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Research Article

Olericulture No-Till System at Mountain Region: Physical and Biological Attributes of the Soil

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The production of vegetables and grains by the family farming in the mountains of the Atlantic Forest is characterized by intensive soil management with ploughing and harrowing practices. These practices are promoting hydric erosion and losses of soil quality in the region. In this context, the objective of this work was to evaluate soil physical and biological characteristics at two seasons of the year in agroecosystems producing vegetables and grains in the no-tillage system (NTS) for 3, 5, and 9 years compared to the conventional management system (CT) in the Atlantic Forest Biome, Brazil. Physical and organic matter attributes and carbon (C) and nitrogen (N) stock were evaluated. NTS showed, in general, greater total porosity than CT systems. The main differences between the systems were found in the organic attributes and C and N stocks. The content of microbial biomass C in NTS with 3, 5, and 9 years was 767.5, 326.5, and 210.0 $mg \cdot kg^{-1}$, while the areas with CT had 93.75, 78.25, and 45.75 $mg \cdot kg^{-1}$, respectively. The stock of C in winter at the 9NTS area was 33.0 and 41.5 $Mg \cdot ha^{-1}$, and the respective area in CT presented only 21.75 and 25.00 $Mg \cdot ha^{-1}$ in the depths of 0–10 and 10–20 cm, respectively. The metabolic quotient of the NTS areas did not differ from the reference ecosystems and is promoting lower C-CO_2 emissions than the CT system. The adoption of NTS in vegetable production improves soil quality in family farm areas of mountains relief at the Atlantic Forest Biome.

1. Introduction

Vegetable production is one of the main agricultural activities in the mountainous region of the State of Espirito Santo, Brazil [1]. The family production system is dominant in this region, keeping the family in rural areas and contributing strongly to the socioeconomic quality of the region. This region is located in the Atlantic Forest Biome, where its conversion to vegetable crops contributes to the degradation of this Biome and its soils [1].

The dominant relief in the region varies from gently to heavily undulating, presenting soils with low natural fertility [1]. Vegetable systems are usually subjected to an intensive cultivation system and unsustainable cultural practices [1], causing the breakdown of aggregates and reduction in soil organic matter contents [2]. Thus, conventional cropping systems can quickly promote losses in the physical, chemical, and biological quality of soils in the region, resulting in a reduction in crop productivity and quality of life for farmers.

To mitigate the impacts of conventional vegetable production systems in the mountain region of Espírito Santo, the State Agricultural Research Institute, together with rural unions, implemented a program with family farmers promoting the no-tillage system (NTS). In this way, no-tillage vegetable crops were installed in part of the areas of conventional cultivation in some family properties.

The NTS has the characteristics of not disturbing the soil and maintaining a living or dead plant cover on it throughout the year [3]. Its effects on the soil are additive over time, reflecting improvements in physical attributes such as increased porosity [2], increased water infiltration and higher water content in dry seasons, reduced compaction in subsurface layers [4], and favoring macroaggregation and aggregate stability [5]. This system may also improve soil organic matter attributes such as microbial community stability, carbon stock, and microbial biomass [6].

In NTS, plant residues from cover crops are left on the ground [7], promoting gradual decomposition of plant residues and favoring the increase of soil organic matter [8] and the mitigation of C-CO_2 emissions [9]. However, information on soil quality improvement in NTS with vegetable crops is lacking, especially in family systems in the Atlantic Forest Biome.

In this context, the aim of this work was to study the impact of short- and long-term no-tillage and conventional cropping systems on soil physical and organic matter attributes in the summer and winter periods in the mountain region of the Atlantic Forest Biome, Brazil. Our working hypothesis is that the no-tillage system reduces C-CO_2 emissions, increases organic matter contents, and promotes improvement in soil physical attributes.

2. Materials and Methods

2.1. Characterization of the Studied Areas. The work was carried out in properties of family farmers at the municipality of Santa Maria de Jetibá, Espírito Santo, Brazil. Nine study sites were selected, divided into 3 groups (Table 1). The climate of the region is Aw (tropical climate with a dry season in winter), characterized by dry winter and rainy summer [10]. The annual average of temperature and precipitation is shown in Figure 1.

Each group was composed of 3 comparative areas: forest (reference ecosystem), conventional planting system (CT), and no-tillage system (NTS), which are adjacent areas within the same soil unit, to minimize environmental interferences such as climate, altitude, relief, and mineralogy. The physical and chemical characteristics of the soils in each area are shown in Tables 2 and 3.

The reference ecosystems were Atlantic Forest fragments. CT soil management is characterized by turning the surface layer (0–20 cm) 2 to 3 times a year, using ploughs, harrows, rotary hoes, and rotary tillers. In the studied areas, there are signs of laminar erosion and the presence of furrows. Vegetables are planted by transplanting them into beds (onions, etc.) or directly into the ground (cabbage, broccoli, peppers, zucchini, etc.) and sown directly into the ground (carrots). In the case of grains (corn and beans), planting is performed in holes. Level curves are not adopted. The management of spontaneous plants is carried out by desiccants, mowing, and weeding. Liming, chemical, and organic (mainly with poultry manure) fertilization of the soil is carried out. Crop residues remain in the area and are incorporated into the soil in tillage operations.

In the NTS, the three principles of the NTS were adopted: tilling the soil only in the planting row, keeping the soil covered by living or dead vegetation, and employing crop rotation to maximize biodiversity. The straw was formed by two cycles of economic crops, vegetables (chayote, broccoli, cabbage, and zucchini) and grains (corn and beans), and a cycle of cover crops, whose phytotechnical indices are shown in Table 4. Soil cover was obtained by managing cover crops, mowing, or applying herbicides, aiming to reach a dry matter mass production index of 7–10 ton/ha/year [13–15]. For the cultivation of vegetables, the soil was only mobilized in the planting line by opening holes in the straw. Usually, liming, mineral, and/or organic fertilization of the soil is carried out for both the economic culture and the cover crops, and the plant residues remain in the area on the ground.

