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INFLUENCE OF ORGANIC MATTER ON THE PHYSICAL QUALITY OF SOILS UNDER INTENSIVE AGRICULTURAL MANAGEMENT

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ABSTRACT

Intensive agricultural management causes soil alteration, which leads to a decrease in some of its physical characteristics and a change in its quality and fertility. Bulk density and hydraulic conductivity are parameters used to evaluate these effects on food production. Other factors, such as soil organic matter, are also relevant for assessing soil quality, including physical quality, due to their close relationship with other soil properties. The objective of this study was to evaluate the physical quality of soils subjected to frequent changes resulting from intensive agricultural management. Five soils (S1, S2, S3, S4, and S5) classified as Vertisols from Acámbaro, in the state of Guanajuato, Mexico, were evaluated. Sampling was carried out at a depth of 0 to 20 cm to obtain a homogeneous composite sample. Nineteen physical variables and the soil organic matter content were determined. A principal component analysis was applied to rank the most important variables and calculate physical quality indices. Soil S4 had a low degradation index, associated with particle stability and high hydraulic conductivity (7.0 cm h^{-1}). Soils S1, S2, S3, and S5 were classified as having a moderate degradation index, attributable to intense mechanical effects such as subsoiling and harrowing. When the organic matter variable was integrated into the generation of the indices, the physical quality of all soils was considered high, and the degradation index decreased as a result of the high organic matter content (5.85–8.58 %) and reserves, which favor adequate physical conditions. The addition of labile organic materials, such as manure and compost, in intensive agriculture improves the physical quality of the soil over prolonged periods, with positive effects on its conservation.

Keywords: Intensive agriculture, physical fertility, soil conservation, Vertisols.

INTRODUCTION

Intensive agricultural management causes soil alteration, resulting in limited adaptability and recovery capacity. In the medium term, characteristics such as structure, water storage capacity, and resistance to environmental factors such as wind and heavy rainfall lead to a decline in soil quality and fertility (García *et al*., 2018; de Lima *et al*., 2017). This process causes the deterioration of its physical properties, such as compaction, as well as chemical imbalances such as the formation of salt crusts and the release of environmentally significant gases (Lepore *et al*., 2024).

Authors such as Schjønning *et al*. (2015) recommend establishing studies on land use intensity and soil characterization to address degradation processes and generate preventive or corrective strategies against adverse effects on soil susceptibility. Such studies should consider soil characteristics such as bulk density, particle size distribution, and hydraulic conductivity due to their influence on the assessment of effects on crop production (Ward *et al*., 2021) and their sensitivity to changes in soil management (Novillo-Espinoza *et al*., 2018). In this context, soil organic matter is important for creating quality indices, including physical quality, due to its strong connection with other soil properties (Montoya-Jasso *et al*., 2019; Chen *et al*., 2023; Xu *et al*., 2023).

Recently, mathematical models have been created that seek to integrate various variables to define restoration and improvement strategies in the management of agricultural production systems, including soil quality criteria (Lepore *et al*., 2024). These models make it possible to identify attributes with the greatest impact that contribute to the generation of indices of the current state of the soil (Montoya-Jasso *et al*., 2022). These include models for calculating soil water deficit (Schulte *et al*., 2005), drainage rates in different texture classes (Allen *et al*., 1998), and approaches based on lysimeter observations (Diamond and Sills, 2001). However, models of physical soil quality indicators, such as the S-Index (Dexter, 2004) and the Soil Management Assessment Framework (Andrews *et al*., 2004), include organic matter as an empirical variable with arbitrary weighting, without explicitly considering quantitative evidence of its relative weight on pure physical variables. Although these models integrate physical and chemical soil variables, there is a need to combine variables with high degrees of correlation.

Based on the above, the objective of this research was to create soil indices for the proposed models, both with and without organic matter. This was conducted to assess the physical quality of soils that undergo constant changes in their characteristics due to intensive agricultural management.

