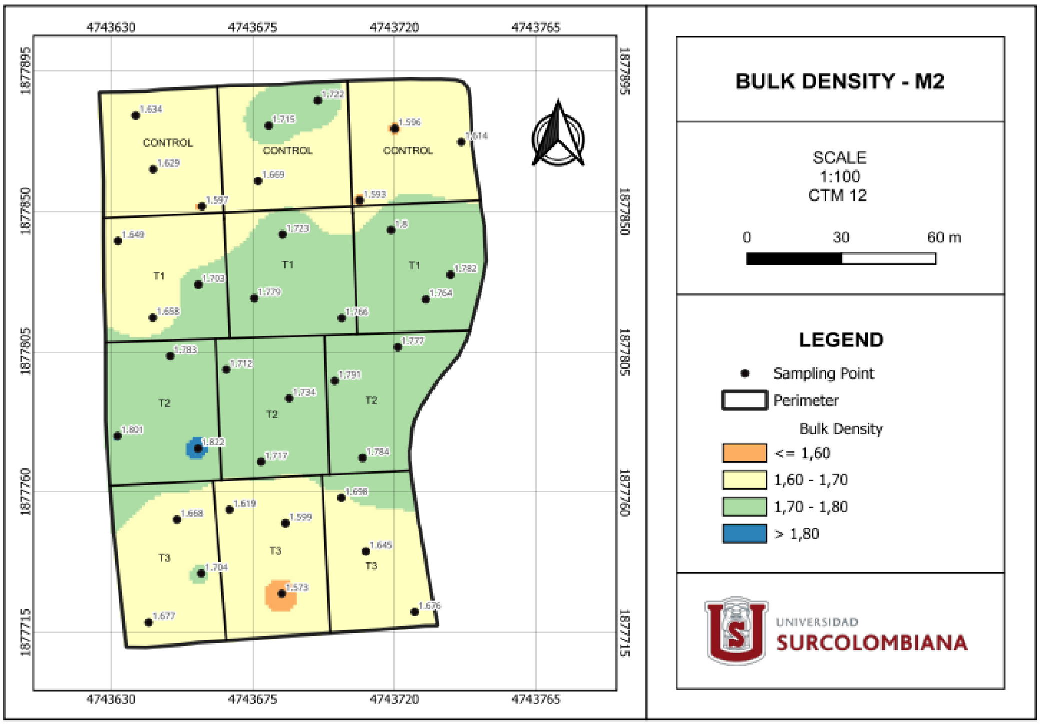

Figure 2. *Map of Bulk Density (ρa) in the Space Generated in QGIS - Sampling 2*

Figure 2 spatially demonstrate the significant similarity in two areas, with which the homogenization achieved by mechanization was further accentuated by dividing between treatments that could be called higher and lower tillage, note that the value of ρa remained high in almost all the experimental areas, and it is predicted that tillage will not lower it to a value suitable for the root development of the plants. Furthermore, in Table 2, all the average values exceed the threshold for root development, beyond which root growth inhibition is observed. This suggests that, even after tillage, the soil in the experimental plots could be considered dense.

In the third sampling, changes were obtained concerning the results of the second sampling. In the temporal analysis, denser soils were observed, evidencing a resilient recovery of the soil, for the control 12.4%, for T1 9.0%, T2 8.5%, and T3 9.5%, being quite equal increases caused by the resilience of the soil when recovering the natural state in which it was and by the crop. The latter cause may be linked to different parameters that may influence these behaviors since rooting generates greater densification in the soil (Bodner *et al.*, 2021; Burrall *et al.*, 2020; Hossne, 2004; Schneider *et al.*, 2017), which occurred throughout the study plot. Furthermore, the densification may have been caused by the passage

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of machinery during tilling operations (tractor) and harvest collection (harvester and tractor), as well as by the limited control over the measurement of irrigation and drainage volumes. Such situations contributed to the increase in ρa (Abich *et al.*, 2022; Blanco & Lal, 2023; Finster, 2021). Similarly, the increase in density observed due to the passage of machinery during harvest allows for the exclusion of the possibility that such densification was caused by the chisel passes.