Normally, the planting season for vegetables (chayote, broccoli, cabbage, carrots, onions, peppers, and zucchini) is between January and September, and the planting season for grains (corn and beans) is between August and December.

Fertilizers were applied to provide nitrogen, phosphorus, and potassium, and acidity correctors were applied to all properties according to soil chemical analysis. The amount of each nutrient was recommended for economic crops (chayote, broccoli, cabbage, carrots, onions, peppers, zucchini, corn, and beans) according to Prezotti et al. [16] and for cover crops according to Raij et al. [17] and Tedesco et al. [18]. All plots had an irrigation system according to their water demand.

2.2. Soil Sampling. Soil sampling was carried out during the winter and summer seasons. The winter sampling was carried out in 08/2019 for physical, chemical, and organic analysis, and the summer sampling was carried out in 01/2020, only for organic analysis. Soil samples were representative of two depths 0–20 and 20–40 cm for physical and chemical analyses and 0–10 and 10–20 cm for organic analyses. The study areas were divided into 4 plots. At the time of sampling, the temperature and soil moisture were measured at a depth of 0–10 cm (Table 5) using the FDR equipment (frequency-domain reflectometry). From each stand, 1 composite sample was collected, consisting of 3 subsamples.

2.3. Soil Physical Attributes. To assess the degree of penetration resistance, an electronic soil compaction meter (penetroLOG Falquer®) was used in the profile from 0 to 40 cm in depth with 10 replications per studied area. Undisturbed soil samples were saturated in water for 24 h and then placed in a sand tension table of −6 kPa. Soil microporosity was calculated after water stabilization into the volumetric ring (72 h). Bulk density was performed by the volumetric ring method, and particle density was determined by the volumetric flask method [19].

The bulk density (BD), total porosity (TP), microporosity, and macroporosity (microp and macrop) were calculated from the following equations:

(1) $\text{BD} = \text{MDS}\ (g)/\text{ring bulk}\ (\text{cm}^{-3})$

(2) $\text{TP} = MSS\ (g) - \text{MDS (g)/ring bulk}\ (\text{cm}^{-3})$

(3) $\text{Microp} = MST\ (g) - \text{MDS (g)/ring bulk}\ (\text{cm}^{-3})$

(4) $\text{Macrop} = \text{TP} - \text{Microp}$

Table 1: Characterization of studied areas on rural properties of family farmers in Santa Maria de Jetibá, ES.

Studied areas	Management of soil	Crop	Soil	Altitude	Coordinates 24K
Characteristics					
Group 1					
Forest	No	No	Typic Humaquepts	961 m	0304091/7774616
CT	Conventional tillage	Chayote	Typic Dystrustepts	646 m	0323977/7784827
3 NTS	3 years no tillage	Chayote	Typic Dystrustepts	905 m	0303273/7775546
Group 2					
Forest	No	No	Typic Haplustox	1057 m	0301241/7771950
CT	Conventional tillage	Vegetables	Typic Haplustox	1021 m	0300788/7772042
5 NTS	5 years no tillage	Vegetables	Typic Haplustox	981 m	0300928/7772244
Group 3					
Forest	No	No	Typic Haplustox	850 m	0314463/7775975
CT	Conventional tillage	Vegetables	Typic Haplustox	850 m	0314169/7776247
9 NTS	9 years no tillage	Vegetables	Typic Haplustox	839 m	0314422/7775996

Soil taxonomy, USDA classification. Vegetables: chayote, broccoli, cabbage, carrots, onions, peppers, zucchini, corn, and beans. Conventional tillage (CT); no tillage (NTS).

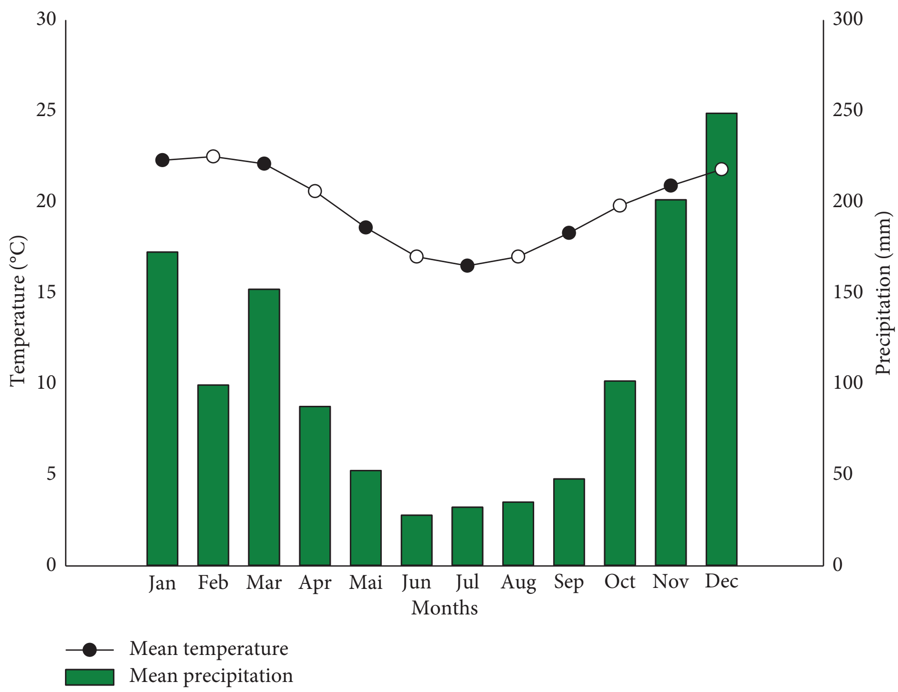


Figure 1: Annual average temperature and precipitation in the municipality of Santa Maria de Jetibá-ES. Adapted from Incaper.

Table 2: Chemical characterization of the soil at a depth of 0–20 cm from different studied areas.

