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Tillage Systems Modify the Soil Properties and Cassava Physiology During Drought

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Abstract: Soils are highly sensitive to the type of tillage practices used, as these practices influence soil properties and affect crops, the environment, and society. However, research on cassava production under different tillage systems during drought conditions in the Peruvian Amazon has not been reported. The objective of this study was to compare soil properties, cassava physiology, and yield under conservation agriculture (CA) and traditional agriculture (TA) practices, with and without mulch, in a water-scarce environment. Soil moisture, earthworm population (Ew), stomatal conductance, leaf area index, and commercial yield under CA were 5.26% (~105.2 m^3 ha^{-1}), 83%, 1.2 times, 1.14 times, and 7.3 t ha^{-1}, respectively, higher than under TA. Hydraulic conductivity (Ks) in TA was 2.1 times higher than that in CA. However, Ks, bulk density, and Ew over time showed a gradual recovery under CA. The mulch factor only affected Ew, which was higher without mulch than with mulch. The results indicate that CA practices were superior to TA practices, improving soil properties, cassava physiology, and yield, and, therefore, offer significant benefits in resource conservation and higher production and profitability in a drought-prone environment.

Keywords: tillage systems; conservation agriculture; traditional agriculture; mulch; hydraulic conductivity; stomatal conductance; cassava yield

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Citation: Ocaña-Reyes, J.A.; Paredes-Espinosa, R.; Quispe-Tomas, A.; Díaz-Chuquizuta, H.; Ore-Aquino, Z.L.; Agurto-Piñarreta, A.I.; Monge, W.M.P.; Lobato-Galvez, R.H.; Reyes, J.G.R.; Zavala-Solórzano, J.W.; et al. Tillage Systems Modify the Soil Properties and Cassava Physiology During Drought. *Agronomy* **2024**, *14*, 3041. https://doi.org/10.3390/agronomy14123041

Received: 1 October 2024
Revised: 28 October 2024
Accepted: 3 November 2024
Published: 20 December 2024

1. Introduction

Crop production under a sustainable agriculture system is imperative for conserving the environment, preserving biodiversity, and producing quality crops [1–3]. However, most crop production, including cassava, is carried out under TA practices, which mainly involve intensive tillage for soil preparation [4–7]. These practices are detrimental to the environment due to their negative effects on soil properties [8,9], reducing soil water storage [10–12], directly affecting crop physiological processes through water stress [13], and ultimately leading to soil erosion and decreased crop yields [5,7,14].

As a suitable alternative for conserving natural resources, conservation agriculture has emerged [6,15–17], based on its principles of minimal soil disturbance, maintaining organic cover on the soil, and crop rotation [8,18]. In further studies, specifically in cassava production, mulch was associated with improved soil structure and increased nutrient availability [5,19,20], leading to higher yields [5]. Studies comparing soil properties under CA and TA have shown that soil erosion significantly decreases under CA practices [5,8,21], while soil moisture [10,11,21] and stomatal conductance [22] are higher. Ew was much higher compared to TA [21], and crop yields [16], including cassava, were higher under CA than under TA [4]. In other studies, cassava yield showed no significant difference between TA and CA [5]. However, there are studies indicating that cassava yields are higher in TA soils [5] compared to CA [19,20] due to the presence and absence of soil cover/mulch, respectively, because they affect soil moisture, drainage, and oxygenation. The benefits of CA are attributed to the gradual increase in soil carbon and improvement in soil structure; increased biological activity; greater aggregation, aeration, and infiltration; and reduced erosion and nutrient loss compared to TA. CA improves the soil's physical, chemical, and biological properties compared to TA. Therefore, CA is regarded as one of the agricultural systems that can favorably contribute to an improvement in soil properties as well as provide techniques for mitigating and adapting to climate change [8,23]. Consequently, the area under CA worldwide is increasing by 10 million hectares per year, with the largest areas in Central and South America [24]. In Peru, cassava production and exports increased by 10.2% and 6.9%, respectively, from 2022 to 2023 [25]. However, the national yield remains at 12.3 t ha^{-1}, less than half of the average yield observed in Asia [26]. These findings highlight an urgent need for improved production techniques. Addressing this information gap, the present study provides a valuable contribution toward enhancing cassava cultivation practices.

However, under the edaphoclimatic conditions of the Peruvian Amazon, characterized by acidic, kaolinitic clay soils, temperatures above 25 °C, and annual precipitation of 1916 mm [27], research on cassava production under CA practices remains limited. Key CA practices, such as organic mulching and no-tillage, are largely unknown and underexplored in cassava cultivation, revealing a knowledge gap on their potential impact on productivity and sustainability in this setting. In this context, setting up a field experiment was important to investigate the dynamics of soil properties and cassava yield under the two tillage systems. The hypothesis was that, by continuing to apply the principles of CA, some soil properties, cassava yield, and physiology might improve or remain similar to those under TA. The main objective was to evaluate the soil property dynamics, cassava yield, and physiology under CA and TA after the rotation of *Desmodium* sp. grass and forage corn.

2. Materials and Methods

2.1. Location

The experimental plot was located in the Campoverde Annex of INIA Pucallpa in the Campoverde district, Coronel Portillo province, and Ucayali department, at 8°32′31.05″ S, 74°52′41.58″ W, at 196 m.a.s.l. The lowest and highest temperatures were 25.41 and 32.3 °C, recorded in June and October, respectively; evaporation ranged from 7.47 to 11.64 mm, indicating a water shortage from June to November (Figure 1). Data were collected from the automated weather station (Vantage Pro2 Plus 6163, Davis, CA, USA) located in the same annex during the cassava phenological development. The landscape of the experimental plot was flat and was classified as Typic Dystrudepts in the soil taxonomy [27]. The soil had a loamy texture with 55, 20, and 25% of sand, silt, and clay, respectively; non-saline electrical conductivity (1.7 dS m^{-1}); strongly acidic $pH_{(1:1.25)}$ of 5.0; medium levels of organic matter (2.2%) and phosphorus (Bray) at 6.1 ppm; low potassium (0.17 $cmol^{(+)}$ kg^{-1}) and cation exchange capacity (4.2 $cmol^{(+)}$ kg^{-1}); and very high aluminum content (56%).

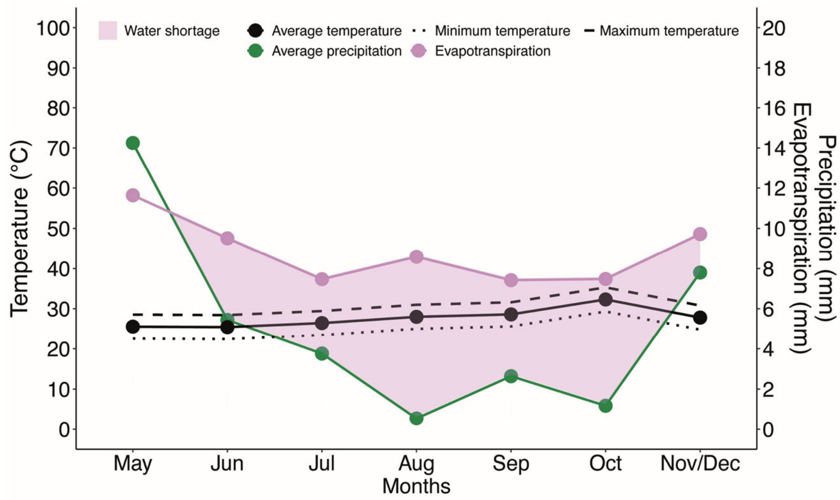


Figure 1. Monthly averages of temperature, precipitation, evapotranspiration, and water shortage during the cassava phenology cycle for the year 2023.

