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Impact of Land Use On Soil Organic Matter Fractions and Physical Quality Under Sub-humid Climate in Algeria

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Abstrait

This study investigates the influence of organic matter and its fractions on changes in soil physical properties under different land uses in surface (H1: 0–10 cm) and subsurface (H2: 10–20 cm) horizons. Four plots were examined: arboriculture (A), cereal cultivation (C), market gardening (M), and a forested control (F). Soil samples were analyzed for total organic carbon (TOC), particulate organic carbon (POC), associated organic carbon (AOC), structure (S), aggregate stability (AS), bulk density (BD), water retention capacity (FC), permanent wilting point (PWP), macroporosity (MP), and microporosity (mP).

Results indicated that physical properties in the surface horizon H1 were significantly enhanced ($p < 0.05$) in the forested plot F, correlating with higher TOC and POC levels. In contrast, subsurface H2 properties showed no significant differences across land uses. Among the measured indicators, POC was the most responsive to land-use changes, whereas mP, AOC, and PWP exhibited minimal variation.

Keywords: Particular organic matter, Soil quality, Land use.

1.Introduction

Soil organic matter (SOM), though comprising only 1-6% of agricultural soil mass, critically influences soil quality through its impact on physical, chemical, and biological properties (Magdoff et al., 2021). Its role in carbon sequestration has further highlighted its importance in climate change mitigation (Murindangabo et al., 2023). The distribution of organic fractions is influenced by land use type (Moratelli et al. 2023 ; Signor et al., 2018) and agriculture practices (Belhadj et al., 2023)

SOM consists of distinct fractions with varying stability and functions. The labile fraction (e.g., particulate organic carbon) features rapid turnover (months to years) and responds quickly to management changes, serving as a sensitive indicator of soil health and providing short-term nutrient cycling (Murindangabo et al., 2023). In contrast, the stable fraction (e.g., associated organic carbon) persists for decades to centuries, contributing to long-term carbon storage and structural stability through mineral associations and aggregate protection (Mayer et al., 2022).

Land use significantly affects SOM dynamics. Forest systems typically maintain higher SOM levels than agricultural lands due to minimal disturbance and continuous litter inputs (Mayer et al., 2022). Agricultural conversion often reduces SOM, particularly labile fractions, through tillage and reduced organic inputs (Murindangabo et al., 2023). However, management practices like reduced tillage and organic amendments can mitigate these losses.

SOM fractions differentially influence soil physical properties. Labile fraction promotes macroaggregate formation, improving aeration and water infiltration, while stable fraction enhances microaggregate stability. Both fractions increase water retention capacity and reduce bulk density (Magdoff et al., 2021).

Despite this understanding, knowledge gaps remain regarding of SOM dynamics in subsurface horizons, and the specific contributions of different fractions to physical properties across land uses (Mayer et al., 2022). Our study addresses these gaps by examining organic fractions effects on physical properties (structure, porosity, water retention) in surface and subsurface horizons across four land uses (arboriculture, cereal cultivation, market gardening, and forest). The findings will inform sustainable management strategies for maintaining soil quality through SOM conservation.

2.Materials and methods

Description of the study area

The research site is located within the commune of Sidi Rachid, situated in the Tipasa province of Algeria, at coordinates 36°34'1.80" N, 2°33'30.41" E. This area is part of the broader West Mitidja plain. The region experiences a subhumid Mediterranean climate, with an elevation of approximately 80 meters above sea level. The mean annual temperature is 13.8°C, and the average annual precipitation is 620 millimeters, primarily occurring from October through May. The soils in the study area are predominantly deep, with a neutral,silty clay texture, low in calcareous content, and salinity.

Four distinct land use types were selected for this study: arboriculture (A), cereal cultivation (C), market gardening (M), and a control plot under forest (F). The forest plot represented a natural ecosystem with minimal human disturbance and served as a reference for comparison with the agricultural land uses. The arboriculture plot consisted of fruit trees (primarily apple and pear) that had been established for over 15 years. The cereal cultivation plot was under a wheat- fallow rotation system with conventional tillage practices. The market gardening plot was used for intensive vegetable production with frequent tillage and high input of organic amendments. Each land use type included three replicate plots, selected for uniform soil texture, consistent ≥10-year management history, comparable initial conditions.