Studied areas	pH H_2O	P (mg dm^{-3})	K	Ca^{2+}	Mg^{2+}	Al^{3+} (cmolc dm^{-3})	H + Al	t	T	V (%)
Forest	4.45	13.85	37.50	0.83	0.36	1.80	9.85	3.13	11.17	11.55
CT	6.90	869.13	423.00	10.32	2.09	0.00	1.45		15.18	90.30
3 NTS	6.70	167.80	160.00	5.07	1.44	0.00	1.32	6.97	8.29	84.02
Forest	3.90	3.05	22.75	0.06	0.14	2.20	11.22	2.51	11.53	2.75
CT	5.46	67.80	138.00	3.29	0.74	0.30	4.73	4.76	9.19	47.20
5 NTS	5.70	73.27	103.50	4.17	0.79	0.03	3.87	5.30	9.14	57.62
Forest	4.50	4.75	74.75	1.30	0.68	1.44	11.35	3.63	13.53	15.47
CT	5.60	104.80	274.50	4.31	1.05	0.02	3.42	6.11	9.51	63.92
9 NTS	5.90	36.57	70.75	3.50	1.41	0.09	3.57	5.21	8.69	57.97

Conventional tillage (CT); no tillage (NTS); pH, active acidity; phosphorus (P); potassium (K); calcium (Ca^{2+}); magnesium (Mg^{2+}); exchangeable acidity (Al^{3+}); total acidity (H + Al); effective cation exchange capacity (t); total cation exchange capacity at pH 7.0 (T); saturation of bases (V). pH in water, KCl and CaCl2 ratio 1 : 2.5; phosphorus (P), potassium (K) Mehlich 1 extractor; calcium (Ca), magnesium (Mg), aluminum (Al) KCl 1 mol/L extractor; H + Al SMP extractor [11].

Table 3: Physical soil characterization at depths of 0–20 cm and 20–40 cm from different study areas and soil temperature and moisture conditions at depths of 0–10 measured in the winter and summer.

Study areas	Sand	Silt ($g\ kg^{-1}$)	Clay	Sand	Silt ($g\ kg^{-1}$)	Clay	Temperature (°C)	Moisture ($m^3\ m^{-3}$)	Temperature (°C)	Moisture ($m^3\ m^{-3}$)
	0–20 cm			20–40 cm			Winter		Summer	
Forest	52.17	185.4	762.41	59.96	211.8	728.23	19.50	0.24	26.60	0.30
CT	256.35	262.23	481.41	211.95	270.3	517.74	17.70	0.29	28.10	0.33
3 NTS	488.4	152.9	358.69	514.84	132.46	352.68	19.90	0.33	29.40	0.32
Forest	333.78	189.67	476.53	336.68	113.11	550.19	19.40	0.17	26.20	0.21
CT	267.37	104.33	628.28	266.52	98.92	634.54	19.40	0.16	38.00	0.23
5 NTS	525.55	86.35	388.08	539.54	82.31	378.13	20.50	0.19	37.00	0.19
Forest	505.34	102.11	392.53	505.31	99.96	394.71	19.80	0.17	24.10	0.20
CT	361.68	78.46	559.85	359.86	74.06	566.06	19.80	0.16	26.00	0.26
9 NTS	521.29	73.3	405.4	529.4	75.41	395.17	21.00	0.16	25.70	0.20

Conventional tillage (CT); no tillage (NTS).

Table 4: Technical indicators for cover crops used for soil coverage and stubble formation in no-till areas [12].

	Cover plants	Cultivars	Planting season	Spacing (cm)	Seed density In rows	Seed density In haul
Spring-summer	*Crotalaria breviflora* (D.C.)	Comum	Set-Nov	50	33	75–80
	Crotalaria juncea (*L.*)	IAC KR1	Set-Nov	50	25	55–60
	Crotalaria ochroleuca (G. Don)	Comum	Set-Nov	50	43	100–120
	Crotalaria spectabilis (Roth)	Comum	Set-Nov	50	33	80–85
	Canavalia ensiformis (*L.*) *D.C.*	Comum	Set-Nov	50	5	10
	Helianthus annuus (L.)	Catissol 01	Set-Nov	80	7	20–25
	Cajanus cajan (*L.*) *Millsp.*	IAPAR 43	Set-Nov	50	23	55–60
	Dolichos lablab (L.)	Rongai	Set-Nov	50	11	25–30
	Pennisetum glaucum (L.) R. Brown	BRS 1501	Set-Nov	25	53	240–250
	Zea mays (L.)	Ag 1051	Set-Nov	80–100	5	10
	Mucuna deeringiana var. anã	Comum	Set-Nov	50	7	14–16
	Mucuna pruriens	Comum	Set-Nov	50	4	10
Fall-winter	*Avena sativa* (L.)	IPR 126	Abr-Jun	25	65	300–320
	Avena strigosa	IAPAR 61	Abr-Jun	25	55	250–350
	Lolium multiflorum (*Lan.*)	Comum	Abr-Jun	25	1 (g/ml)	1200–1300
	Secale cereale (L.)	IPR 89	Abr-Jun	25	80–90	250–350
	Pisum sativum ssp. *Arvense*	IAPAR 83	Abr-Jun	50	15–20	38–50
	Vicia sativa (L.)	Comum	Abr-Jun	50	30	90–100
	Vicia vilosa (Roth.)	Comum	Abr-Jun	50	30	90–100
	Raphanus sativus (L.)	IPR 116	Abr-Jun	25	25	120–140
	Lupinus angustifolius (L.)	IPR 24	Abr-Jun	60–80	8	18–20
	Lupinus albus (L.)	Comum	Abr-Jun	60–80	8	18–20

Number of seeds per linear meter. Number of seeds per square meter. Number of seeds per linear meter of furrow.