2.2. Experimental Design and Treatments

Considering two study factors, tillage system and mulch, a split-plot design was used. The main plots were assigned to the tillage systems, TA and CA. The subplots were assigned to the mulch factor, with mulch (WM) and without mulch (WOM), resulting in four treatments, each replicated three times, forming a total of 12 experimental units, each measuring 10 × 4 m.

2.3. Management of the Experimental Plot

The experiment began on 6 October 2022 with the cutting of a cover crop of *Desmodium* sp. that had been established for seven years. A desmodium mulch of 0.24 ± 0.06 kg m^{-2} was left on the soil surface for the experimental units under the CA treatment, while it was removed for the TA treatment. After that, corn was sown, and at the end of the harvest, a corn mulch of 1.59 ± 0.11 kg m^{-2} of oven-dried material (65 °C for 72 h) was left for the CA treatments, while it was removed for the TA treatments. The Señorita Cassava variety was subsequently planted on 4 May 2023, using 30 cm stakes with three buds. These were planted without tilling the soil, maintaining the previous cover crop residues on the soil for the CA treatment. For the TA treatment, the soil was tilled, and the previous cover crop residues were removed. Planting was performed at 0.8 m between plants and rows, resulting in a potential density of 15,625 plants per hectare. The fertilization was performed at plant emergence (14 days after the sowing), and the dose for cassava was 80 N–40 P_2O_5–70 K_2O, whose sources were urea, rock phosphate, and potassium chloride, respectively. Urea was applied in two equal parts, with the second application performed 25 days after the first. Cassava gall (*Latrophobia brasiliensis*) was controlled with cypermethrin applied at 0.2% at 15 days after cassava emergence. There was an abundant fall of mature cassava leaves before 143 days, leaving a dry oven residue of 0.06 ± 0.002 kg m^{-2} across the entire experimental plot. Sampling and determination of the evaluated variables were carried out according to an established methodology and schedule. The harvest was performed on 12 December 2023.

2.4. Evaluated Variables

2.4.1. Soil Physical Variables

Hydraulic Conductivity (Ks)

Ks was determined 143 days after sowing (das). All plant or foreign residues were removed from the sample surface. A metal ring, 15 cm high and 15 cm in diameter, was inserted 1 cm deep into the soil. The sequence of water volume application and Ks calculation followed the methodology of Alvaro and Fuentes et al. [28].

Soil Moisture (M°) and Bulk Density (Bd)

The M° and Bd were determined at 143 das and 248 days after sowing (at the time of cassava harvest), respectively. These two variables were measured using the cylinder method [29] and were sampled at two soil depths: 0–10 cm and 10–20 cm. The extracted soil had 100 cm^3, and the fresh and dry soil weights (fsw and dsw, respectively) were recorded by drying in an oven at 105 °C for 48 h. The soil gravimetric moisture (M°) was then determined using the following formulas:

$$\mathrm{M}^{\circ}(\%) = \frac{(fsw - dsw)}{dsw} \times 100\% \quad (1)$$

$$Bd(\mathrm{g\ cm})^{-3} = \frac{dsw}{total\ volume} \quad (2)$$

2.4.2. Soil Biological Variables

Earthworm Population (Ew)

The earthworm population was sampled at 143 das. After removing the plant residues from the soil surface, a soil monolith in the shape of a parallelepiped (25 cm base and 10 cm depth) was extracted. The monolith was broken down on a white plastic sheet; the earthworms were counted, multiplied by 16, and then returned to the soil to estimate the number of earthworms per square meter [30].

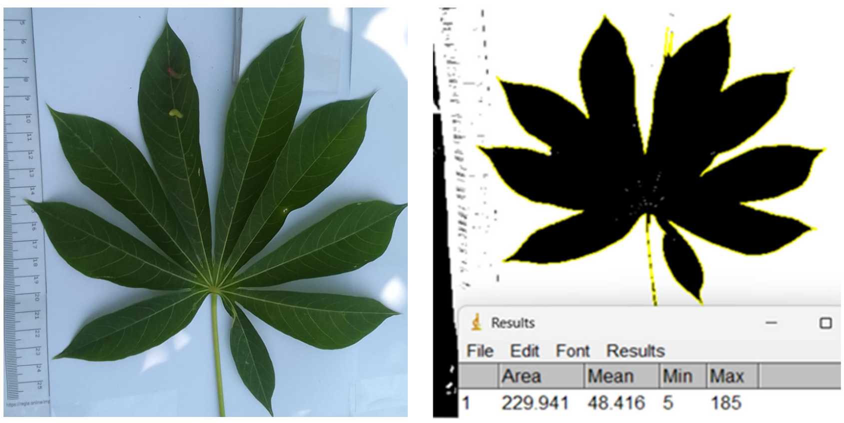
2.4.3. Physiological and Biometric Variables of the Cassava Plant

Stomatal Conductance (Gs)

The Gs was measured in each experimental unit at 11 a.m. at 143 das using a portable leaf porometer (METER SC1 Leaf Porometer, METER, Pullman, Washington, DC, USA). Young, fully expanded leaves were sampled. The average Gs for three plants from each experimental unit was recorded, and each average was calculated from three Gs measurements taken on a single leaf at the upper, middle, and lower parts [22].

Leaf Area Index (LAI)

The LAI was determined from 62 to 184 das, with a 15-day average interval. The leaves of a representative plant from each experimental unit were photographed against a white sheet with a printed ruler (Figure 2). Using ImageJ software (Version 1.54., National Institute of Mental Health, Bethesda, MD, USA), these photographs were processed to determine the plant leaf area (cm^2), which was then converted to LAI considering the relationship between the plant's population and the soil area occupied.



(**a**) (**b**)

Figure 2. LAI processing: (**a**) Photo of a cassava leaf on a white sheet; (**b**) Leaf area determined using ImageJ software.

Cassava Yield

To determine the commercial yield (CY) and non-commercial yield (NCY) of cassava, a central plot from each experimental unit was harvested, corresponding to 5 m in length from three sowing rows (15 m^2). The tubers were cut from the main stem and weighed on a digital analytical balance (Ruishan, Shandong, China) within the same experimental plot.

2.5. Statistical Analysis

The data collected from the variables were subjected to outlier detection and removal. Normality was verified using the Shapiro–Wilk test, and the data were processed through variance analysis (ANOVA), considering a split-plot design with randomized blocks. Averages were compared using the Di Rienzo, Guzman, and Cassanoves (DGC) test with a significance level of 5%. Additionally, Pearson correlation analysis was applied to the studied variables. The statistical analysis was performed using RStudio software (Version 1.3.1).

3. Results

The results of the variables obtained during the cassava phenological cycle are summarized in Table 1, showing the mean ± standard error.

Table 1. Values of soil properties, physiology, and yield of cassava under the tillage system and mulch treatments.