Therefore, although the crop had the same effect throughout the experimental area, which could be associated with settlement due to time, its weight, the effect of water, soil resilience, and rooting of the crop, it resulted similarly in each treatment area.

In general terms, Table 3 shows an increase in soil ϕ as a result of mechanization. A significant temporal difference was observed between plots (p-value=0.02; F-value=13.1; F-critic=7.71), but spatially, there are no significant differences between samples 1 and 3 because, as mentioned earlier, in the second sampling, the plots were zoned into high and low tillage. To determine the ϕ, Equation 3 was used. In this context, a higher ϕ percentage is beneficial for the plant, as it promotes more efficient rooting and, in turn, optimizes water use (González-Barrios *et al.*, 2011).

Table 3. P*orosity in space and time*

[%]		Average	Standard deviation	Standard error	Coefficient variation (%)
Samplings	**Treatments**				
S1^{D}	Control	29.95^{a}	0.266	0.153	4.704
S1^{D}	T1	32.02^{a}	0.140	0.081	1.298
S1^{D}	T2	33.31^{a}	0.141	0.081	1.319
S1^{D}	T3	32.17^{a}	0.119	0.069	0.943
S2^{E}	Control	39.42^{b}	0.399	0.230	10.616
S2^{E}	T1	37.62^{b}	0.224	0.129	3.343
S2^{D}	T2	34.68^{a}	0.201	0.116	2.680
S2^{E}	T3	39.57^{b}	0.217	0.125	3.125
S3^{D}	Control	33.81^{a}	0.143	0.082	1.355
S3^{D}	T1	32.22^{a}	0.100	0.058	0.669
S3^{D}	T2	30.18^{a}	0.325	0.188	7.060
S3^{D}	T3	34.21^{a}	0.110	0.063	0.813

Different uppercase letters denote significantly different means between samples. Different lowercase letters denote significantly different means between treatments (p-value<0.05).

The property depends on the densities already presented, with the ρ being relatively constant and homogeneous. As a result, the ϕ varied according to the changes experienced by the ρa. In the first sampling, low results were obtained, between 30 and 33%, typical of a soil that is between compact and moderately porous (Gutiérrez- Marroquín, 2018), without demonstrable significant differences. For the first sampling, the experimental area showed higher ϕ in the central zone, and the machining process promoted an increase in ϕ in different sectors throughout the entire area. In the third sampling, the soil showed greater homogeneity.

In the second sampling, when compared to the first over time, it is observed that the zoning caused by the machining in the ρa had a similar effect on ϕ, but with an increase in all treatments, suggesting that the change was due to tillage. In the area of higher tillage, control increased by 31.6%, and in T3, it increased by 23.0%, while in the area of lower tillage, T1 increased by 17.5% and T2 only increased 4.1% in the percentage of pores, leading to convert the most tilled soil into a porous soil while the least tilled remained moderately porous. This can lead to this area having problems in storing moisture in the soil and poor runoff (Alam *et al*., 2020; Somasundaram *et al*. 2020; Wang *et al*., 2024).

In the third sampling, an equivalence in all data was obtained, but when it was compared with the second sampling, it shows a loss of porosity in all treatments. This phenomenon is caused by resilient recovery and by the crop, as ϕ is related to the land's drainage system. Rice, as a flood-irrigated crop with high water consumption, does not have runoff and is always waterlogged, which significantly affects the ϕ throughout the study area (Amin *et al*., 2021; Goulart *et al*., 2020; Jaramillo *et al*., 2020; Ellies *et al*., 1993). The decrease in porosity between the second and third samplings resulted in a decrease of 14.2% for the control, 14.4% for T1, 13.0% for T2, and 13.5% for T3, showing that the effect of crop, water, and time on the decrease in soil "n" was homogeneous, similar to the trend evidenced in the ρa.