MATERIALS AND METHODS

Soils

Five soils classified as Vertisols were used, originating from Jaral del Refugio, in the municipality of Acámbaro, Guanajuato, Mexico. Sampling was carried out in soils under intensive agricultural management (subsoil, harrowing, and leveling at the beginning of each agricultural cycle for more than 30 years) (Table 1), at a depth of 0–20 cm. A sub-sampling system with an auger was applied at five points, and the samples were mixed to obtain a homogeneous composite sample per plot. The soils were dried

Table 1. Description of intensive agricultural management practices at the site evaluated.

Handling practice	Description	Impacts on the soil
Conventional farming	Subsoiling, plowing, and harrowing with tractors to turn the soil to a depth of 0–30 cm, followed by leveling and sowing with precision seeders. This method is used on 70–80 % of plots used for annual crops (corn and sorghum in the spring-summer cycle, wheat, oats, and chickpeas in the fall-winter cycle).	Improves initial aeration and weed control but accelerates water erosion and loss of organic matter (González-Contreras *et al*., 2025). High dependence on machinery (100 % tractors).
Fertilization and incorporation of amendments	Intensive chemical application (320 kg ha^{-1} of N; 41–100 kg ha^{-1} of P) in furrows, followed by sowing. Transition to mixed application with organic matter (50 %) and 100 % weed management with herbicides.	It corrects deficiencies, but generates losses of up to 165 kg N ha^{-1}; inefficiency 20–40 %. In transition plots, chemical doses are reduced by 20–50 % (Bhople *et al*., 2025).
Stubble management	Incorporation of post-harvest stubble (in corn and sorghum, 5–10 Mg of residues ha^{-1}). Currently, burning is avoided in only 60 % of the soils evaluated, and manure and compost are added (farmers do not have actual data on the amount added).	It stimulates soil biology, increases organic matter, reduces compaction by machinery, and improves yields, increasing corn grain yields by up to 1020 kg ha^{-1} (González-Contreras *et al*., 2023).

in the shade at room temperature to constant weight. They were then sieved with a 2.0 mm mesh. In cases where macroaggregates were present, they were ground with a porcelain mortar to reduce their size to 2.0 mm.

Laboratory determinations

The determinations were carried out at the Soil Physics Laboratory of the Postgraduate College. To remove the organic matter from the soil and ensure representativeness in subsequent analyses, a preliminary treatment with 30 % hydrogen peroxide was carried out. In soils where organic matter needed to be quantified, its content was determined using the Walkley and Black (1947) method.

Bulk density and saturated hydraulic conductivity were determined from unaltered samples, for which PVC cores 80 mm in diameter and 10 cm in length were installed, forming soil columns. Bulk density was calculated using the following equation:

$$Bulk\ density\ (g\ cm^{-3}) = \frac{Soil\ mass\ (g)}{Core\ volume\ (cm^{3})}$$

Subsequently, with the soil dried and sieved to 2.0 mm, the total porosity was calculated:

$$Total\ porosity\ (\%) = \left(1 - \left(\frac{Dap(g\ cm^{-3})}{Dr\ (g\ cm^{-3})}\right)\right) * 100$$

Textural classification was determined using the Bouyoucos (1936) method. Field capacity and permanent wilting point were obtained using the methodology proposed by Reynolds and Elrick (1986). The weighted mean diameter was estimated following the procedure described by Burés-Pastor (1997).

Likewise, the variables corresponding to the Atterberg limits (liquid limit, plasticity index, shrinkage index, and workability range) were determined. Based on these properties, the particle separability index (ISP) and the sealing-coating index (ISE) and coating index (IE) were estimated using the equations proposed by Florentino (1998) and Comerma *et al*. (1992):

$$ISP = \frac{\%\ of\ clay}{\%\ of\ silt + \%\ of\ sand}$$

$$ISE = \frac{6.7433 * \%\ of\ organic\ matter}{0.55001 * (\%\ of\ silt + \%\ of\ sand)}$$

$$IE = \frac{1.1255 * \%\ of\ silt}{(\%\ of\ clay + 10)(\%\ of\ organic\ matter)}$$

Multivariate analysis

For the analysis of determinations, SAS 9.3 statistical software (SAS Institute Inc., Cary, NC, USA) was used, and the methodology proposed by Florentino (1998) was applied, which recommends using principal component analysis (CP) to obtain a hierarchy of the most important variables and calculate the physical quality indices of the soils, taking into account their distribution and correlation along the component with the highest explained variance (Chen *et al.,* 2025).