Factors	Ks × 10^{-3} mm s^{-1}	M° $_{0–10\ cm}$ %	M° $_{10–20\ cm}$	Bd $_{0–10\ cm}$ g cm^{-3}	Bd $_{10–20\ cm}$	Ew $_{0–10\ cm}$ counts m^{-2}	Gs mmol m^{-2} s^{-1}	LAI	CY t ha^{-1}	NCY
Tillage systems (TS)										
CA	12.04 ± 0.0001 B	17.78 ± 0.52 A	17.23 ± 1.02 A	1.50 ± 0.03 A	1.51 ± 0.01 A	366.67 ± 10.54 A	0.212 ± 0.005 A	4.49 ± 0.05 A	32.62 ± 2.02 A	4.22 ± 0.26 A
TA	25.92 ± 0.0006 A	12.52 ± 0.64 B	15.98 ± 0.46 A	1.51 ± 0.03 A	1.50 ± 0.02 A	200.00 ± 9.13 B	0.178 ± 0.003 B	3.93 ± 0.05 B	25.32 ± 1.81 B	3.27 ± 0.23 B
Mulch (M)										
WM	19.08 ± 0.0005 A	15.52 ± 1.42 A	17.57 ± 0.82 A	1.48 ± 0.03 A	1.49 ± 0.01 A	266.67 ± 38.01 B	0.193 ± 0.010 A	4.18 ± 0.14 A	27.17 ± 2.59 A	3.50 ± 0.22 A
WOM	18.88 ± 0.0005 A	14.77 ± 1.16 A	15.65 ± 0.61 A	1.53 ± 0.03 A	1.52 ± 0.02 A	300.00 ± 37.64 A	0.197 ± 0.008 A	4.18 ± 0.14 A	30.78 ± 2.16 A	3.98 ± 0.28 A
TS × M										
CA × WM	11.81 ± 0.0004 B	18.47 ± 0.66 A	18.63 ± 1.33 A	1.51 ± 0.05 A	1.50 ± 0.02 A	350.00 ± 14.43 A	0.213 ± 0.007 A	4.48 ± 0.09 A	30.42 ± 3.42 A	3.93 ± 0.45 A
CA × WOM	12.27 ± 0.0001 B	17.10 ± 0.70 A	15.83 ± 1.22 A	1.50 ± 0.04 A	1.52 ± 0.02 A	383.33 ± 8.33 A	0.210 ± 0.010 A	4.50 ± 0.08 A	34.82 ± 1.95 A	4.50 ± 0.25 A
TA × WM	26.26 ± 0.0002 A	12.60 ± 1.12 B	16.50 ± 0.66 A	1.45 ± 0.03 A	1.49 ± 0.01 A	183.33 ± 8.33 B	0.173 ± 0.003 B	3.89 ± 0.06 B	23.90 ± 3.35 A	3.07 ± 0.41 A
TA × WOM	25.48 ± 0.0013 A	12.42 ± 0.91 B	15.47 ± 0.59 A	1.56 ± 0.03 A	1.52 ± 0.04 A	216.67 ± 8.33 B	0.183 ± 0.003 B	3.97 ± 0.07 B	26.73 ± 1.77 A	3.47 ± 0.24 A

CA: conservation agriculture; TA: traditional agriculture; Ks: hydraulic conductivity; M°: soil moisture; Bd: bulk density; Ew: earthworm population; Gs: stomatal conductance; LAI: leaf area index; CY: cassava commercial yield; NCY: cassava non-commercial yield; WM: with mulch; WOM: without mulch; A–B: different capital letters in a column indicate significant differences among TS, M, and TS × M, according to the DGC test with $p < 0.05$.

3.1. Soil Physical Variables

3.1.1. Hydraulic Conductivity (Ks)

In 2023, the tillage system factor showed a statistically significant difference in Ks ($p < 0.05$), with the TA practices reporting 13.88 × 10^{-3} mm s^{-1} more than the CA practices. This was similar to the results from 2022 (Figure 3). The mulch factor did not show a statistically significant difference between mulched and non-mulched conditions for Ks ($p > 0.05$). Meanwhile, the interaction between the two factors, tillage system × mulch, showed a significant difference ($p < 0.05$), with the mulch × TA interactions resulting in more than double the Ks compared to the mulch × CA interactions (Table 1).

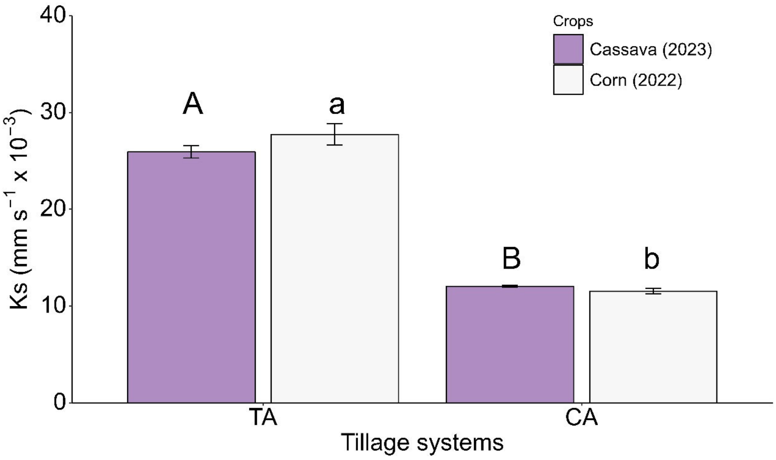


Figure 3. Hydraulic conductivity values over time under conservation and traditional agriculture. Ks: hydraulic conductivity; TA: traditional agriculture; CA: conservation agriculture; A–B/a–b: different capital (comparison of Ks in 2022) and small (comparison of Ks in 2023) letters in bars indicate significant differences among the tillage systems according to Student's *t*-test with $p < 0.05$.

3.1.2. Soil Moisture (M°)

In the CA and TA treatments, M° showed a statistically significant difference only at the first soil depth (0–10 cm) under the effect of the tillage system ($p < 0.05$). M° in the CA treatment at the 0–10 cm soil depth was 5.26% higher than that in TA (Table 1). This M° variable did not show a statistically significant difference with or without mulch in either soil layer ($p > 0.05$). Meanwhile, the interactions between the two factors showed statistically significant differences in M° only at the 0–10 cm soil depth ($p < 0.05$). The CA × mulch and CA × no mulch interactions had 5.87% and 4.68% higher M°, respectively, compared to the TA × mulch and TA × no mulch interactions (Table 1).

3.1.3. Bulk Density (Bd)

In 2023, bulk density (Bd) at two soil depths, 0–10 cm and 10–20 cm, did not show a statistically significant difference under the factors of tillage systems, mulch, or their interactions ($p > 0.05$) (Table 1). However, over the application period of the CA and TA practices, at the 0–10 cm depth, Bd in CA decreased significantly ($p < 0.05$), whereas TA did not show a significant difference but increased slightly (Figure 4).