Soil sampling and analyses

Soil samples were collected in Avril 2023. Three samples of disturbed and undisturbed soil were collected randomly for each of the Horizon, H1 :0 - 10 and H2 : 10 -20 cm.

Total organic carbon (TOC) was analysed according to Walkley method described by Nelson and Sommers (1996) which involves oxidation of organic carbon with potassium dichromate ($K_2Cr_2O_7$) in the presence of concentrated sulfuric acid (H_2SO_4). The excès dichromate was titrated with ferrous ammonium sulfate.

Particulate organic carbon (POC) was determined using the physical fractionation method described by Cambardella and Elliott (1992). Briefly, 20 g of air-dried soil was dispersed in 100 ml of sodium hexametaphosphate solution (5 g L^{-1}) and shaken for 18

hours on a reciprocal shaker. The soil suspension was then passed through a 53-µm sieve, and the material retained on the sieve (sand plus particulate organic matter) was collected, dried at 60°C, weighed, and analyzed for carbon content using the same wet oxidation method used for TOC. The POC content was expressed as a percentage of the total soil mass. Associated organic carbon (AOC) was calculated as the difference between TOC and POC: AOC (%) = TOC (%) - POC (%)

This fraction represents the organic carbon associated with the mineral fraction of the soil (silt and clay) and is considered more stable than the particulate organic carbon

Structure (S), aggregate stability (AS), bulk density (BD), field capacity (FC) and the soil water content at the permanent wilting point (PWP), were determinated on undisturbed soil samples. The S was evaluated by visual observations and scoring method of Ball *et al*. (2017), from good structure quality (score 1) to bad structure quality (score 5). The AS was determined according to Le Bissonnais (1996) method and BD was estimated using cylinder (100 cm3). The undisturbed samples were saturated for 24 h and subjected to the tensions set at -33 and 1500 KPa to analyze the volumetric humidity (cm3/100cm3) corresponding to FC and PWP, respectively. Macroporosity (MP) and microporosity (mP) are determined by applying Jurin's law which establishes a relationship between water retention and pore size. Pores with diameters greater than 6.12 µm correspond to macroporosity and pores with diameters less than 6.12 µm correspond to microporosity.

Statistical analysis

All statistical analyses were performed using the R statistical software (version 4.4.2). The data were first tested for normality using the Shapiro-Wilk test and for homogeneity of variances using Levene's test. When necessary, data transformations (log or square root) were applied to meet the assumptions of parametric tests.

A two-way analysis of variance (ANOVA) was conducted to assess the effects of land use type, soil depth, and their interaction on soil organic matter fractions and physical properties. When significant effects were detected ($p < 0.05$), post-hoc comparisons were performed using Tukey's Honestly Significant Difference (HSD) test to identify specific differences among land use types and between soil depths. Additionally, principal component analysis (PCA) was performed to explore the multivariate relationships among the measured variables and to identify the main factors explaining the variation in soil properties across different land use types and soil depths. The PCA was performed after normalizing the original values of the variables with a mean equal to 0 and a variance equal to 1. The number of components was selected based on the eigenvalues greater than 1 and an accumulated variance greater than 70%. Thus, using PCA to verify the multi-relationships between soil indicators and to select the indicators that contribute most to soil variability between land use types and between measurement depths. All results are presented as means ± standard errors, and statistical significance was determined at $p < 0.05$ unless otherwise stated.

3.Results

Organic Matter Fractions

As presented in Table 1, the storage of TOC, POC, and AOC varies significantly (*p* < 0.05) across different land-use types in the H1 and H2 horizons.

Table 1. Comparison of mean TOC, POCand AOC storage (Mg/ha) across land-use types (F, A, C, M) under soil horizons (H1 and H2) at p < 0.05.

	TOC Mg/ha	POC Mg/ha	AOC Mg/ha
Horizon H1			
Arboriculture (A)	29.5 b	11.5 a	17.8 ab
Cereal (C)	27.3 b	9.7 a	17.6 ab
Machage (M)	19.7 a	10.5 a	19.2 b
Forest (F)	42.3 c	28.2 b	14.1 a
Horizon H2			
Arboriculture (A)	24.1 b	11.9 c	12.2 a
Cereal (C)	30.3 c	13.1c	17.2 b
Machage (M)	23.6 b	9.2 b	14.4 ab
Forest (F)	20 a	5.3 a	14.7 ab

In surface horizons, forest soils storage significantly higher TOC (42.3 Mg/ha) than agricultural systems (19.7- 29.5 Mg/ha , $p<0.05$), following: F>A≈M>C.

