AGRO PRODUCTIVIDAD

Colegio de Postgraduados

Physical, chemical, and microbiological parameters of soil under different tillage types

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Citation: Serrano-López, L. A., Armenta-Ayala, J. O., Cázarez-Flores, L. Ll., Zazueta-López, J. E., Ayala-Tafoya, F., Estrada-Acosta, M. D., Amarillas-Bueno, L. A., Mendoza-Gómez, A., & Angulo-Castro, A. (2024). Physical, chemical, and microbiological parameters of soil under different tillage types. *Agro Productividad*. https://doi.org/10.32854/agrop.v17i11.3139

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: May 14, 2024.
Accepted: September 26, 2024.
Published on-line: December XX, 2024.

Agro Productividad, 17(11) supplement. November. 2024. pp: 225-231.

ABSTRACT

Objective: To determine the effect on the chemical, physical and biological properties of soils under minimum tillage and conservation tillage in different locations in Sinaloa.

Design/methodology/approach: The treatments were evaluated using a completely randomized experimental design, with a total of eight treatments or sampling sites, where five samples per site were collected at a depth of 30 cm. A total of 40 samples were obtained, which were preserved in a thermal box and were transferred to the microbiology laboratory of the Faculty of Agronomy (UAS). The variables evaluated included the quantification of bacteria on plates, where the number of total bacterial colonies (TB), phosphate solubilizing bacteria (PSB), nitrogen-fixing bacteria (NF) and indole-promoting bacteria (IPB) were determined. In addition, organic matter, electrical conductivity and pH were determined.

Results: Soils under minimum tillage modality significantly promoted higher percentage of organic matter, a greater number of bacterial colonies and higher electrical conductivity compared to soils with conventional tillage modality.

Findings/conclusions: Agricultural tillage intervenes in the physical, chemical and microbiological properties of soils, as the sampling sites where minimum tillage is practiced show a higher concentration of organic matter and therefore leads to greater microbiology and electrical conductivity in those evaluated soils.

Keywords: Microbiological, Tillage, Organic matter.

INTRODUCTION

In the state of Sinaloa, different types of tillage are used in agricultural practices. It is essential to understand how these affect the various properties of the soil, as it is a vital natural resource for the development of life and a key element in the natural cycle of matter and energy. To fulfill its functions in agriculture, the soil must have adequate physical, chemical, and biological conditions (Brito *et al.*, 2019). Soil is composed of minerals, organic matter, microorganisms, macroorganisms, air, and water. It is important to note that the plants and animals that grow and die in and on the soil are decomposed by the

action of microorganisms, transformed into organic matter, and mixed with the soil (FAO, 2019). However, by incorporating organic matter through soil tillage, the degradation of its arable layer increases, promoting the progressive degradation of the soil surface and facilitating erosion, one of the main methods of degradation resulting from agricultural practices (Gómez *et al.*, 2018).

Soil degradation not only decreases crop yields but also reduces carbon storage in agricultural ecosystems and biodiversity (Castro *et al.*, 2022). As a consequence of all the soil degradation problems, many developing countries face the challenge of implementing sustainable agricultural models that allow for food production to meet the growing demand of the population in a manner more compatible with the environment and natural resources (Thilagar *et al.*, 2016). Tillage systems directly influence soil properties, such as aggregate fractions (Tiemann *et al.*, 2015). The aggregation process is a dynamic one in which micro-aggregates bind together through roots, fungi, bacteria, organic polymers, and residues (Lehmann *et al.*, 2015).

Soil organic matter is composed of animal and plant remains, which serve as a substrate for plant growth and as a source of carbon and nitrogen for microorganisms, providing chemical and biological stability to the soil (Murillo *et al.*, 2020). A portion of this organic matter consists of living microorganisms, whose activity is crucial in the biogeochemical cycles of nutrients, as they are involved in the processes of nutrient mineralization and immobilization (Moreno, 2023). Babalola (2010) mentions that microbial biomass accelerates the availability and assimilation of soil nutrients through various mechanisms such as atmospheric nitrogen fixation and phosphorus solubilization. Additionally, it promotes plant growth and health by controlling damage caused by pathogenic microorganisms and synthesizing phytohormones like auxins, gibberellins, and cytokinins. Furthermore, symbiotic relationships are established between plants and microorganisms, strengthening their natural defense mechanisms (Beltrán & Bernal, 2022). For this reason, the objective of this research is to determine the effect of minimum tillage and conservation tillage on the chemical, physical, and biological properties of soils in different locations in Sinaloa.