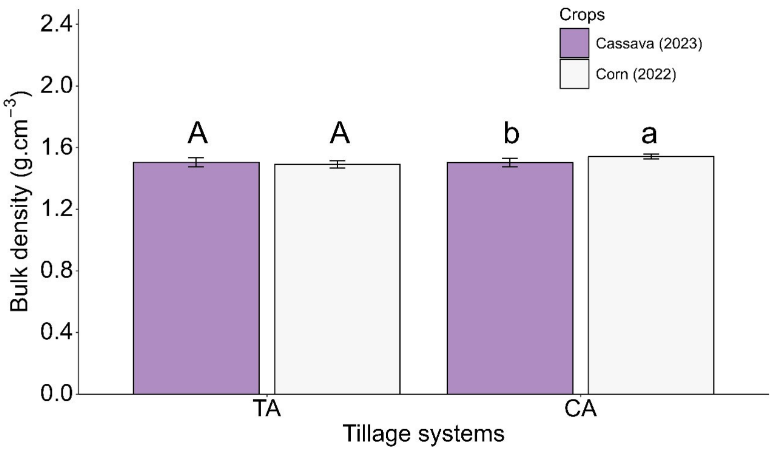


Figure 4. Bulk density (0–10 cm) over time under conservation and traditional agriculture. Bd: bulk density; TA: traditional agriculture; CA: conservation agriculture; A/a–b: different capital and small letters in bars indicate significant differences within a tillage system over the years according to Student's *t*-test with $p < 0.05$.

3.2. Soil Biological Variables

Earthworm Population (Ew)

The tillage system factor, mulch, and the interaction between these two factors showed statistically significant differences in Ew at a depth of 0–10 cm ($p < 0.05$) during cassava production (Table 1).

CA practices reported 166.67 earthworms m^{-2} more than TA. The treatment without mulch reported 33.33 earthworms m^{-2} more than the mulch treatment. The tillage system factor significantly affected the interactions, with the CA × WM and CA × WOM interactions showing 167 more earthworms m^{-2} than TA × WM and TA × WOM, respectively (Table 1).

In the second soil layer, at a depth of 10–20 cm, earthworms were not found over the years. Additionally, Ew in both CA and TA increased notably from 2022 to 2023, with 123 and 190 more earthworms m^{-2}, respectively (Figure 5).

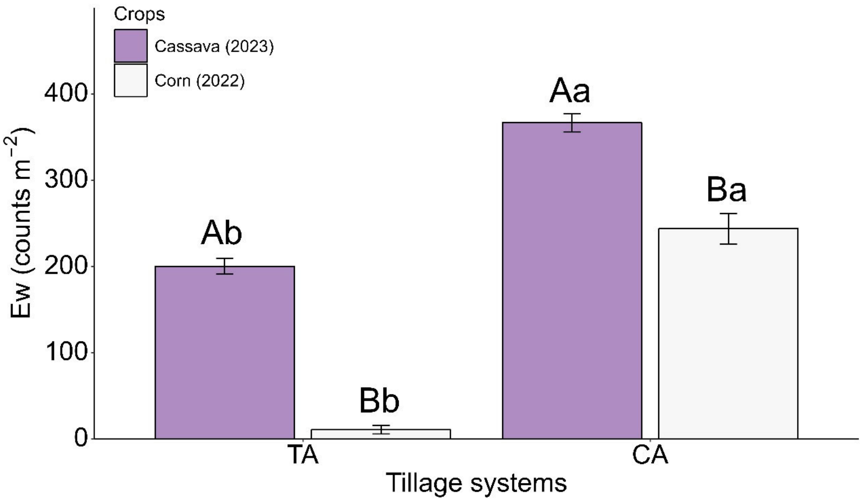


Figure 5. Earthworm population (0–10 cm) over time under conservation and traditional agriculture. Ew: earthworm population; TA: traditional agriculture; CA: conservation agriculture; A–B/a–b: different capital and small letters in bars indicate significant differences within a tillage system and between the tillage systems in the same year, respectively, according to Student's *t*-test with $p < 0.05$.

3.3. Plant Variables

3.3.1. Stomatal Conductance (Gs)

Gs showed a statistically significant difference only under the tillage system factor and in the interaction between tillage system and mulch ($p < 0.05$) (Table 1).

The CA treatment showed 0.034 mmol m^2 s^{-1} more than TA, which affected the interactions, with CA × WM and CA × WOM being higher by 0.04 and 0.027 mmol m^2 s^{-1} compared to TA × WM and TA × WOM, respectively.

3.3.2. Leaf Area Index (LAI)

LAI increased substantially during the root system formation and during part of the tuber bulking stage up to 127 days after sowing (das), showing the maximum LAI (Figure 6). Throughout the cassava plant growth, LAI up to 127 das did not show a statistically significant difference between TA and CA practices ($p > 0.05$) (Figure 6). From 143 to 184 das, LAI in both tillage systems decreased slightly. At this stage, cassava plants in CA and TA showed significant differences, with LAI values of 4.49 ± 0.05 and 3.93 ± 0.05, respectively ($p < 0.05$). This was reflected in the CA × WM and CA × WOM interactions, which were significantly higher than TA × WM and TA × WOM, respectively. Meanwhile, the mulch factor did not show statistically significant differences in LAI ($p > 0.05$) (Table 1).

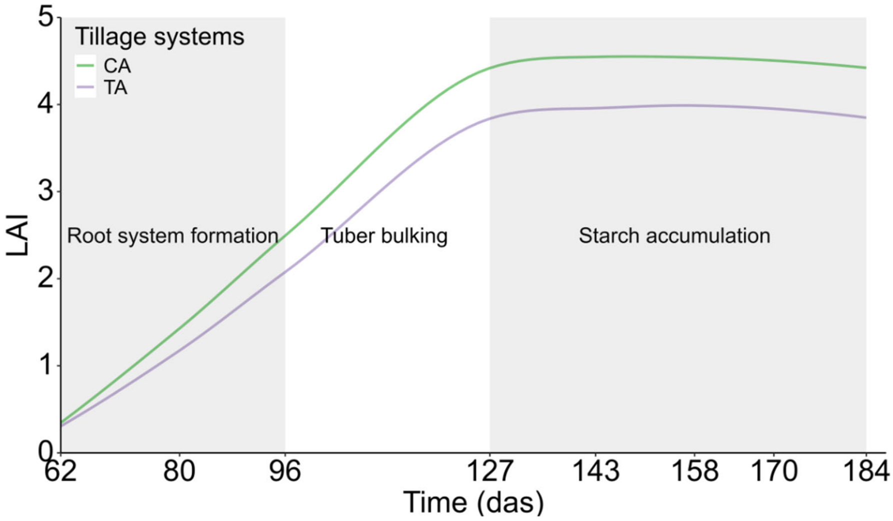


Figure 6. Leaf area index (LAI) during the cassava phenological cycle under conservation and traditional agriculture. das: days after sowing; TA: traditional agriculture; CA: conservation agriculture.

3.3.3. Cassava Yield

Commercial and non-commercial cassava yields under the tillage system factor showed statistically significant differences ($p < 0.05$). The mulch factor and the interaction between tillage system and mulch did not show statistically significant differences in either type of cassava yield ($p > 0.05$). The cassava commercial yield under CA was 7.3 t ha^{-1} higher than that under TA, and the non-commercial cassava yield was 0.95 t ha^{-1} higher than that under TA (Table 1).

4. Discussion

4.1. Soil Physical Variables

4.1.1. Hydraulic Conductivity (Ks)

Over time, the results indicated that the Ks (Figure 3) was higher under TA practices compared to CA ($p < 0.05$); the former was moderately rapid, and the latter was moderate, respectively, according to Alvaro-Fuentes et al. [28]. Comparative studies of soil properties between CA and TA reported similar results [4,31]. This was due to the immediate effect of tillage in TA [32,33] and because macropores could be larger because of an increase in the number of pores [34]. However, other studies found that Ks in CA soils was up to 3, 1.5, and 1.8 times higher than Ks in TA, according to Alletto et al., Mloza-Banda et al., and Nebo et al. [11,35,36], respectively.