Two CP analyses were performed. The first included the organic matter variable for all soils, while in the second this variable was excluded, with the aim of evaluating the impact of organic matter on the generation of soil physical quality indicators. Five levels of degradation (1 to 5) were identified, and the level degradation identity value (ID_N) was obtained using the following equation:

$$ID_N = \frac{V_{min}}{V_{max}}$$

where V_{min} corresponds to the level with the least degradation (1, 2, 3, or 4, as applicable) and V_{max} to the level with the greatest degradation (5).

The degradation index (*ID*) was calculated using the following expression:

$$ID = \sum_{i=1}^{n} \left(\frac{ID_N}{\#V}\right)$$

where $\#V$ corresponds to the number of variables selected by the model as the most representative ones.

Finally, the physical quality index of soils (ICFS) was calculated as:

$$ICFS = \frac{1}{ID}$$

RESULTS AND DISCUSSION

The physical characterization and organic matter content of the soil (Table 2) showed homogeneity in clay content (40 %), presumably expansive clays given the soil classification, which predisposes it to compaction (Dexter, 2004). However, the bulk density is low (<1.11 g cm^{-3}), indicating an absence of compaction despite frequent mechanization (Bondi *et al*., 2020) with subsoiling and harrowing, as well as the high organic matter content (>5.85 %), which, according to Dorji *et al*. (2019), promotes continuous improvements in physical and chemical properties, such as increased soil microporosity.

Soils S2, S3, and S5 exhibited zero hydraulic conductivity upon saturation, indicating a reduction in total pore space and suggesting structural alteration associated with intensive soil preparation for agricultural purposes (de Jong van Lier, 2017). In contrast, soils S1 and S4, with a smaller weighted mean diameter (<5.83 mm) and a crusting index <1, exhibit high stability, with no issues of surface compaction and greater mechanical resistance to losses due to irrigation water or precipitation.

In the principal component analysis of the model that included soil organic matter (MOS), CP1 explained 97.4 % of the variance, followed by CP2 with 1.41 %, which together accounted for 98.81 % of the total variability (Figure 1A). In the model excluding MOS, the component with the highest explained variance was CP1 at 97.31 %, followed by CP2 at 1.46 %, together explaining 98.76 % of the variability (Figure 1B). These results reinforce the reliability and applicability of both models for determining physical quality indices.

To calculate the degradation and physical quality indices, it is necessary to use the variables with the highest eigenvalues of CP1, as this component explains the largest percentage of variance and helps reduce measurement errors (Chen *et al*., 2025). In the

Table 2. Average values of the soil determinations made in Vertisols of Jaral del Refugio, in Guanajuato, Mexico.

Variable	Evaluated soils				
	S1	S2	S3	S4	S5
BD (g cm^{-3})	0.96	1.01	0.94	1.11	1.07
TPS (%)	61	57	55	54	57
MiP (%)	23	26	12	23	12
MaP (%)	38	31	43	31	45
Sa (%)	8	3	13	20	7
Si (%)	52	57	47	40	53
Cl (%)	40	40	40	40	40
FC (%)	48	59	38	46	39
PWP (%)	29	36	31	33	29
SHC (cm h^{-1})	1.33	0	0	7	0
WMD (mm)	5.83	6.22	6.67	4.39	6.62
OM (%)	6.63	8.58	5.85	8.19	6.24
PSI	0.667	0.667	0.667	0.667	0.667
SCI	0.495	0.563	0.383	0.188	0.548
CrI	1.355	1.753	1.195	1.673	1.275
SL	34	33	36	37	30
PL	38	37	37	41	37
LL	57	63	61	63	59
RW	19	26	24	22	22

BD: bulk density; TPS: total pore space; MiP: microporosity; MaP: microporosity; Sa: sands; Si: silts; Cl: clays; FC: field capacity; PWP: permanent wilting point; SHC: saturated hydraulic conductivity; WMD: weighted mean diameter; OM: organic matter; PSI: particle separability index; SCI: sealing-crusting index; CrI: crusting index; SL: shrinkage limit; PL: plastic limit; LL: liquid limit; RW: range of workability.

model including MOS, the representative variables were the liquid limit, sand content, permanent wilting point, crusting index, and sealing-crusting index (Figure 1A). In contrast, in the model excluding MOS, the selected variables were the liquid limit, total pore space, sand content, sealing-crusting index, and particle separability index, as they exhibited higher correlation and a high discriminatory value (Figure 1B).