Table 5: Mean values of microporosity (Microp); macroporosity (Macrop); total porosity (PT); bulk density (DS); particle density (DP); permanent wilting point (PMP); field capacity (CC) at 0–20 and 20–40 cm depth.

	Microp	Macrop ($m^3 \cdot m^{-3}$)	PT	Macrop/PT	DS ($g \cdot kg^{-1}$)	DP	PMP (%)	CC
Study areas	0–20 cm							
Forest	0.42b	0.06b	0.48b	0.12b	0.57c	1.54c	46.96a	56.68a
CT	0.50ab	0.16a	0.67a	0.24a	1.38b	3.16b	26.53b	33.97b
3 NTS	0.57a	0.07b	0.64a	0.10b	1.96a	4.21a	24.71b	40.67b
Forest	0.37ab	0.09a	0.46b	0.20a	0.9b	2.86b	33.52a	48.54a
CT	0.35b	0.12a	0.48b	0.26a	0.77c	2.23c	26.45b	36.33b
5 NTS	0.42a	0.13a	0.56a	0.24a	1.57a	3.48a	22.99c	33.06b
Forest	0.37a	0.18a	0.56a	0.33a	1.27b	3.07a	21.95a	28.09a
CT	0.31b	0.13b	0.45b	0.29a	0.90c	2.33b	20.10a	29.10a

Table 5: Continued.

9 NTS	0.37ab	0.20a	0.57a	0.35a	1.38a	3.05a	15.02b	25.76b
Study areas				20–40 cm				
Forest	0.46ab	0.07a	0.54ab	0.14a	0.56c	1.62c	49.23a	73.67a
CT	0.40b	0.02b	0.42b	0.05b	1.21b	3.07b	21.98b	39.17b
3 NTS	0.57a	0.07a	0.63a	0.12ab	2.3a	4.08a	21.79b	40.16b
Forest	0.35b	0.18a	0.53b	0.34a	0.98b	2.91b	29.44a	50.35a
CT	0.41a	0.12b	0.54b	0.23b	0.79b	2.22c	30.00a	46.50ab
5 NTS	0.46a	0.22a	0.68a	0.31a	1.59a	3.53a	26.75a	42.57b
Forest	0.40a	0.21a	0.62a	0.34a	1.26a	3.38a	21.45a	35.86a
CT	0.33a	0.07b	0.40b	0.17b	0.95b	2.24b	20.01a	30.59b
9 NTS	0.39a	0.20a	0.60a	0.33a	1.28a	3.39a	16.51b	28.38b

Conventional tillage (CT); no tillage (NTS). Means followed by the same letter within each study group do not differ by the *t* test ($p < 0.05$).

where MDS, MSS, and MST stand for mass of dried soil, mass of saturated soil, and mass soil after tension −6 kPa, respectively.

Deformed soil samples were packed in rubber rings and subjected to pressures of 10 and 1500 kPa, respectively, in a Richards extractor to determine the field capacity and permanent wilting point [11].

2.4. Soil Organic Matter Attributes. To determine the total organic carbon (TOC) and total nitrogen (N), the soil samples were ground and sieved in a 0.2 mm·mesh. The TOC was quantified by wet oxidation with $K_2Cr_2O_7$ 0.167 mol·L^{-1} and sulfuric acid with external heat [20]. *N* was quantified by sulfuric digestion followed by distillation in a semi-micro-Kjeldahl apparatus [21]. The stock of C and N was calculated using the equivalent soil mass method [22].

The C and N contents of the microbial biomass (CBM and NBM) were determined using the irradiation-extraction method [21, 23].

The emission of C-CO_2 from the soil was carried out in January 2020 using an LI-COR flow chamber (LI-6400-09, LI-COR, NE, USA). In each stand, 3 PVC rings (0.10 m diameter × 0.10 m high) were inserted to perform the readings, which allowed the calculation of the metabolic quotient [21, 24].

Anaerobically mineralizable N was determined in samples of 0.2 g of ground soil placed in Falcon tubes together with deionized water and incubated at 40°C for 7 days (hermetically sealed bottles). After incubation, ammonium (NH_4^+) present in the samples was measured through the amount of ammonia (NH_3) released by distillation in an alkaline medium. The initial NH_4^+ content was determined from unincubated samples [25].

2.5. Statistical Analysis. Data were subjected to analysis of variance and *t* test at the level of 5% probability, in a completely randomized design using Sisvar software (version 5.7) [26]. The data referring to physical (PT, microp, macrop, DS, DP, PM, and CC) and organic (CBM, NBM, TOC, NT, and Nmin) attributes of the soil were related to the average clay content of each study group to standardize the values regarding this source of variation, through the equation: AC = (AR × TMA)/TRA, where AC is the value of the physical or organic attribute corrected in relation to the clay content, AR is the actual attribute value of an area, TMA is the average of clay content among the 3 comparative areas, and TRA is the actual clay content of the area in question. Data of soil resistance to the penetrometer of agro-ecosystems were compared statistically at 0–20 and 20–40 cm of depth.

3. Results

3.1. Physical Attributes of the Soil. In general, soils under the NTS system showed greater resistance to root penetration than the soils under the CT and forest systems (Figure 2).

The 3NTS area had a higher proportion of micropores than the CT system; however, the proportion of macropores in the CT system was higher than that of the NTS only at 0–20 cm depth. The 5NTS area, at a depth of 20–40 cm, and the 9NTS area, at both depths, showed a higher proportion of macropores and total porosity than the respective areas in CT, even with higher density values. In general, the density of soil and particles was higher for areas under the NTS system than for those under the CT system, at all studied depths. In general, the field capacity of soils under forest was higher for both depths, with no difference between NTS and CT areas (Table 5).