In line with this, our study observed a slight quantitative increase in Ks over the years with CA practices (Figure 3), attributed to the dead cover of *Desmodium* sp. and maize, which served as a source of cellular carbon (carbon in earthworms and other microorganisms). Furthermore, these residues, after being transformed into humus, likely contributed to particle aggregation and, thus, increased porosity and facilitated water movement. Similarly, some soil properties under CA improved within a few years of applying CA principles [37,38]. For instance, the ratio of water content to field capacity relative to total porosity was higher than 0.6, and soil organic carbon was 69% higher than that under TA [11].

4.1.2. Soil Moisture (M°)

Due to the combined agricultural practices of CA, such as the absence of tillage and the maintenance of organic cover on the soil, soil water evaporation decreased, leading to increased soil moisture [32,39–41]. This was consistent with the higher moisture content in CA compared to TA, which was more than 5.26% (Table 1), equivalent to 105.2 m^3 ha^{-1}. This additional moisture could help mitigate water stress in cassava plants during extended dry periods. A similar result was observed in the years preceding cassava planting. In line with this, similar studies showed an 8% higher soil moisture under CA practices compared to TA [11,36,38]. However, other studies found that soil moisture in TA was 3–4% higher than that in CA [35]. These variations in soil moisture under CA or TA are explained by differences in soil texture, climate, and agricultural practices employed [35,40,42].

4.1.3. Bulk Density (Bd)

In the evaluation of Bd under CA and TA, over the years, the results indicate that the Bd at depths 0–10 cm and 10–20 cm under CA showed improvement through a significant decrease ($p < 0.05$), while Bd under TA increased quantitatively, becoming denser in the topsoil layer (Figure 4). However, despite the improvement under CA and the deterioration under TA, neither represented an ideal or restrictive Bd, respectively, for root development according to its loamy clay sand textural class [28].

In this study, the decrease in Bd under CA was attributed to the decomposition of the fibrous roots of *Desmodium* sp. and forage maize (previous crops) and to the formation of soil galleries by earthworms, influenced by their increasing population, which could enhance soil volume and create macropores [36,43]. Similar results were reported during the few years of transition from TA to CA by Mloza-Banda et al. [11], where Bd under CA was lower than that under TA, at 1.34 and 1.51 g cm^{-3}, respectively. However, other studies comparing soil properties between CA and TA found that Bd in CA soils was higher than that in TA soils [35,44]. Additionally, some studies found no significant difference in Bd between the two tillage systems [7,45].

4.2. Soil Biological Variables

Earthworm Population (Ew)

The results of this study indicate that, during cassava production, applying the principles of CA and TA increased Ew (Table 1) due to the absence of tillage and the presence of organic cover in CA. Unexpectedly, however, the adult cassava leaves fell, providing cover in TA, which increased Ew.

Additionally, in this study, the Ew under CA increased significantly over time, considering the constant supply of organic cover on the soil. In contrast, TA showed a sparse Ew during the 2022 sowing season (Figure 5). Consistent with this, similar studies reported that Ew increased by 2, 3.22, and 3.81 times than in TA, according to Mcinga et al., Castellanos et al., and Dulaurent et al. [45–47], respectively. The increase in earthworms under CA is likely due to the absence of tillage and the maintenance of organic cover on the soil, which prevent physical damage to the earthworms, maintain an adequate microclimate, and provide food availability for them [21,32,45–47].

However, over time, the absence of earthworms in the second soil layer (10–20 cm), which is clayey, was due to the soil's heavy, clayey, and acidic nature. Earthworms require significant energy to move through soil with high resistance to penetration [48], poor aeration, and drainage, all of which restrict nutrient availability and earthworm activity [48,49].

Moreover, the correlations between Ew and LAI, CY, Gs, $H°_{0\text{–}10\ cm}$, and Ks were high, at r = 0.90, 0.71, 0.80, 0.86, and −0.97, respectively (Figure 7). The increase in cassava biometric parameters and yield could be explained by the fact that earthworms enhance nutrient availability and produce growth-promoting metabolites [46,47], contributing to a 6.5% increase in crop production [50]. Adequate soil moisture, 11–21% [51], is essential for earthworm survival, which is why there was a high correlation between these two variables in the upper soil layers, whereas in the second soil layer, the correlation decreased. The correlation between earthworms and Ks was highly negative, likely due to the clayey texture of the second soil layer, which impeded proper Ks.

Figure 7. Pearson's correlation coefficient matrix of the hydraulic conductivity (Ks), soil moisture ($M°_{0–10,\ 10–20\ cm}$), bulk density ($Bd_{0–10,\ 10–20\ cm}$), earthworm population (Ew), stomatal conductance (Gs), leaf area index (LAI), cassava commercial yield (CY), and cassava non-commercial yield (NCY).

4.3. Physiological and Biometric Variables of the Cassava Plant

4.3.1. Stomatal Conductance (Gs)

The results for Gs were consistent with those of different cassava germplasms [52,53]. However, in a study where CO_2 concentrations were altered, the Gs of cassava increased, ranging from 0.52 to 0.61 mmol m^{-2} s^{-1} [54].

Gs is regulated by stomatal opening [55], which is directly and strongly related to soil moisture [56–58]. Consistently, in this study, the Gs of cassava in the CA soil was higher than that in the TA soil, as the moisture content in CA soil was significantly higher than that in TA soil ($p < 0.05$) (Table 1). Additionally, these findings were supported by the Pearson correlation between Gs and soil moisture, with an r = 0.72 (Figure 6). In a similar study, pea plants showed higher Gs in CA soil compared to TA soil [22].

Furthermore, LAI, Ew, and CY showed a high correlation with Gs, showing values of 0.89, 0.80, and 0.53, respectively (Figure 6). The explanation could be that, when Gs increases, CO_2 and photosynthate concentration also increase, potentially leading to greater plant growth and development, such as an increase in LAI [59].

4.3.2. Leaf Area Index (LAI)

The maximum LAI of the cassava crop was observed at the end of the root system formation stage (Figure 6), which was similar to the 4.7 and 4.1 reported in studies on LAI determination for different cassava progenies, according to Phonchaoren et al. [60] and Oliveira et al. [61], respectively.

From the tuber bulking stage in the cassava phenological cycle, 96 das, until harvest, the LAI under CA practices was higher than that under TA practices (Figure 6), attributed to higher M°, Ew, and Gs in the CA treatment (Table 1). This was supported by a higher

Pearson correlation, with r = 0.79 (Figure 7), and the higher soil moisture in CA compared to TA (Table 1).

4.3.3. Cassava Yield

The average cassava yield in this study was 28.97 ± 1.7 t ha^{-1}, which was more than double the national average yield of 12,344 kg ha^{-1} [26]. This higher yield can be attributed to agricultural practices not commonly adopted by most farmers, such as high fertilizer application rates, and splitting nitrogen applications into two parts. Similarly, in different studies, cassava yields as high as 19.9 and 28.2 t ha^{-1} were reported, according to Fasinmirin et al. [7] and Garreto et al. [5], respectively.