MATERIALS AND METHODS

Rhizospheric soil was collected from four maize-producing areas under minimum tillage in the state of Sinaloa, along with four samples of rhizospheric soil from maize under conventional management, as shown in Table 1.

Table 1. Sampling locations and their physical properties (soil textures).

	Estación Bamoa/ MT	**Palos Blancos/ MT**	**Las Tapias/ MT**	**La Unión/ MT**	**Costa Rica/ LC**	**Elota/ CT**	**Alhuey/ CT**	**San Pedro/ CT**
Sand (%)	44	46	82	45	15	53	43	45
Clay (%)	34	38	8	39	64	21	39	36
Silt (%)	22	16	10	16	21	26	18	20
Texture	CL	CL	SCL	CL	C	SCL	CL	CL

MT=Minimum Tillage; CT=Conventional Tillage; CL=Clay Loam; SCL=Sandy Clay Loam; C=Clayey.

Laboratory and field analyses were conducted in the Microbiology Laboratory and in a greenhouse at the Faculty of Agronomy of the Autonomous University of Sinaloa (UAS), located at km 17.5 of the Culiacán-Eldorado highway, in the municipality of Culiacán, Sinaloa. According to the Köppen climate classification, modified by García (1973), the climate type is B1 S1, described as semi-arid, with summer rains, occasional winter rains, and an annual precipitation of 670 mm. The area has an average annual temperature of 24 °C, with a maximum of 41 °C in summer and a minimum of 5 °C in winter. The average annual relative humidity is 66.66%. Sampling was conducted in maize fields under minimum tillage and conventional tillage. The treatments were evaluated using a completely randomized experimental design, with a total of eight treatments or sampling sites. Five samples were collected from each site at a depth of 30 cm, resulting in a total of 40 samples. These samples were preserved in a thermal box and transported to the Microbiology Laboratory at the Faculty of Agronomy (UAS). The evaluated variables included the quantification of bacteria on plates, where the number of total bacterial colonies (TB), phosphate-solubilizing bacteria (PSB), nitrogen-fixing bacteria (NFB), and indole-promoting bacteria (IPB) was determined. Additionally, organic matter, electrical conductivity, and pH were measured. The quantification of bacterial colonies was performed according to the technique established by NOM-092-SSA1-1994 (method for counting bacteria on plates). The samples were processed in a laminar flow hood (61010-1, Labconco) under aseptic conditions. Ten grams of each sample were weighed and placed in glass containers with 90 ml of sterile distilled water (first dilution), and from this solution, serial decimal dilutions were made. Subsequently, 0.1 ml of each sample was added to Petri dishes and spread over the surface of the solid culture medium using an L-shaped cell spreader. Specific culture media were used: nutrient agar TB (DOF, 1994); NBRIP to detect phosphate-solubilizing bacteria (PSB) (Nautiyal, 1999); Rennie for nitrogen-fixing bacteria (NFB) (Rennie, 1981); and Luria-Bertani (LB) for indole-promoting bacteria (IPB) (Luria and Burrous, 1957). The colonies were quantified after three days in an incubator (9025E, Ecoshel) at 28 °C.

Specific culture media were used: nutrient agar TB (DOF, 1994); Pikovskaya agar to detect phosphate-solubilizing bacteria (PSB) (Nautiyal, 1999); Rennie for nitrogen-fixing bacteria (NFB) (Rennie, 1981); and Luria-Bertani (LB) for indole-promoting bacteria (IPB) (Luria and Burrous, 1957). The colonies were quantified after three days in an incubator (9025E, Ecoshel) at 28 °C. Additionally, the organic matter content of the soil for each treatment was evaluated. For this, 0.50 g of the sample was weighed, and 10 mL of 1 N potassium dichromate, 10 mL of sulfuric acid, 2 mL of phosphoric acid, and 200 mL of distilled water were added per sample. Subsequently, the sample was titrated with 0.5 N ferrous sulfate (Walkley and Black, 1934). The pH and EC were measured using the saturated paste technique, which involved bringing the sieved soil sample (2 mm sieve) to saturation with distilled or deionized water, and then extracting the filtered soil solution using a vacuum pump (Warncke, 1986). The pH and EC of this solution were determined using a Hanna HI98130 meter. The data obtained were analyzed using the SAS program for Windows (SAS Institute Inc., 2002). An analysis of variance was performed, along with a means comparison test ($p \leq 0.05$) and a Pearson correlation.