The labile POC fraction showed greater sensitivity to land use (28.5- 9.7 Mg/ha). TOC constituted 51% of TOC in forests versus 31-39% in agricultural systems. In contrast, stable AOC varied less (14.1- 19.2 Mg/ha), with only F-C differences being significant ($p<0.05$) (Figure 1).

In subsurface horizons, exhibited minimal land-use effects, with non-significant TOC differences (20-30.3 Mg/ha). Vertical stratification was most pronounced for POC (68% decrease in F vs 42% in C) and least for AOC (18-32% decrease), highlighting POC's sensitivity to management versus AOC's stability.

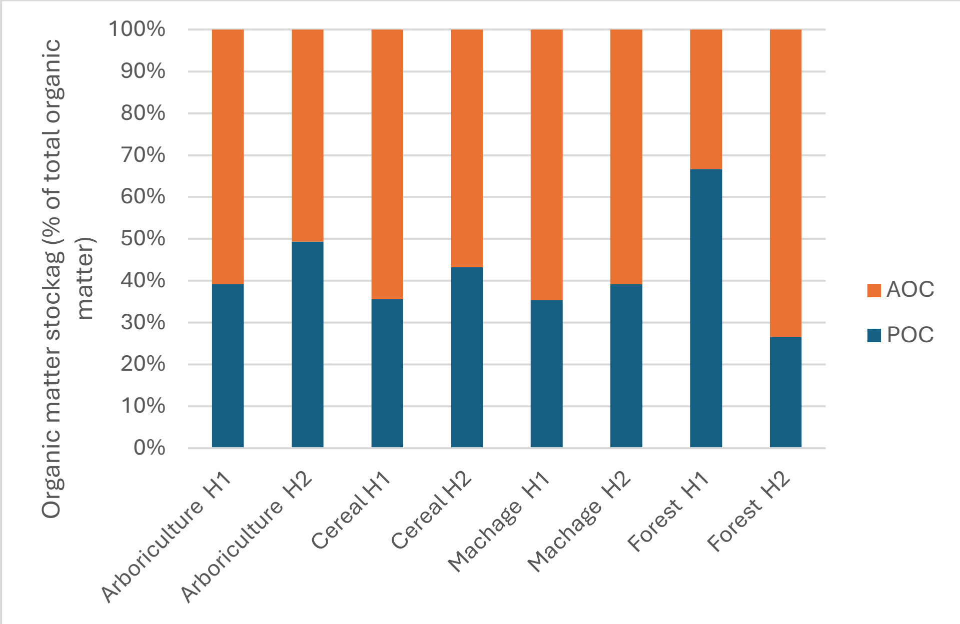

Figure 1. Contribution of POC and AOC fractions to total organic carbon (TOC) storage among land-use types (F, A, C, M) in the H1 and H2 horizons.

These patterns demonstrate that land-use impacts on organic matter are surface-concentrated, with forest systems showing the strongest vertical gradients.

Physical Properties

The analysis of Table 2 indicates that soil morphological and physical indicators are significantly different at $p < 0.05$ among various land use types in the H1 and H2 horizons.

Land use significantly affected surface horizon H1 physical properties ($p<0.05$). Forest soils showed infererior scor structural quality S (1 vs 2 in agricultural systems) and superior AS (2.14 mm vs 0.93-1.04 mm). BD inversely correlated with organic content (forest: 1.41 g cm^{-3}; Machage: 1.55 g cm^{-3}).

FC was highest in forests (30.6%) and lowest in cereals (24.25%), while PWP showed no significant differences (9.2-10.4%). MP exhibited a clear forest-to-cereal gradient (11.4% vs 8.7%), contrasting with less variable mP (21.7-15.9%).

Subsurface horizons (10-20 cm) showed no significant land-use effects, confirming surface-concentrated impacts. The results demonstrate forest systems' superior physical quality, with cereal cultivation showing the greatest degradation.