The results regarding cassava yield were influenced by the tillage system, with CA showing a 28.8% higher yield compared to TA (Table 1). This difference is likely because cassava tubers and roots could penetrate the soil in both CA and TA systems with similar ease or difficulty given that the bulk density (Bd) of both tillage systems was so similar (Table 1). A similar result was found by Garreto et al. [5], where the yield in CA was 12.7% higher than that in TA. Conversely, in a similar study, cassava yield was higher in TA compared to CA by 30.6%, 24.6%, and 10%, according to Reichert et al., Fasinmirin et al., and Lamidi et al. [4,7,20], respectively. However, both cost–benefit and environmental impacts of each tillage system should be considered.

Additionally, cassava yield showed a high Pearson correlation with stomatal conductance (Gs), leaf area index, and earthworm population (r = 0.53, 0.72, and 0.72) (Figure 7). This correlation is likely because higher Gs leads to greater carbon assimilation, resulting in a larger leaf area and, consequently, a higher crop yield [43,59].

5. Conclusions

This study demonstrated that soil properties, cassava Gs, and yield exhibited distinct responses under CA and TA, underscoring that CA remains an underexplored approach in the Peruvian Amazon. Under CA, M°, Ew, Gs, and commercial yield were 5.26% (~105.2 m^3 ha^{-1}), 1.8 times, 1.2 times, and 7.3 t ha^{-1} higher, respectively, than those under TA. Additionally, the absence of mulch showed 1.12 times more earthworms compared to when mulch was applied. The interaction between tillage systems and mulch, particularly the CA × mulch factor, resulted in higher values of M°, Ew, Gs, and LAI compared to the TA × mulch factor. Therefore, this study could encourage producers to shift from TA to CA, as it requires less labor, offers greater efficiency, increases soil water retention in the face of rainfall scarcity, mitigates plant water stress, and yields higher production and profitability. Future research should include comparisons of soil property dynamics under these planting systems, considering labile soil carbon, soil pore space, soil CO_2 emissions, and microbial populations.

Author Contributions: Conceptualization, J.A.O.-R. and R.P.-E.; methodology, J.A.O.-R., C.P.L.O., H.A.H.Y., H.D.-C. and J.W.Z.-S.; software, R.P.-E. and J.A.O.-R.; validation, J.A.O.-R.; formal analysis, R.P.-E., H.D.-C. and J.A.O.-R.; investigation, J.A.O.-R., R.P.-E., A.I.A.-P., A.Q.-T., G.E.-J., J.G.R.R., Z.L.O.-A., H.A.H.Y., H.D.-C. and J.W.Z.-S.; resources, A.I.A.-P., R.H.L.-G., J.G.R.R. and Z.L.O.-A.; data curation, J.A.O.-R., A.I.A.-P., G.E.-J., A.Q.-T., H.D.-C., R.H.L.-G. and C.P.L.O.; writing—original draft preparation, J.A.O.-R., R.P.-E., J.W.Z.-S., H.A.H.Y., H.D.-C. and C.P.L.O.; writing—review and editing, J.A.O.-R., C.P.L.O., A.I.A.-P., R.H.L.-G. and G.E.-J.; visualization, R.P.-E. and J.A.O.-R.; supervision, R.H.L.-G., A.I.A.-P. and W.M.P.M.; project administration, A.I.A.-P., W.M.P.M., J.G.R.R., Z.L.O.-A. and R.H.L.-G.; funding acquisition, A.I.A.-P. and W.M.P.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the project "Creación del servicio de agricultura de precisión en los Departamentos de Lambayeque, Huancavelica, Ucayali y San Martín 4 Departamentos" CUI 2449640 of the Ministry of Agrarian Development and Irrigation (MIDAGRI) of the Peruvian Government.

Data Availability Statement: All data generated during this study are included in this published article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Szczepanek, M.; Piotrowska-Długosz, A.; Konopka, I. Sustainable Crop Production Protects the Quality of Soil and Plant Raw Materials. *Agronomy* **2021**, *11*, 1178. [CrossRef]
2. Çakmakçı, R.; Salık, M.A.; Çakmakçı, S. Assessment and Principles of Environmentally Sustainable Food and Agriculture Systems. *Agriculture* **2023**, *13*, 1073. [CrossRef]
3. Pereponova, A.; Grahmann, K.; Lischeid, G.; Bellingrath-Kimura, S.D.; Ewert, F.A. Sustainable Transformation of Agriculture Requires Landscape Experiments. *Heliyon* **2023**, *9*, e21215. [CrossRef]
4. Reichert, J.M.; Fontanela, E.; Awe, G.O.; Fasinmirin, J.T. Is Cassava Yield Affected by Inverting Tillage, Chiseling or Additional Compaction of No-till Sandy-Loam Soil? *Rev. Bras. Ciênc. Solo* **2021**, *45*, e0200134. [CrossRef]
5. Garreto, F.G.S.; Fernandes, A.M.; Silva, J.A.; Silva, R.M.; Figueiredo, R.T.; Soratto, R.P. No-Tillage and Previous Maize–Palisadegrass Intercropping Reduce Soil and Water Losses without Decreasing Root Yield and Quality of Cassava. *Soil Tillage Res.* **2023**, *227*, 105621. [CrossRef]
6. Thomaz, E.L.; Fidalski, J. Interrill Erodibility of Different Sandy Soils Increases along a Catena in the Caiuá Sandstone Formation. *Rev. Bras. Ciênc. Solo* **2020**, *44*, e0190064. [CrossRef]
7. Fasinmirin, J.T.; Reichert, J.M. Conservation Tillage for Cassava (Manihot Esculenta Crantz) Production in the Tropics. *Soil Tillage Res.* **2011**, *113*, 1–10. [CrossRef]
8. Page, K.L.; Dang, Y.P.; Dalal, R.C. The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. *Front. Sustain. Food Syst.* **2020**, *4*, 31. [CrossRef]
9. Stagnari, F.; Pagnani, G.; Galieni, A.; D'Egidio, S.; Matteucci, F.; Pisante, M. Effects of Conservation Agriculture Practices on Soil Quality Indicators: A Case-Study in a Wheat-Based Cropping Systems of Mediterranean Areas. *Soil Sci. Plant Nutr.* **2020**, *66*, 624–635. [CrossRef]
10. Carbonell-Bojollo, R.; Veroz-Gonzalez, O.; Ordoñez-Fernandez, R.; Moreno-Garcia, M.; Basch, G.; Kassam, A.; de Torres, M.A.R.R.; Gonzalez-Sanchez, E.J. The Effect of Conservation Agriculture and Environmental Factors on CO2 Emissions in a Rainfed Crop Rotation. *Sustainability* **2019**, *11*, 3955. [CrossRef]
11. Mloza-Banda, H.R.; Makwiza, C.N.; Mloza-Banda, M.L. Soil Properties after Conversion to Conservation Agriculture from Ridge Tillage in Southern Malawi. *J. Arid Environ.* **2016**, *127*, 7–16. [CrossRef]
12. Mojid, M.A.; Mainuddin, M. Water-Saving Agricultural Technologies: Regional Hydrology Outcomes and Knowledge Gaps in the Eastern Gangetic Plains—A Review. *Water* **2021**, *13*, 636. [CrossRef]
13. Komarek, A.M.; Thierfelder, C.; Steward, P.R. Conservation Agriculture Improves Adaptive Capacity of Cropping Systems to Climate Stress in Malawi. *Agric. Syst.* **2021**, *190*, 103117. [CrossRef]
14. Schmaltz, E.M.; Krammer, C.; Dersch, G.; Weinberger, C.; Kuderna, M.; Strauss, P. The Effectiveness of Soil Erosion Measures for Cropland in the Austrian Agri-Environmental Programme: A National Approach Using Local Data. *Agric. Ecosyst. Environ.* **2023**, *355*, 108590. [CrossRef]
15. Hobbs, P.R.; Sayre, K.; Gupta, R. The Role of Conservation Agriculture in Sustainable Agriculture. *Philos. Trans. R. Soc. B Biol. Sci.* **2008**, *363*, 543–555. [CrossRef]
16. Dev, P.; Khandelwal, S.; Yadav, S.C.; Arya, V.; Mali, H.R.; Yadav, K.K. Conservation Agriculture for Sustainable Agriculture. *Int. J. Plant Soil Sci.* **2023**, *35*, 1–11. [CrossRef]
17. Bhattacharjee, S.; Panja, A.; Panda, M.; Dutta, S.; Dutta, S.; Kumar, R.; Kumar, D.; Yadav, M.R.; Minkina, T.; Kalinitchenko, V.P.; et al. How Did Research on Conservation Agriculture Evolve over the Years? A Bibliometric Analysis. *Sustainability* **2023**, *15*, 2040. [CrossRef]
18. FAO. *El Estado de Los Recursos de Tierras y Aguas Del Mundo Para La Alimentación y La Agricultura: La Gestión de Los Sistemas En Situación de Riesgo*; Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO): Rome, Italy, 2012; ISBN 9788484765530.
19. Byju, G.; Ravindran, C.S.; Nair, R.R.; Ravi, V. Tillage and planting methods on soil properties, yield, root rot and nu-trient uptake in a continuously grown cassava field in a semi arid Vertisol of India. *Adv. Hortic. Sci.* **2010**, *24*, 176–182.
20. Lamidi, W.A. Effect of Different Tillage Practices on Cassava Production in Osun State of Nigeria. *Res. J. Agric. Environ. Manag.* **2016**, *5*, 114–121.
21. Ocaña-Reyes, J.A. Short-Term Impacts of Conservation and Traditional Agriculture on Natural Resources and Corn Yield. *Rev. Investig. Agrar.* **2020**, *2*, 27–36. [CrossRef]
22. Bojarszczuk, J. The Influence of Soil Tillage System on Changes in Gas Exchange Parameters of *Pisum Sativum* L. *Agronomy* **2021**, *11*, 1000. [CrossRef]
23. Mulatu, G. Influence of Conservation Agriculture on Certain Soil Qualities Both Physical and Chemical in Relation to Sustainable Agriculture Practices a Review. *Int. J. Biochem. Biophys. Mol. Biol.* **2024**, *9*, 1–13. [CrossRef]
24. Kassam, A.; Friedrich, T.; Derpsch, R. State of the Global Adoption and Spread of Conservation Agriculture. *Agronomy* **2022**, *12*, 769. [CrossRef]