3.2. Stocks of C and N and Biological Attributes of the Soil. The C stock of the 3NTS area was similar to that of the CT area in both winter and summer, for both depths, and the N stock was higher in CT than in 3NTS only in the winter at a depth of 10–20 cm. The C stock in the 5NTS area (33.0 Mg·ha^{-1}) was higher than in the CT (22.0 Mg·ha^{-1}), as well as the N stock, which presented 2.75 and 1.75 Mg·ha^{-1} at a depth of 0–10 cm, respectively. In the winter season, and at a depth of 10–20 cm, the stock of C and N in the 5NTS area did not differ from the reference ecosystem (Figure 3).

In the summer, the 5NTS area also showed a higher C stock (31.5 Mg·ha^{-1}) than the CT (22.75 Mg·ha^{-1}); however, the N stock did not differ between the areas for a depth of 0–10 cm. The 9NTS area presented C stocks of 33.0 and 33.5 Mg·ha^{-1}, higher than the CT that presented 21.75 and 21.0 Mg·ha^{-1} in the winter and summer seasons, respectively, at 0–10 cm depth. At a depth of 10–20 cm, the 9NTS area had similar C stock to the forest in the winter

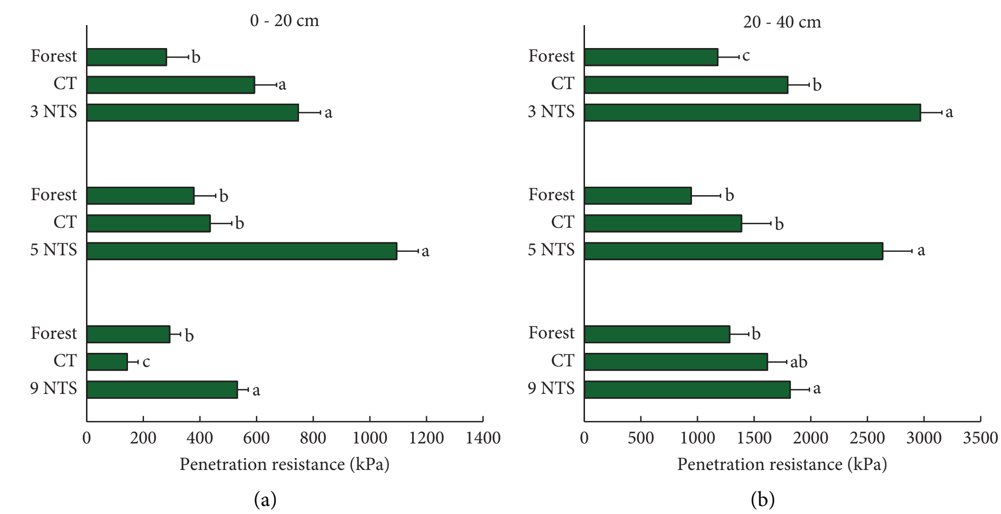


Figure 2: Mean values of soil resistance to penetration (kPa) at depths of 0–20 (a) and 20–40 cm (b). Means followed by the same letter within each study group do not differ by the t test ($p < 0.05$). Conventional tillage (CT); no tillage (NTS).

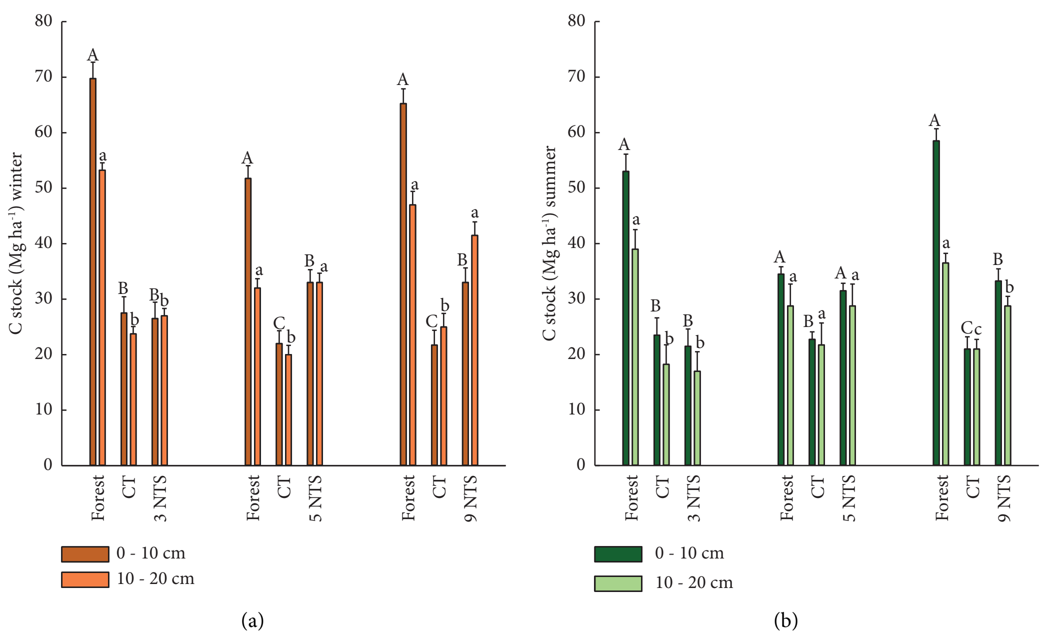
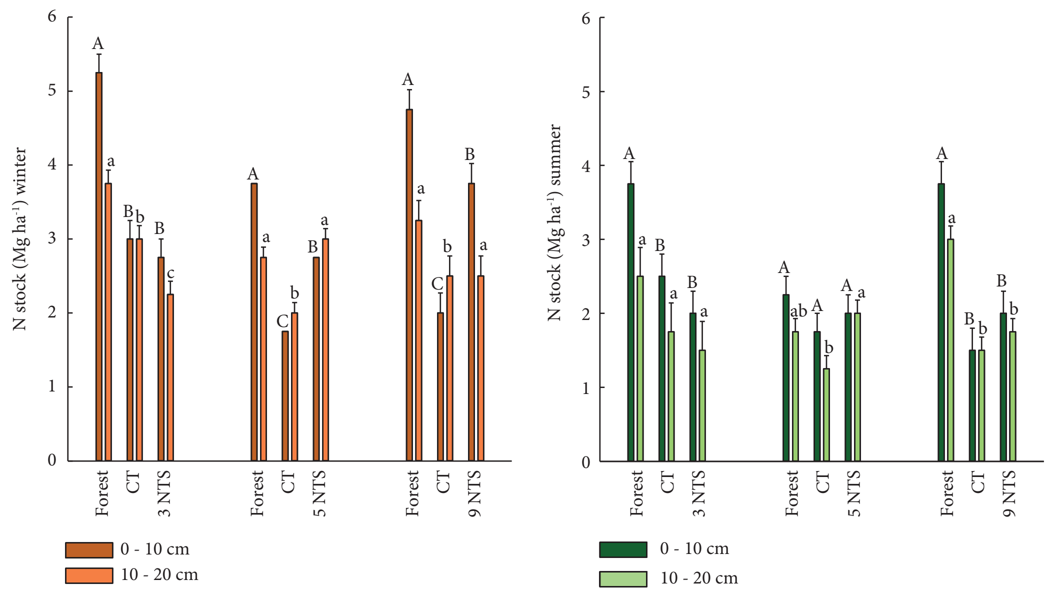