Table 2. Mean soil physical quality in land-use type (F, A, C, M) under soil horizon (H1, H2) at p < 0.05

	S Scor	BD g/cm3	AS mm	FC %	PWP %	mP %	MP %
Horizon H1							
Arboriculture (A)	2b	1.5b	0.95a	28.36b	9.65a	18.91b	10.02b
Cereal ©	2b	1.52b	1.04a	24.25a	9.23a	15.95a	11.10b
Machage (M)	2b	1.55b	0.93a	27.96b	10.41a	18.04b	8.74a
Forest (F)	1a	1.41a	2.14b	30.6c	10.3a	21.70c	11.48b
Horizon H2							
Arboriculture (A)	3a	1.55a	1.24a	29.5a	9.1a	19.03a	**7.75a**
Cereal ©	4b	1.58a	1.22a	30.2a	10.3a	19.11a	6.44a
Machage (M)	4b	1.6a	1.20a	30.7a	9.8a	19.19a	5.58a
Forest (F)	3a	1.57a	1.22b	30.4a	10.2a	19.36a	6.60a

Subsurface horizons (10-20 cm) showed no significant land-use effects, confirming surface-concentrated impacts. The results demonstrate forest systems' superior physical quality, with cereal cultivation showing the greatest degradation.

Relationships Between Organic Matter Fractions and Physical Properties

Table 3 indicates that the first three principal components (Dim1, Dim2, and Dim3), with eigenvalues greater than 1, explain 47%, 32%, and 14% of the data variation, respectively, accounting for a cumulative 93% of the total variance.

Tableau 3. Link between the variable and the continuous variables (R-square)

	Dim1	Dim2	Dim 3
Eigenvalue	4.7	3.2	1.4
Variance %	47.4	32.2	14
Cumulative %	47.4	79.7	93.7
S	12.5*	11.4	0
BD	17.5**	3.9	1.1
AS	14.1*	5	2.7
FC	1.2	27.9***	0.5
PWP	2.3	4.3	48.8*
mP	10.1	14.7	0
MP	6.6	20.3*	1.4
TOC	17.3**	0.4	4.7
POC	19.1***	0	0
AOC	0.8	11.6	40.6*

In Dim1, the soil indicator POC contributes the most to the variability, with a 19% contribution, followed by BD and TOC, each contributing 17%, and AS and S contributing 14% and 12%, respectively.

In Dim2, FC and MP are the most influential indicators, contributing 27% and 20%, respectively. In Dim3, PWP and mp are the primary contributors, with 48% and 40% contributions, respectively.

Figure 2 shows that these indicators are well-projected and correlated along the Dim1 and Dim2 axes. On Dim1, S and BD are negatively correlated, while POC, TOC, and AS are positively correlated. In Dim2, FC is positively correlated, whereas MP is negatively correlated.

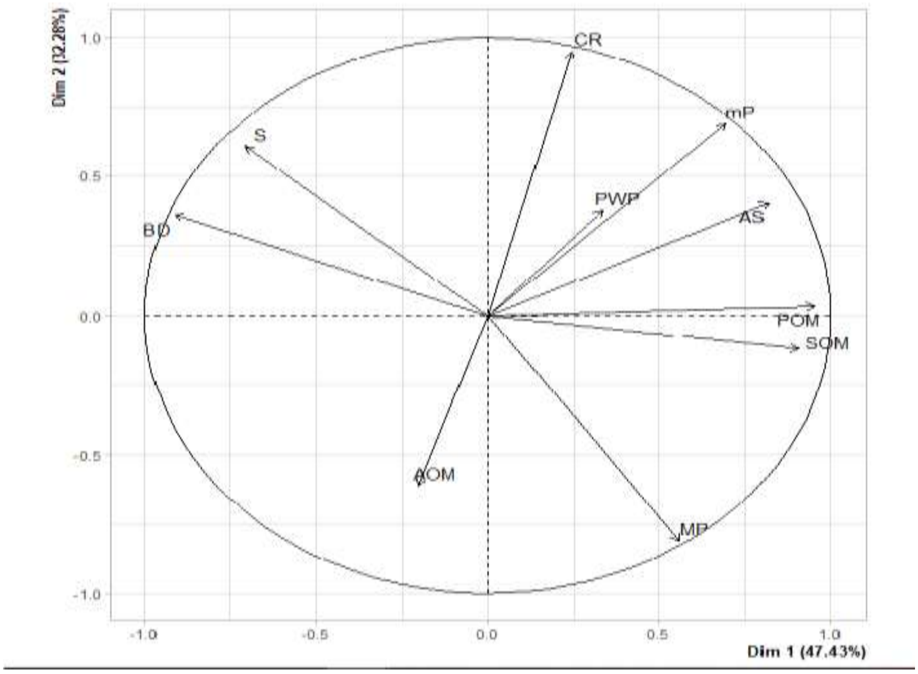

Figure 2.Principal component analysis of soil indicators (TOC, POC, AOC, S, BD, AS, FC, PWP, mP and MP).