25. Bonett, D.C.; Altamirano, P.A.; Aguilar, J.V.; Jáuregui, E.; Asesora, L.; Torres, I.A.; Del Castillo, A.; Farfán, M.; Mezones, J.; Cusicuna, F.; et al. *Perú Económico*; Instituto Nacional de Estadistica e Informatica (INEI): Lima, Peru, 2023. Available online: https://www.inei.gob.pe/biblioteca-virtual/boletines/panorama-economico-departamental/ (accessed on 2 November 2024).
26. Marcelo, M.; Celestino, D.; Martínez, B.; Hinostroza, L.; Vasquez, J. *Descriptores Para Yuca*; Instituto Nacional de Innovación Agraria (INIA): La Molina District, Peru, 2023. Available online: https://repositorio.inia.gob.pe/handle/20.500.12955/2067 (accessed on 2 November 2024).
27. Gobierno Regional de la Region Ucayali. *Zonificación Ecológica Económica Base para el Ordenamiento Territorial de la Región Ucayali*; Gobierno Regional de Ucayali: Pucallpa, Peru, 2017.
28. Álvaro-Fuentes, J.; Lóczy, D.; Thiele-Bruhn, S.; Zornoza, R. *Handbook of Plant and Soil Analysis for Agricultural Systems. Diversification and Low-Input Farming across Europe: From Practitioners' Engagement and Ecosystems Services to Increased Revenues and Value Chain Organisation*; Cartagena, Spain, 2019; ISBN 9788416325863. Available online: https://zenodo.org/ (accessed on 2 November 2024).
29. Bazán, R. *Manual de Procedimientos de Los Análisis de Suelos y Agua Con Fines de Riego Programa Presupuestal 0089 Reducción de La Degradación de Los Suelos Agrarios*; Lima, Peru, 2017. Available online: https://repositorio.inia.gob.pe/handle/20.500.12955/504 (accessed on 2 November 2024).
30. Boonchamni, C.; Boonthai Iwai, C.; Ta-Oun, M. Physical-Chemical Properties of Earthworm Casts in Different Earthworm Species. *Int. J. Environ. Rural Dev.* **2019**, *1*, 1–5.
31. Mondal, S.; Poonia, S.P.; Mishra, J.S.; Bhatt, B.P.; Karnena, K.R.; Saurabh, K.; Kumar, R.; Chakraborty, D. Short-Term (5 Years) Impact of Conservation Agriculture on Soil Physical Properties and Organic Carbon in a Rice–Wheat Rotation in the Indo-Gangetic Plains of Bihar. *Eur. J. Soil Sci.* **2020**, *71*, 1076–1089. [CrossRef]
32. Ocaña-Reyes, J.A.; Gutiérrez, M.; Paredes-Espinosa, R.; Riveros, C.A.; Cárdenas, G.P.; Bravo, N.; Quispe-Tomas, A.; Amaringo-Cordova, L.P.; Ocaña-Canales, J.C.; Zavala-Solórzano, J.W.; et al. Tillage Practices and Liming: Comparative Study of Soil Properties and Forage Corn Production. *Agronomy* **2024**, *14*, 558. [CrossRef]
33. Hu, W.; Shao, M.; Wang, Q.; Fan, J.; Horton, R. Temporal Changes of Soil Hydraulic Properties under Different Land Uses. *Geoderma* **2009**, *149*, 355–366. [CrossRef]
34. Verhulst, N.; Govaerts, B.; Verachtert, E.; Castellanos-Navarrete, A.; Mezzalama, M.; Wall, P.C.; Chocobar, A.; Deckers, J.; Sayre, K.D. Conservation Agriculture, Improving Soil Quality for Sustainable Production Systems? In *Food Security and Soil Quality*; CRC Press: Boca Raton, FL, USA, 2018; pp. 137–208.
35. Alletto, L.; Cueff, S.; Bréchemier, J.; Lachaussée, M.; Derrouch, D.; Page, A.; Gleizes, B.; Perrin, P.; Bustillo, V. Physical Properties of Soils under Conservation Agriculture: A Multi-Site Experiment on Five Soil Types in South-Western France. *Geoderma* **2022**, *428*, 116228. [CrossRef]
36. Nebo, G.I.; Manyevere, A.; Araya, T.; van Tol, J. Short-Term Impact of Conservation Agriculture on Soil Strength and Saturated Hydraulic Conductivity in the South African Semiarid Areas. *Agriculture* **2020**, *10*, 414. [CrossRef]
37. La Scala, N.; Bolonhezi, D.; Pereira, G.T. Short-Term Soil CO_2 Emission after Conventional and Reduced Tillage of a No-till Sugar Cane Area in Southern Brazil. *Soil Tillage Res.* **2006**, *91*, 244–248. [CrossRef]
38. Sartori, F.; Piccoli, I.; Polese, R.; Berti, A. Transition to Conservation Agriculture: How Tillage Intensity and Covering Affect Soil Physical Parameters. *Soil* **2022**, *8*, 213–222. [CrossRef]
39. Yousefi, M.; Dray, A.; Ghazoul, J. Assessing the Effectiveness of Cover Crops on Ecosystem Services: A Review of the Benefits, Challenges, and Trade-Offs. *Int. J. Agric. Sustain.* **2024**, *22*, 2335106. [CrossRef]
40. Meyer, N.; Bergez, J.E.; Constantin, J.; Justes, E. Cover Crops Reduce Water Drainage in Temperate Climates: A Meta-Analysis. *Agron. Sustain. Dev.* **2019**, *39*, 3. [CrossRef]
41. Zhang, H.; Ghahramani, A.; Ali, A.; Erbacher, A. Erbacher Cover Cropping Impacts on Soil Water and Carbon in Dryland Cropping System. *PLoS ONE* **2023**, *18*, e0286748. [CrossRef]
42. Sithole, N.J.; Magwaza, L.S.; Thibaud, G.R. Long-Term Impact of No-till Conservation Agriculture and N-Fertilizer on Soil Aggregate Stability, Infiltration and Distribution of C in Different Size Fractions. *Soil Tillage Res.* **2019**, *190*, 147–156. [CrossRef]
43. Lotfi, R.; Pessarakli, M. Effects of Crop Rotation and Tillage on Winter Wheat Growth and Yield under Cold Dryland Conditions. *Crops* **2023**, *3*, 88–100. [CrossRef]
44. Naab, J.B.; Mahama, G.Y.; Yahaya, I.; Prasad, P.V.V. Conservation Agriculture Improves Soil Quality, Crop Yield, and Incomes of Smallholder Farmers in North Western Ghana. *Front. Plant Sci.* **2017**, *8*, 996. [CrossRef]
45. Castellanos-Navarrete, A.; Rodríguez-Aragonés, C.; De Goede, R.G.M.; Kooistra, M.J.; Sayre, K.D.; Brussaard, L.; Pulleman, M.M. Earthworm Activity and Soil Structural Changes under Conservation Agriculture in Central Mexico. *Soil Tillage Res.* **2012**, *123*, 61–70. [CrossRef]
46. McInga, S.; Muzangwa, L.; Janhi, K.; Mnkeni, P.N.S. Conservation Agriculture Practices Can Improve Earthworm Species Richness and Abundance in the Semi-Arid Climate of Eastern Cape, South Africa. *Agriculture* **2020**, *10*, 576. [CrossRef]
47. Dulaurent, A.-M.; Houben, D.; Honvault, N.; Faucon, M.-P.; Chauvat, M.; France, N. Beneficial Effects of Conserva-tion Agriculture on Earthworm and Collembola Communities in Northern France Beneficial Effects of Conservation Agriculture on Earthworm and Collembola Communities. *Plant Soil* **2023**. [CrossRef]
48. Klok, C.; Faber, J.; Heijmans, G.; Bodt, J.; Van Der Hout, A. Influence of Clay Content and Acidity of Soil on Development of the Earthworm Lumbricus Rubellus and Its Population Level Consequences. *Biol. Fertil. Soils* **2007**, *43*, 549–556. [CrossRef]