Figure 3: Continued.



(c) (d)

FIGURE 3: Mean carbon and nitrogen stock for the winter and summer seasons. Uppercase letters compare the depth averages of 0–10 cm, and lowercase letters compare the depth of 10–20 cm. Conventional tillage (CT), no tillage (NTS).

season, and in the summer, it was superior to the CT. In relation to the N stock, 9 NTS and CT areas presented different contents only in the winter and in a depth of 0–10 cm, which showed 3.75 Mg·ha^{-1} and 2.0 Mg·ha^{-1}, respectively (Figure 3).

The highest values of microbial biomass were found for reference forests. In winter, the MBC values of NTS areas were similar to those of CT areas, but in summer, areas 3NTS, 5NTS, and 9NTS presented 800, 300, and 200 mg·Kg^{-1}, respectively, values similar to or close to the values found in forests that presented 1000, 450, and 300 mg·Kg^{-1} and higher than those found in the respective CT areas, which showed 100, 80, and 40 mg·Kg^{-1} (Figures 4(a) and 4(b)). In winter and summer, the MBN values of the NTS areas did not differ or present lower values than those of the CT areas, except for the 9NTS area, which in the summer showed a higher value than the CT at a depth of 0–10 cm (Figures 4(c) and 4(d)).

The qMIC of areas 3NTS, 5NTS, and 9NTS in winter was similar to forests and CT. However, in summer, there was a considerable increase in qMIC in the 3NTS area, in the 0–10 cm layer, from 0.3% to 3.0%, while the comparative CT had little variation. For this same depth, soils under 5NTS and 9NTS also presented higher qMICs than soils under CT (Figures 5(a) and 5(b)).

For Nmin, in winter, there was a higher content in the 0–10 cm layer for the 3NTS and comparative areas, which showed similar values at both depths. The 5NTS area presented a higher value than the CT area, and the 9NTS area did not differ from the CT system. In summer, there was a decrease in Nmin content for all areas evaluated, with the 3NTS area showing a lower value than the CT area. In contrast, the 5NTS area was superior to the CT and the 9NTS areas did not differ from the respective CT system (Figure 5).

Soil C-CO_2 emission did not differ between systems within each study group (Figure 5(e)). However, qMET differed between management systems. The qMET values of the 3NTS, 5 NTS, and 9NTS areas were, respectively, 0.39, 1.1, and 0.75, lower than those found in the respective areas in CT (3.96, 4.97, and 5.53). The qMET values presented by all areas under the NTS system were similar to those found in the respective reference ecosystems (Figure 5(f)).

4. Discussion

This work evaluated soil physical and organic matter attributes of areas owned by family farmers who used soil conservation practices through the NTS compared to soil from areas under CT.

The soils of the studied systems showed great variability, so the systems were evaluated in independent groups (CT, NTS, and forest) for each period 3, 5, and 9 years of NTS adoption. The areas in the NTS showed high soil penetration resistance homogeneity along the 0–40 cm profile. In the establishment of NTS, farmers did not promote, as technical recommendation, the breaking of the compacted layers, making it difficult to establish the system and reducing the improvement in the physical attributes of the soils [27]. However, in areas with the CT system, there was low resistance in the 0–20 cm layer but high resistance at greater depth, indicating a phenomenon known as "grid foot," reducing macroporosity and the rate of soil water infiltration [28]. The homogeneity of resistance to soil penetration in no tillage is due to the soil not being turned over, which does not happen in areas under conventional planting, in which the surface layer is periodically turned over, resulting in compaction at greater depths, which compromises water absorption by the plants and favors erosion processes [4].