RESULTS AND DISCUSSION

The quantification of beneficial plant growth-promoting bacteria (PGPB) from four soils under minimum tillage and four soils under conventional tillage in the state of Sinaloa is shown in Table 2. In the analyzed soil samples, the presence of beneficial microbial populations (phosphate-solubilizing bacteria, nitrogen-fixing bacteria, and indole-promoting bacteria) was observed, along with a significant presence of total bacteria. It is worth noting that the sample from Unión, Angostura (37.6×10^6) promoted a significantly higher number of colony-forming units of bacteria compared to the other evaluated samples ($p\leq0.05$). On the other hand, the sample from Palos Blancos, Guasave (10.2×10^6) induced a significantly greater number ($p\leq0.05$) of colony-forming units of bacteria in Pikovskaya agar culture medium, achieving the best results compared to the other analyzed samples. Similarly, the bacterial colonies that developed in the Rennie culture medium from the soils of Palos Blancos, Guasave (11.6×10^6) and La Unión, Angostura (11.6×10^6) produced the best results, although it is worth noting that they are significantly similar ($p\leq0.05$) to the sample from Estación Bamoa, Guasave (11.3×10^6). Finally, the soil from Estación Bamoa, Guasave (2.4×10^6) showed the best results compared to the rest of the analyzed samples. However, it only showed a significant difference ($p\leq0.05$) with the soils from San Pedro (1.9×10^6), Costa Rica (1.8×10^6), Las Tapias (1.1×10^6), and Alhuey (1.0×10^6), respectively.

On the other hand, the physicochemical properties of four soils under conventional tillage and four soils under minimum tillage were analyzed, as shown in Table 3. The soil from Estación Bamoa, Guasave (2.1%) showed the best results in organic matter, although statistically ($p\leq0.05$) it was equal to the sample from Palos Blancos, Guasave (1.85%) and La Unión, Angostura (1.95%).

Regarding the EC variable, the soil from Estación Bamoa, Guasave (1.4 dS m^{-1}) obtained the best results, statistically ($p\leq0.05$) superior to the rest of the evaluated treatments. Finally, the sample from Alhuey, Angostura (7.4 pH) showed the best results in

Table 2. Microbiological properties of four soils with minimum tillage and four soils with conventional tillage in the state of Sinaloa.

Sample / **Locality**	**Total bacteria**	**Pikovskaya (P)**	**Rennie (N)**	**Luria B. (indoles)**
	CFU mL^{-1}			
Estación Bamoa, Guasave/ML	21.2×10^6 c	8.1×10^6 b	11.3×10^6 a	2.4×10^6 a
Las Tapias, Culiacán/ML	15.6×10^6 d	1.8×10^6 ef	8.2×10^6 b	1.1×10^6 c
Palos Blancos, Guasave/ML	34.8×10^6 b	10.2×10^6 a	11.6×10^6 a	2.0×10^6 ab
La Unión, Angostura/ML	37.6×10^6 a	5.8×10^6 c	11.6×10 a	2.1×10^6 ab
Alhuey, Angostura/LC	9.8×10^6 f	1.2×10^6 f	1.7×10^6 d	1.0×10^6 c
Costa Rica, Culiacán /LC	11.5×10^6 e	2.2×10^6 de	1.1×10^6 d	1.8×10^6 b
San Pedro, Navolato/LC	8.1×10^6 g	1.4×10^6 f	1.2×10^6 d	1.9×10^6 b
Elota, La Cruz/LC	15.2×10^6 d	2.4×10^6 d	3.9×10^6 c	2.2×10^6 ab

Means with different letters in a column are statistically different (Tukey, $p\leq0.05$). MT=Minimum Tillage, CT=Conventional Tillage, P=Phosphorus, N=Nitrogen.

Table 3. Physicochemical properties of four soils with minimum tillage and four soils with conventional tillage from the State of Sinaloa.