49. Singh, S.; Sharma, A.; Khajuria, K.; Singh, J.; Vig, A.P. Soil Properties Changes Earthworm Diversity Indices in Different Agro-Ecosystem. *BMC Ecol.* **2020**, *20*, 27. [CrossRef]
50. Fonte, S.J.; Hsieh, M.; Mueller, N.D. Earthworms Contribute Significantly to Global Food Production. *Nat. Commun.* **2023**, *14*, 5713. [CrossRef]
51. Al-Maliki, S.; Al-Taey, D.K.A.; Al-Mammori, H.Z. Earthworms and Eco-Consequences: Considerations to Soil Biological Indicators and Plant Function: A Review. *Acta Ecol. Sin.* **2021**, *41*, 512–523. [CrossRef]
52. Pacheco, R.I.L.; Macias, M.P.; Campos, F.C.F.; Izquierdo, A.J.R.; Izquierdo, G.A.R. Agronomic and Physiological Evaluation of Eight Cassava Clones under Water Deficit Conditions. *Rev. Fac. Nac. Agron. Medellin* **2020**, *73*, 9109–9119. [CrossRef]
53. De Souza, A.P.; Wang, Y.; Orr, D.J.; Carmo-Silva, E.; Long, S.P. Photosynthesis across African Cassava Germplasm Is Limited by Rubisco and Mesophyll Conductance at Steady State, but by Stomatal Conductance in Fluctuating Light. *New Phytol.* **2020**, *225*, 2498–2512. [CrossRef]
54. Rosenthal, D.M.; Slattery, R.A.; Miller, R.E.; Grennan, A.K.; Cavagnaro, T.R.; Fauquet, C.M.; Gleadow, R.M.; Ort, D.R. Cassava About-FACE: Greater than Expected Yield Stimulation of Cassava (Manihot Esculenta) by Future CO_2 Levels. *Glob. Chang. Biol.* **2012**, *18*, 2661–2675. [CrossRef]
55. Giménez, C.; Gallardo, M.; Thompson, R.B. Plant–Water Relations. In *Reference Module in Earth Systems and Environmental Sciences*; Elsevier: Cordoba, Spain, 2013.
56. Xu, Z.; Tian, Y.; Liu, Z.; Xia, X. Comprehensive Effects of Atmosphere and Soil Drying on Stomatal Behavior of Different Plant Types. *Water* **2023**, *15*, 1675. [CrossRef]
57. Qi, Y.; Zhang, Q.; Hu, S.; Wang, R.; Wang, H.; Zhang, K.; Zhao, H.; Zhao, F.; Chen, F.; Yang, Y.; et al. Applicability of Stomatal Conductance Models Comparison for Persistent Water Stress Processes of Spring Maize in Water Resources Limited Environmental Zone. *Agric. Water Manag.* **2023**, *277*, 108090. [CrossRef]
58. Anav, A.; Proietti, C.; Menut, L.; Carnicelli, S.; De Marco, A.; Paoletti, E. Sensitivity of Stomatal Conductance to Soil Moisture: Implications for Tropospheric Ozone. *Atmos. Chem. Phys.* **2018**, *18*, 5747–5763. [CrossRef]
59. Marschner, P. *Mineral Nutrition of Higher Plants*, 3rd ed.; Elsevier: Amsterdam, The Netherlands, 2011; ISBN 9780123849052.
60. Phoncharoen, P.; Banterng, P.; Vorasoot, N.; Jogloy, S.; Theerakulpisut, P. Determination of Cassava Leaf Area for Breeding Programs. *Agronomy* **2022**, *12*, 3013. [CrossRef]
61. De Oliveira, E.C.; De Almeida, L.H.C.; Zucareli, C.; Valle, T.L.; De Souza, J.R.P.; Miglioranza, É. Analysis of Cassava Growth at Different Harvest Times and Planting Densities. *Semin. Cienc. Agrar.* **2019**, *40*, 113–126. [CrossRef]