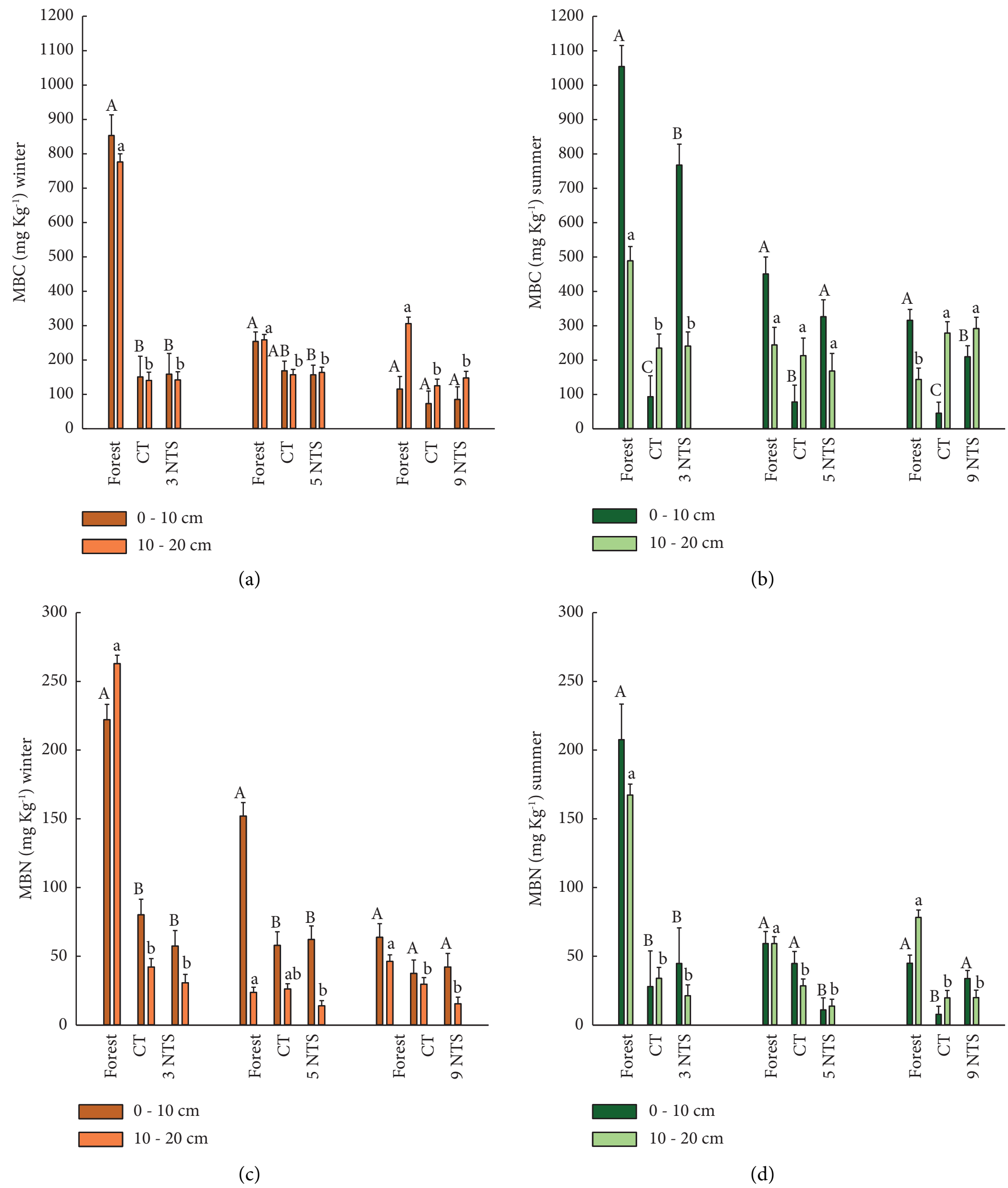


Figure 4: Mean microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) values for the winter (a, c) and summer seasons (b, d). Uppercase letters compare the depth averages of 0–10 cm, and lowercase letters compare the depth of 10–20 cm. Conventional tillage (CT), no tillage (NTS).

However, due to the high content of organic matter, the constant plowing and harrowing of the Typic Humaquepts soil reduced its density on the soil surface, improving soil aeration and root development in the plants (Table 5).

The highest proportion of macropores and total porosity was found in the 5NTS and 9NTS systems, even with the highest soil density values, which is not common. It is well documented in the literature that high soil density has greater proportion of micropores [2]. However, the cultivation of different species of cover crops, with different root arrangements, explores the soil profile at different depths, contributing to soil aggregation and promoting greater pore connectivity, resulting in an increase in total porosity [29, 30].

Removing the variability of the texture and density of the studied soils, the soils under forest and 5 NTS and 9NTS presented higher C and N stocks. This behavior is related to the greater organic input and the nonsoil turning in these systems [12]. These systems also showed lower metabolic quotient by microorganisms in relation to the CT system, indicating greater incorporation of C into the microbial biomass and lower emission of C-CO_2 per unit of microbial biomass (Figure 4). Thus, the adoption of NTS in horticultural systems is reversing the impact of the CT system over time [31, 32].

The reduction of C and N stocks in forest areas and NTS in the summer season confirms the high dynamics of organic matter in tropical systems. In these regions, high temperatures