Based on the similarity of land indicators, the land cover types form three hierarchical cluster groups. The first cluster includes H1F, the second includes H1M, H1C, and H1A, and the third includes H2F, H2A, H2C, and H2M (Figure 3).

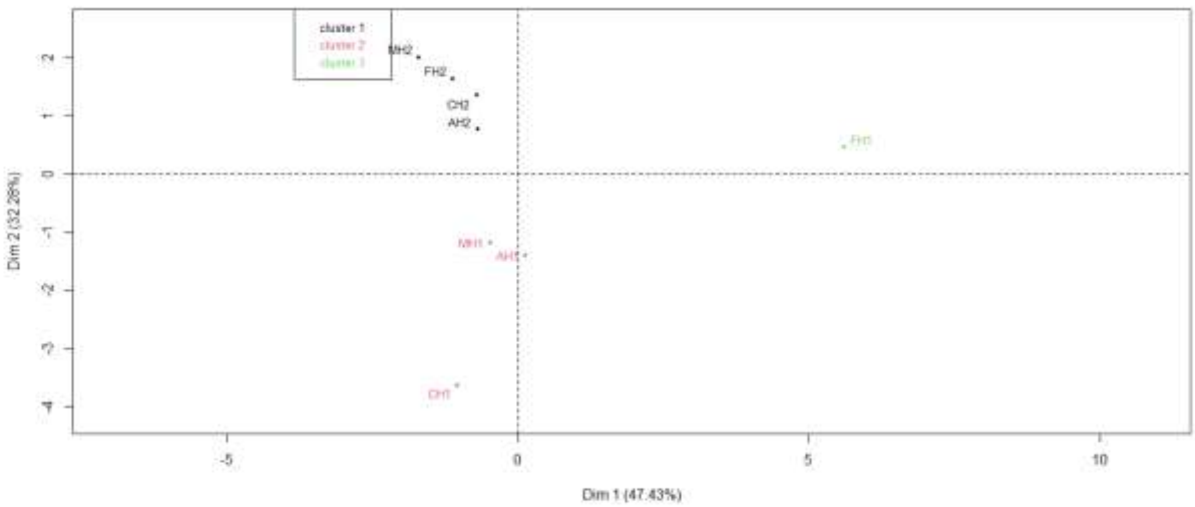

Figure 3. Correlation between soil horizons (H1 and H2) and land use type (F, A, C and M).

Principal component analysis and dendrogram provides a visual summary of the differentiation between the different land use types (F, A, C and M) by horizons H1 and H2.

In the surface horizon H1, land cover F forms a distinct cluster compared to A, C and M. This suggests that F has unique soil properties which may be due to the high accumulation of organic matter, especially, in the labile fraction POC. This indicator can directly improve the total stock TOC, S, BD, AS, CF, MP.

4.Discussion

Impact of Land Use on Organic Matter Fractions

The results of this study clearly demonstrate that land use has a significant influence on soil organic matter content and its fractions, particularly in the surface horizon. The consistently higher levels of total organic carbon (TOC) and particulate organic carbon (POC) observed in the forest plot compared to agricultural land uses align with findings from numerous previous studies (Six et al., 2002; Murindangabo et al., 2023; Mayer et al., 2022). This pattern can be attributed to several factors inherent to forest ecosystems.

Forests typically have higher organic matter inputs through continuous litterfall and root turnover compared to agricultural systems where a significant portion of biomass is removed through harvest (Lal, 2004). Additionally, the absence of tillage in forest soils minimizes the physical disruption of soil aggregates that would otherwise expose protected organic matter to microbial decomposition (Six et al., 2000). The more favorable microclimate in forests, characterized by reduced temperature fluctuations and higher soil moisture, also contributes to slower decomposition rates and greater accumulation of organic matter (Jobbágy and Jackson, 2000).

Among the agricultural land uses, the gradient of organic matter content (arboriculture > market gardening > cereal cultivation) reflects differences in management intensity and organic inputs. Arboriculture, with its perennial vegetation and reduced soil disturbance, creates conditions more similar to natural ecosystems compared to annual cropping systems (Lal, 2004). The higher organic matter content in market gardening compared to cereal cultivation can be attributed to the more frequent application of organic amendments in vegetable production systems (Haynes and Naidu, 1998).