Crop yield evaluation

It was observed that there was not a significant difference (*p*-value=0.06; F-value=3.63; F-critic=4.07) in the measurements of plant growth; therefore, the averages of each group of samples and those of each plot were taken to obtain a single characteristic data per treatment. Figure 3 shows that the crop presented a low height according to the opinion of Vergara-Cordero (2022) and Villalba *et al*. (2017). It shows the characteristic sigmoid curve where, for treatments T1, T2 and Control, despite being low, they were homogeneous over time, while throughout the growth phase, T3 presented a slightly higher growth; the growth was caused by being the initial inlet of the water supply, which, according to the texture of the soil (sandy loam), presents lower infiltration losses in transport (in the canal), and it allows them to increase as the distance between entries increases. Similarly, the irrigation time for each plot varied according to the distance covered from one inlet to another, with the time of water inlet and the distance covered being shorter in T3. On the other hand, Carrasco-Castañeda (2019) shows that, for unlined canals with sandy loam soils, infiltration losses can be up to 26% of the irrigation water used. Therefore, this estimate assumes that there is no impact of machining on crop growth.

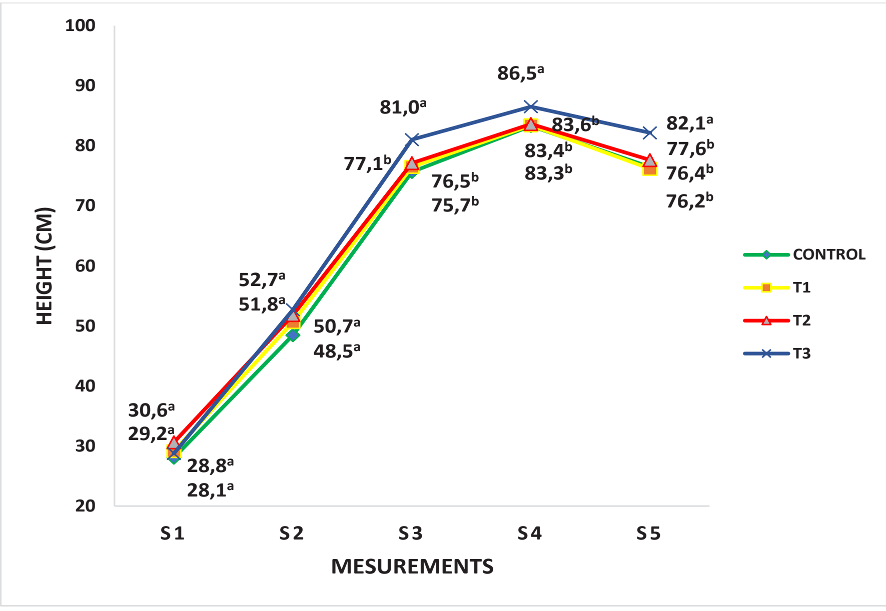

Figure 3. *Graph of growth at different stages of crop development*

Different letters denote significantly different means (*p*-value<0.05).

The yield was established in the last sampling, that of maturity at harvest, where the grains with 26% moisture were collected and weighed in each gauge. This weight is equivalent to an area of 0.25 m2, so this weight was easily extrapolated to the one that would produce a hectare under equal conditions. After the ANOVA, the projected yield of each treatment was established, so, according to the measurements, a yield of 7.8 t ha-1 was predicted for the Control, 8.2 t ha-1 for T1 and T2, and 8.4 t ha-1 for T3 (p-value=0.77; F-value=0.37; F-critic=2.9). This forecast did not take into account the unfilled spikelets or harvester losses, but it took into account natural losses that could not be harvested. Although some uniformity was predicted, the differences may be due to the topography of the study area, the form of irrigation used, and the lack of homogeneity in the application of fertilizers and pesticides (they were applied conventionally). On the other hand, the points where the gauges were located coincided in the medium- and high-yield areas.

This project did not show a substantial effect between the different increasingly less aggressive tillage strategies and the yield of the rice crop at the USCO Granja Experimental; however, it showed major growth in T3 compared to the other treatments in samplings 3 (*p*-value=0.02; F-value=3.18; F-critical=2.69) to 5 (p-value=0.01; F-value=3.98; F-critical=2.69).