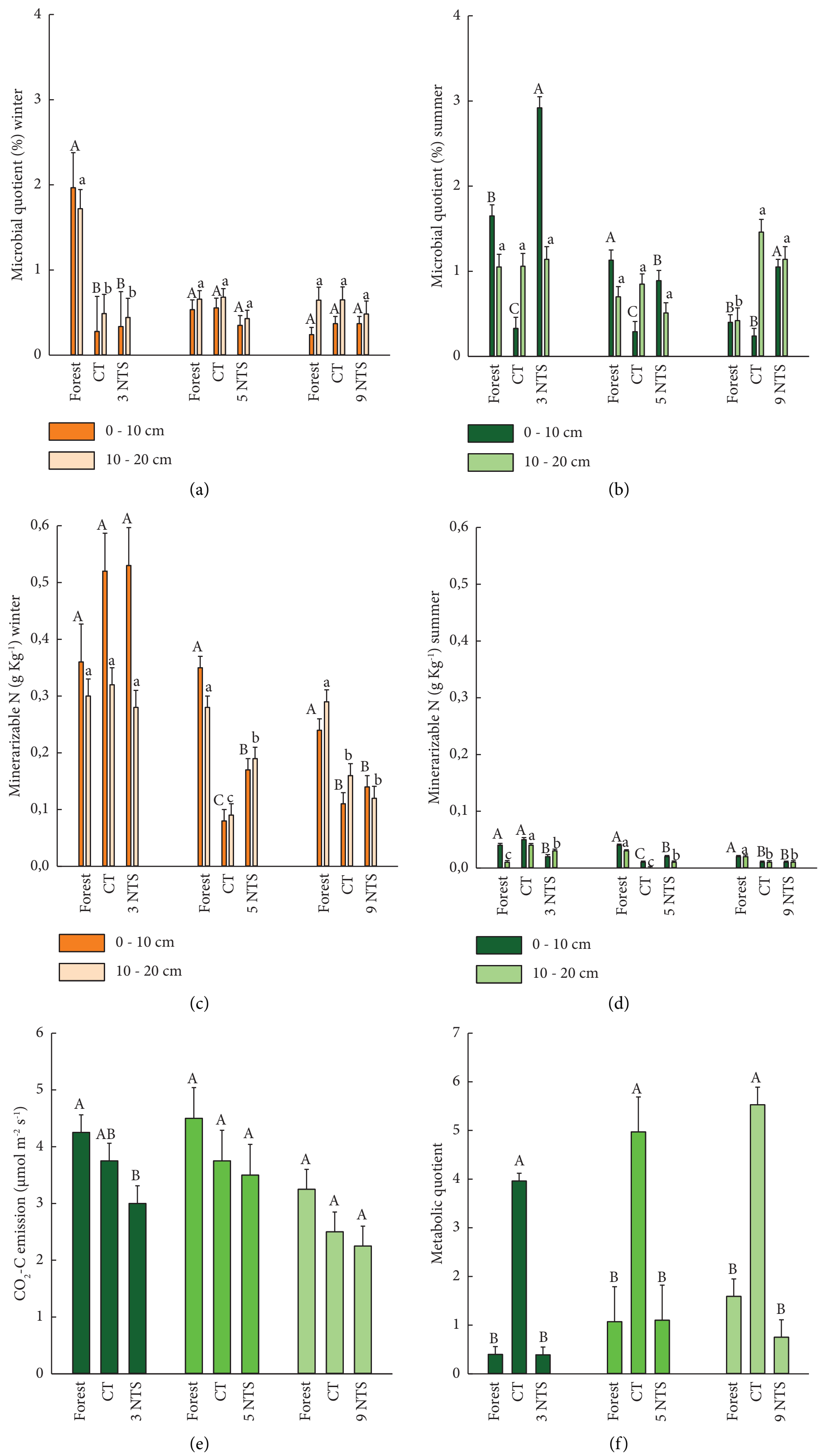


Figure 5: Mean values of the microbial quotient (a, b) and mineralizable N (c, d) for the winter (a, c) and summer (b, d) seasons, respectively. Mean values of CO_2-C emission (e) and quotient metabolic (f) for the summer season. Uppercase letters compare the depth averages of 0–10 cm, and lowercase letters compare the depth of 10–20 cm. Means followed by the same letter do not differ from each other using the t test ($p < 0.05$). Conventional tillage (CT), no tillage (NTS).

and rainfall in the summer increase soil biological activity, increasing microbial metabolism, C-CO_2 emission, and N volatilization [33]. However, in the CT areas, the stocks of C and N were not significantly influenced by the seasons. In these areas, the soils are constantly turned throughout the year, reducing the organic matter-mineral fraction interaction, and they receive organic manure, compensating part of the C and N losses in the summer period. Organic fertilization in the CT system may also increase the amount of N incorporated into the microbial biomass, presenting similar and/or superior N contents of the microbial biomass to soils under NTS. This behavior suggests that the organic supply in NTS should be adjusted to increase N fixation. This adjustment will favor nutrient cycling and C immobilization in the system [27].

The greater diversity of organic compounds added to the soil and the accumulation of plant material on the surface of the soils under forest and NTS resulted in higher values of CBM in relation to the soil under the CT system. The constant vegetation cover of the soil, in addition to the supply of substrate, favors the maintenance of soil temperature and moisture, providing a more favorable environment for microbial activity [34]. In the area under NTS, this effect is high in the summer, because in these areas, the soil remains covered in all crop and off-season cycles, through the planting and management of different cover crops that result in a high volume of biomass and consequently addition of organic waste with variable composition. The greater the richness and abundance of species in the system, the greater the microbial biomass in the soil [35].

The highest qMIC of NTS, in the summer period, in relation to CT systems, regards not only the high temperature and humidity of the period but mainly to the constant organic contribution of the NTS. This behavior indicates that in NTS, there is greater dynamic of organic matter and nutrients [36] and greater immobilization of C in the microbial biomass. In winter, due to the reduction of soil temperature and moisture, there was no difference in qMIC between NTS and CT areas.

The net emission of C-CO_2 from soils did not differ between the systems. However, the areas under NTS showed the lowest qMET values, similar to the reference areas. qMET represents the respiration rate per C unit of the microbial biomass, and the lower the value, the greater the stability and balance of the soil microbial community. In anthropic areas, microbial biomass increases metabolism by using the small resource of labile C to maintain the population, which characterizes a situation of constant stress [37]. Thus, even with higher levels of CBM, soils under NTS are, proportionally, emitting less C to the atmosphere than soils under the CT system.

5. Conclusions

Despite the great changes in the crop system and strategies of management adopted by farmers, the studied soils showed greater proximity of their physical characteristics and organic matter to the reference system with the increase in the time of adoption of the NTS. This result indicates that the natural balance of that agricultural cultivation ecosystem is being reestablished. The NTS systems showed higher C and N stocks, higher microbial biomass content and microbial quotient, and lower metabolic quotient and C-CO_2 emission than CT systems, revealing that the NTS in vegetable crops favors the activity and balance of soil microbial fauna. Thus, the adoption of NTS, with diversified organic input, should be encouraged in the sea of hill areas of the Atlantic Forest Biome but should consider the great changes in altitude and topographic positions of the soils in the biome to adjust the management strategy.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Additional Points

Highlights. (i) No-till systems are recommended for managing vegetable production in mountainous region. (ii) No-till systems increase soil C stock and reduce C-CO_2 emissions. (iii) No-till systems promote greater balance of soil microbial biomass. (iv) Soils under no-till systems have greater total porosity than soils under conventional systems.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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