Sample Locality	O.M. %	E.C. dS m^{-1}	pH 1-14
Estación Bamoa, Guasave/MT	2.1 a	1.4 a	7.1 c
Las Tapias, Culiacán/MT	0.9 b	0.9 bc	7.1 c
Palos Blancos, Guasave/MT	1.8 a	0.6 cd	7.2 bc
La Unión, Angostura/MT	1.9 a	1.1 ab	8.4 b
Alhuey, Angostura/CT	1.0 b	0.9 bc	7.4 a
Costa Rica, Culiacán /CT	1.1 b	0.5 cd	7.1 c
San Pedro, Navolato/CT	0.8 b	0.6 cd	6.7 d
Elota, La Cruz/CT	1.1 b	0.4 d	7.2 bc

Means with different letters in a column are statistically different (Tukey, $p \leq 0.05$). MT=Minimum Tillage, CT=Conventional Tillage, O.M.=Organic Matter, E.C.=Electrical Conductivity, pH=Hydrogen Potential.

terms of pH, being statistically ($p \leq 0.05$) better compared to the rest of the evaluated soil samples.

The correlation coefficients are shown in Table 4. This indicates that as the percentage of organic matter in the soil increased, the number of total bacteria rose by 85%. Additionally, the number of phosphate-solubilizing bacteria and nitrogen-fixing bacteria increased by 93% and 87%, respectively. On the other hand, the bacteria that promote indoles increased by 60%, and the electrical conductivity rose by 47% in response to the increase in organic matter. The pH showed no relationship with organic matter, presenting a null correlation.

Direct seeding is a management practice used to preserve the physical structure and increase the carbon stored in the soil. This way, it provides a habitat and higher quality substrates for the biota, improving the soil's biofertility (Holland, 2004). Each fraction of aggregates constitutes a microenvironment with unique physical, chemical, and structural characteristics that influence the microbial communities residing there (Mummey *et al.*, 2006).

Rojas and Camacho (2004) mention that bacterial populations will be higher in minimum tillage soils compared to conventional tillage soils. Additionally, Hernández and López (2002) agree that minimally disturbed soils are rich in carbon; therefore, they contain a greater microbial biomass compared to conventional tillage soils. Soil microbial communities play an integral role in nearly all ecosystem services, including nutrient cycling and the decomposition of organic matter (Trivedi *et al.*, 2017).

Table 4. Correlation analysis of organic matter with physicochemical and microbiological properties.

	BT	BSP	BFN	BPI	CE	pH
M.O.	0.85* p=.007	0.93* p=.001	0.87* p=.005	0.60 p=.115	0.47 p=.235	−0.02 p=.957

*Significant at $P \leq 0.05$. O.M.=Organic matter, TB=Total bacteria, PSB=Phosphate solubilizing bacteria, NFB=Nitrogen fixing bacteria, IPB=Indole promoting bacteria, EC=Electrical conductivity, pH=Hydrogen potential.

Soil organic matter contains about 5% total nitrogen, but it also includes other essential elements for plants, such as phosphorus, magnesium, calcium, sulfur, and micronutrients (Graetz, 1997). For this reason, organic matter in the soil increases cation exchange capacity, nutrient reserves, and mineralization processes (Julca *et al*., 2006). Although the decomposition of organic matter in the soil generates acids, such as carbonic acid, which can acidify the soil (Labrador, 2001), it was observed that organic matter and pH showed a null correlation. This may be due to the fact that the evaluated soils have high percentages of clay (except for the soil from Las Tapias). Sánchez *et al.* (2021) mention that clayey soils have a greater buffering capacity against changes in pH compared to sandy soils.

CONCLUSIONS

Agricultural tillage influences the physical, chemical, and microbiological properties of soils. In the sampling sites where minimum tillage was practiced, a greater concentration of organic matter was observed, leading to a higher number of bacterial microorganisms in the evaluated soils. Therefore, minimum tillage can be a viable strategy for agricultural production, contributing to soil conservation without negatively affecting properties that influence microbial activity.

Contributions of the authors: "Conceptualization, S.L. and A.C.; methodology, S.L. and A.A.; software, S.L.; validation, C.F. and Z.L.; formal analysis, A.T.; investigation, E.A. and A.B.; resources, Z.L.; data curation, M.G. and A.C.; writing—original draft preparation, L.C. and C.F., X.X.; writing—review and editing, A.C. and Z.L.; visualization, M.G.; supervision, A.A.; project administration, A.T.; funding acquisition, E.A. and A.B." All authors have read and approved the published version of the manuscript. Funding: "This research received no external funding." Conflicts of interest: "The authors declare no conflicts of interest."

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