Additionally, as bulk density increased, total pore space decreased (Figure 1A), indicating a decline in the soil's hydraulic properties (Chrysanthopoulos and Kallioras, 2025), including restrictions on root growth (Dexter, 2004). Likewise, MOS exhibited effects associated with a reduction in total pore space due to its high degree of recalcitrance, suggesting a gradual decrease in total porosity (Figure 1A). This behavior is consistent with that described by Minasny and McBratney (2017), who reported limiting effects on soil hydraulic capacity that favor waterlogging conditions and restrict plant growth (de Melo *et al*., 2023) when an easily mineralized organic

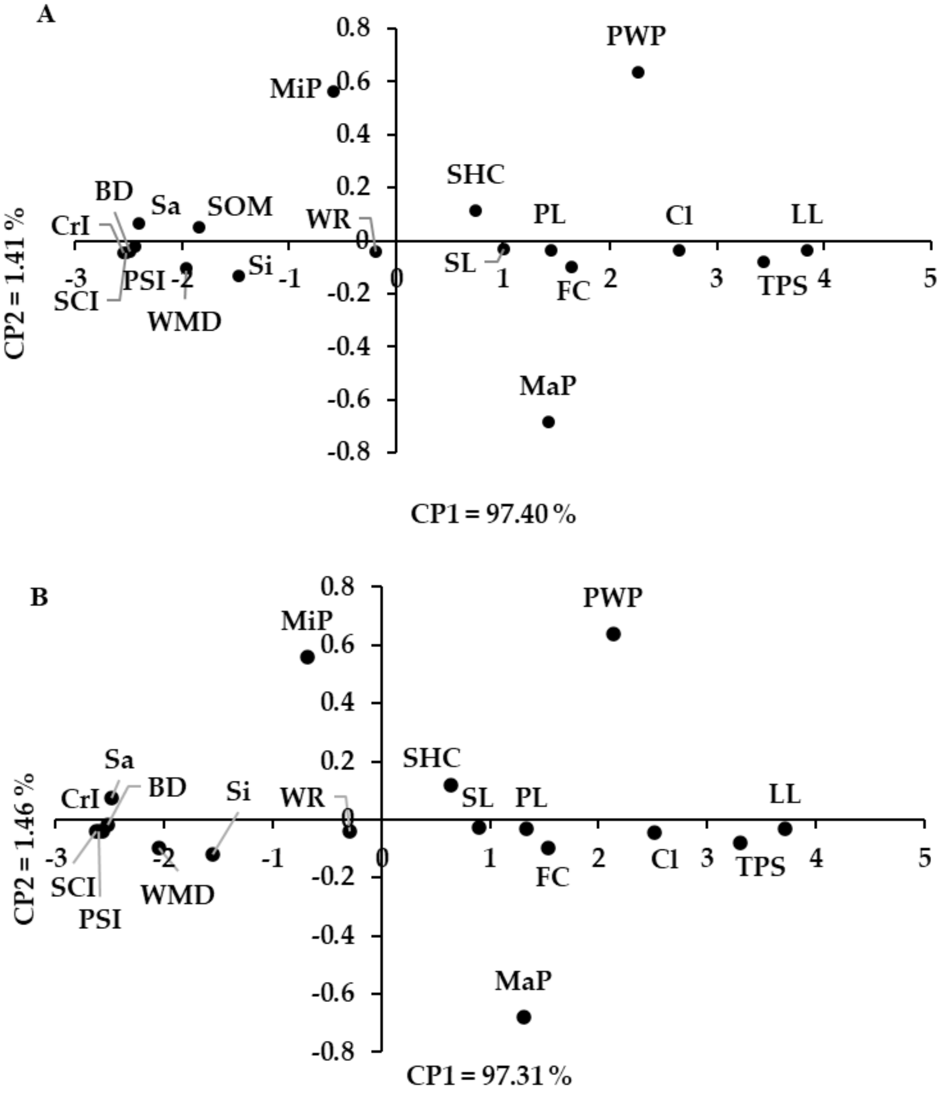

Figure 1. Biplot of the principal component (CP) analysis of soil physical properties. A) Model including soil organic matter (MOS); B) model excluding MOS. BD: bulk density; TPS: total pore space; MiP: microporosity; MaP: macroporosity; Sa: sands; Si: silts; Cl: clays; FC: field capacity; PWP: permanent wilting point; SOM: soil organic matter; SHC: saturated hydraulic conductivity; WMD: weighted mean diameter; PSI: particle separability index; SCI: sealing-crusting index; CrI: crusting index; SL: shrinkage limit; LP: plastic limit; LL: liquid limit; WR: workability range.

source is not incorporated to improve oxygen availability in the medium term (Mori *et al*., 2023).

In both models, field capacity and the permanent wilting point decreased as soil hydraulic conductivity increased (Figure 1) as a result of reduced moisture retention capacity in the surface layers (Salazar *et al*., 2022). However, this behavior is common in soils with high content of expansive clays (Pinheiro *et al*., 2019). Florentino (1998) proposed a classification of soil physical quality based on the degradation index, defined according to the intensity of the model's effect (Table 3).

Table 3. Classification of soil degradation and physical quality indices.

Class	Degradation Index	Interpretation	Physical quality index	Interpretation
1	<0.20	Very low	5.00	Very high
2	0.20–0.40	Low	5.00–2.50	High
3	0.40–0.60	Moderate	2.50–1.67	Moderate
4	0.60–0.80	High	1.67–1.25	Low
5	0.80–1.00	Very high	<1.25	Very low