The vertical distribution of organic matter fractions, characterized by a consistent decrease from the surface to the subsurface horizon across all land use types, reflects the typical depth gradient of organic inputs in terrestrial ecosystems (Jobbágy and Jackson, 2000). However, the magnitude of this decrease varied among land use types and organic matter fractions, providing further evidence of land use effects on soil carbon dynamics.

The more pronounced decrease in POC with depth compared to AOC across all land use types is consistent with the conceptual understanding of organic matter dynamics, where fresh inputs primarily affect the labile fractions in the surface soil, while the stable fractions show more gradual changes with depth (Six et al., 2002). The larger vertical gradient of POC in the forest plot compared to agricultural land uses can be attributed to the concentration of litter inputs at the soil surface in forest ecosystems, in contrast to agricultural systems where tillage redistributes organic matter within the plow layer.

Impact of Land Use on Soil Physical Properties

The observed differences in soil physical properties among land use types parallel the patterns observed for organic matter fractions, with the forest plot consistently showing more favorable physical conditions compared to agricultural land uses. This alignment suggests a strong influence of organic matter on soil physical quality, a relationship that has been well-documented in the literature (Bronick and Lal, 2005; Six et al., 2004).

The differential response of various physical properties to land use change provides insights into the specific mechanisms through which organic matter influences soil physical quality. Properties such as soil structure, aggregate stability, and macroporosity showed greater sensitivity to land use compared to microporosity and permanent wilting point. This pattern suggests that organic matter, particularly the labile fraction, has a stronger influence on macrostructural properties compared to microstructural properties.

The limited variation in soil physical properties in the subsurface horizon among different land use types, despite some differences in organic matter content, suggests that factors other than organic matter may play a more dominant role in determining physical properties at depth. These factors may include inherent soil characteristics such as texture and mineralogy, which were relatively consistent across our study sites.

Relationships Between Organic Matter Fractions and Soil Physical Properties

The correlation analysis and principal component analysis revealed strong relationships between organic matter fractions and soil physical properties, with particulate organic carbon (POC) showing stronger correlations with most physical properties compared to associated organic carbon (AOC). This finding highlights the disproportionate influence of the labile organic matter fraction on soil physical quality, despite its typically smaller contribution to total organic carbon.

These results are similar to several researches such as, Melo et al., (2017) ; Moratelli et al., (2023). In contrast, in the subsurface horizon H2, F clusters with A, C and M, indicating a strong similarity in soil properties. This is mainly due to the different vertical disturbance of the soil by different tillage tools.

The principal component analysis provided a holistic view of the relationships among organic matter fractions, soil physical properties, and land use types. The clear separation of land use types along the first principal component, which was associated with organic matter content and most physical properties, confirms the dominant role of land use in shaping soil quality through its effects on organic matter dynamics.

The positioning of forest plots at the positive extreme of the first principal component, associated with higher organic matter content and better physical properties, underscores the ecological significance of forest ecosystems in maintaining soil quality. The intermediate positions of arboriculture and market gardening plots suggest that these agricultural systems, with appropriate management, can maintain soil quality at levels closer to natural ecosystems compared to more intensive cropping systems like cereal cultivation.

The superior soil quality observed in the forest plot suggests that agroforestry systems and other approaches that mimic natural ecosystems may offer promising pathways for sustainable agricultural intensification. By integrating trees or perennial vegetation into agricultural landscapes, these systems can enhance organic matter inputs, reduce soil disturbance, and create more favorable microclimates, thereby improving soil physical quality while maintaining agricultural productivity.

5.Conclusion

The conversion of natural soils to agricultural use, regardless of the specific type, has led to a decline in soil physical quality in both the surface and subsurface layers. This degradation is primarily due to the reduction and dilution of organic matter, particularly the labile and particulate fractions.

The particulate organic carbon (POC) fraction is the most sensitive indicator of land use change. When POC decreases in the soil, it can negatively impact the total organic carbon stock (TOC), leading to poor soil structuring (S), increased soil compaction (BD), reduced aggregate stability (AS), poor aeration (MP), and decreased water retention capacity (FC). Conversely, the associated organic fraction remains relatively stable in this type of soil.

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