Techno-economic analysis: The cost of land preparation is directly proportional to the number of tractors passes. As such, the control and T3 treatments were similar and duplicated in cost to T1; only that the bulk of the cost of production is concentrated in management: seeds and agro-inputs (fertilizers and pesticides), which represents about 65%, while the cost of preparation can be between 5 and 10%, which makes its incidence not significant either. The following costs corresponding to land preparation (USD 54.41 ha-1), inputs for weed control (USD 73.49 ha-1), sowing (USD 263.10 ha-1), fertilization (USD 365.45 ha-1), supplies for spike protection (USD 40.61 ha-1), irrigation water (USD 261.15 ha-1), and labor (USD 165.99 ha-1) were the same for all treatments. Sowing costs include planter time, labor, and certified seed, as it is contracted as a package. Irrigation water is contracted with the irrigation district and is charged per hectare per harvest to all users; Labor includes all contracted wages for fumigation and fertilization, and other crop maintenance tasks. While Table 4 presents the costs that do differ between treatments, note that the adequacy, for which micro-leveling and level contouring services are contracted, was included among the shared costs; the preparation differs because it is the treatment under study, while the harvest, which includes the cost of the harvesting machine with operator and the hiring of the dump truck for transport to the mill, differs because the projected productions were different (although the difference was not statistically significant).

Table 4. *Shared Costs*

Item	COST T1 (USD ha^{-1})	COST T2 (USD ha^{-1})	COST T3 (USD ha^{-1})	COST T4 (USD ha^{-1})
Preparation	21.76	43.53	65.29	65.29
Harvest	201.09	196.78	196.78	186.72
Total	222.85	240.30	262.07	252.01

Table 5 reports the economic income generated by each treatment and a profitability indicator calculated simply as the quotient between income and expenses. Finally, the fact that reduced tillage practices do not negatively affect production is appreciated since this fact shows the possibility of implementing less aggressive practices with the soil, which are ecologically more sustainable and do not affect the farmer's profitability.

Table 5. *Profitability of treatments*

	T1 (USD ha^{-1})	T2 (USD ha^{-1})	T3 (USD ha^{-1})	T4 (USD ha^{-1})
Income	$ 3,189.62	$ 3,121.29	$ 3,121.29	$ 2,961.81
Profitability	2.20	2.13	2.10	2.01

CONCLUSIONS

To maximize rice cultivation outcomes, it is essential to optimize soil preparation and proper irrigation management, as the latter can significantly impact the soil's physical properties. When evaluating these properties, it was found that the ρ remained constant characteristic of the soil because it depends on its composition, and that machining caused the greatest decrease in ρa in the control with 13.5% and in T3 with 11.5%, while T1 only decreased 6.8% and T2, curiously, only 1.5%. It was also demonstrated that machining increased ϕ in an equivalent form. The correlation could not be demonstrated between tillage strategies and rice cultivation; both crop growth and yield were homogeneous throughout the experimental area, and small differences showed that irrigation with a single inlet caused more water availability in treatment T3 and that it took longer and arrived in smaller quantities in treatment T4 (Control). There is no evidence that reduced tillage negatively affects production. Therefore, its implementation is recommended, considering that there will be no effect on the profitability of the projects, but there will be less effect on the soil structure, making it a conservationist practice that is more sustainable in the future. Excessive use of the chisel may lead to reduced water retention, particularly in sandy subsoils, potentially affecting both water efficiency, farmer economics. The depth of use should be calibrated, and infiltration should be measured using a double-ring infiltrometer.

ACKNOWLEDGMENTS

We thank the Surcolombiana University for allowing this project to be carried out at its Experimental Farm, which is coordinated by Eng. Lina Meza and her technical and administrative staff, as well as the soil laboratory (LABGAA), directed by the MSc. Diana Polanía, to the coordinator of the Agricultural Machinery Laboratory, MSc. Juan Ardila, and especially Engineer Juan Carlos Zuleta Saavedra, for his support in obtaining sampling data, LABGAA tests, and statistical analysis of the data.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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