Based on the classification of the degradation indices (DI) and physical soil quality indices (ICFS) for the evaluated soils (Table 4), it was observed that soil S4 had the lowest DI. This was due to aggregate stability resulting from the presence of particles with a mean diameter <4.39 mm and high hydraulic conductivity (7.0 cm h^{-1}) (Table 2). According to Reyes (2019), this reduces the risk of erosion. The remaining soils had a moderate DI, indicating a decrease in moisture retention and availability (hydraulic conductivity values <1.0 cm h^{-1}) (Minasny and McBratney, 2017) due to higher intensity of mechanized tillage (Liu *et al*., 2022).

Table 4. Assessment of the physical quality of Vertisols in Jaral del Refugio, Guanajuato, Mexico, subjected to intensive tillage.

Soil	DI	DI classification	ICFS	ICFS Classification	ICFS(t)	ICFS Classification(t)
S1	0.84	Very high	1.19	Very low	4.52	High
S2	0.84	Very high	1.19	Very low	4.78	High
S3	0.96	Very high	1.04	Very low	4.60	High
S4	0.88	Very high	1.14	Very low	4.49	High
S5	0.92	Very high	1.09	Very low	4.56	High

DI: Degradation index; ICFS: soil physical quality index; ICFS(t): transformed soil physical quality index.

Notably, ICFS values improved (Table 4) when labile organic matter was added to the soil, leading to a significant enhancement in physical quality through the formation of soil aggregates resulting from the release and formation of chelates during the mineralization of organic matter in conjunction with soil clays (Montoya-Jasso *et al*., 2021). The addition of waste creates a reserve of slowly mineralizing organic materials, which ensures the long-term preservation of soil physical quality (Głąb *et al*., 2016).

CONCLUSIONS

Intensive agricultural management reduces the ability of the topsoil to retain and distribute moisture, reflecting significant degradation effects. Despite extensive mechanization, the addition of labile organic matter in intensive agriculture improves soil physical quality over a considerable period, which has a positive impact on soil conservation. To minimize errors in interpreting the results of multivariate analysis, it is important to use reference tables specific to the soil type when evaluating soil degradation indices and physical quality.

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