IECAG 2025 Conference
The 5th International Electronic Conference on Agronomy
15–18 December 2025 | Online
MDPI
sciforum-145097

Soil Quality Enhancement through Integrated Farming Systems

Martha Elena Domínguez-Hernández[1], Arnulfo Domínguez-Hernández[2], Elisa Domínguez-Hernández[3], Rosalba Zepeda-Bautista[2]
1Department of Agricultural Sciences, Faculty of Higher Education Cuautitlán, National Autonomous University of Mexico, Cuautitlán Izcalli, State of Mexico, 54714, México
2 Higher School of Mechanical and Electrical Engineering, National Polytechnic Institute, Gustavo A. Madero 07738, Mexico
3 Department of Mathematics, Faculty of Higher Education Cuautitlán, National Autonomous University of Mexico, Cuautitlán Izcalli, State of Mexico, 54714, México

INTRODUCTION & AIM

Soil quality is fundamental to sustaining agricultural productivity, ecosystem functioning, and long-term food security [1,2]. It affects nutrient cycling, water retention, carbon sequestration, and overall crop development. As global demand for food rises and climate variability intensifies, maintaining and improving soil quality has become essential for building resilient agri-food systems [3]. In Mexico and many other regions, conventional practices such as continuous monoculture, reduced agrobiodiversity, and limited organic inputs, have accelerated soil degradation, threatening long-term productivity and system resilience [4].

Management practices strongly influence soil quality trajectories. Practices that increase plant diversity, introduce legumes, integrate livestock, and maintain year-round soil cover tend to enhance soil organic matter, improve nutrient availability, and reduce compaction [5–8]. In contrast, monoculture systems and the absence of controlled grazing often deplete nutrients, reduce biological activity, and deteriorate soil structure over time.

Integrated crop-livestock systems offer a promising alternative to counter these negative trends by enhancing nutrient recycling through manure deposition, diversifying root structures, and stabilizing soils with continuous vegetative cover [8,9].

Despite growing interest in integrated systems, empirical evidence on how different levels of integration influence soil quality remains limited, particularly in regions transitioning from conventional maize monoculture. This study addresses this gap by evaluating soil quality dynamics across four farming systems with contrasting integration levels, ranging from low-integration maize monoculture to diversified crop-livestock configurations. By assessing physical and chemical soil properties, identifying key indicators through Principal Component Analysis (PCA), and developing a Soil Quality Index (SQI), this research provides a comprehensive understanding of how integration practices affect soil quality.

METHOD

Four farming systems were evaluated: FS1, a low-integrated system characterized by maize monoculture without grazing, and three medium-to-high integrated systems that all included grazing: FS2 (grass + legume), FS3 (grass + maize + cover crop), FS4 (grass + maize + legume) (Figure 1). The farming systems were arranged in a randomized block design with three replicates per treatment. Each experimental unit covered 1000 m^2, with a net plot area of 900m^2 from which soil samples were collected at the beginning and end of two crop cycles.

Soil cores (30 cm) were extracted from each farming system at the beginning and end of two crop cycles (2022, 2023). The measured parameters were bulk density with the disturbed soil method [10], soil organic matter (SOM) [11], soil available nitrogen (NO^{-3} and NH^{+4}), available Phosphorus (PO_4^{+3}) and available Potassium, methods were described previously in [12] (Figure 2).

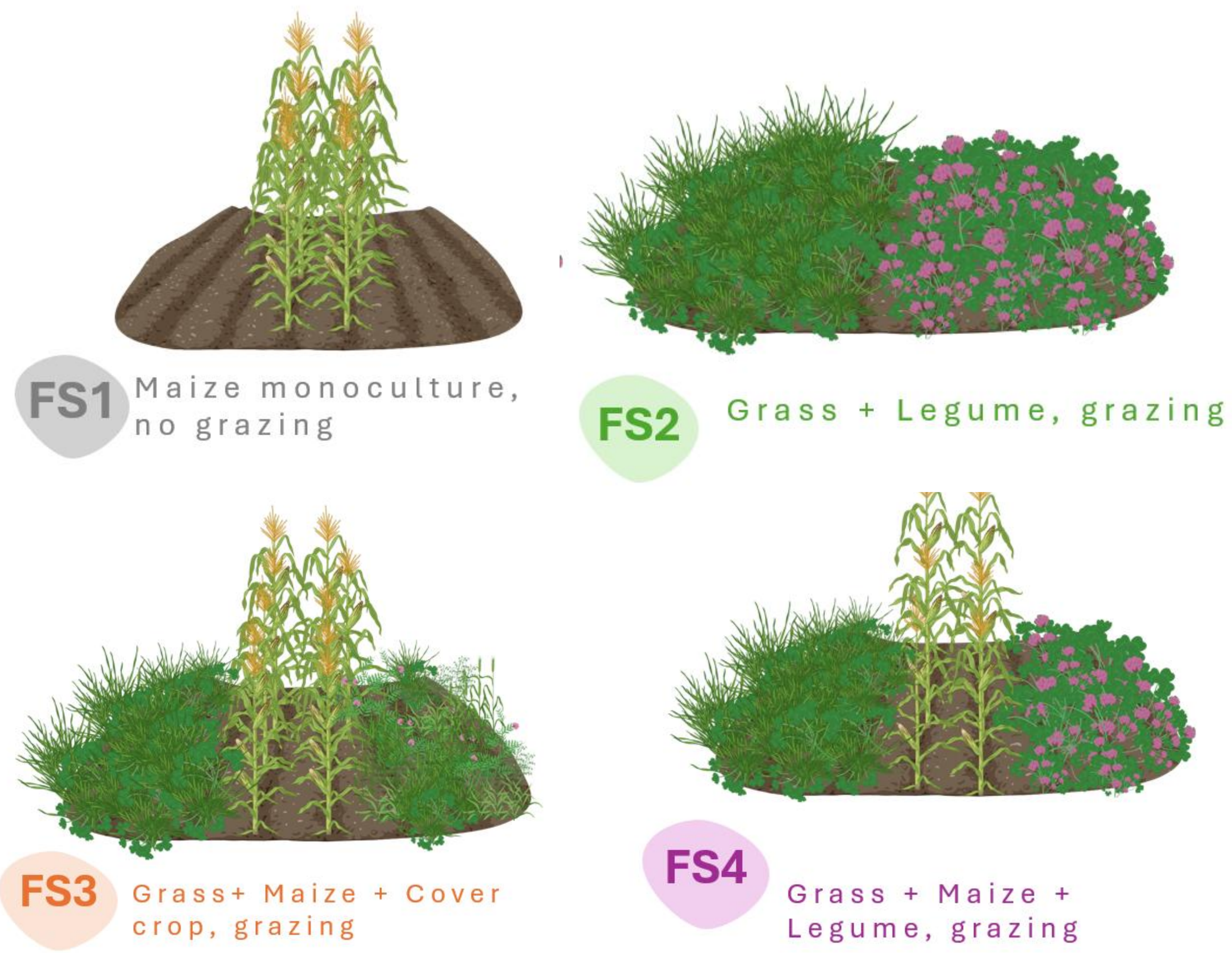

Figure 1. Evaluated Farming Systems

Soil Quality Index (SQI) was calculated using the weighted additive model [11] showed in (1).

$$SQI = \Sigma_{i=1}^{n} w_i s_i \quad (1)$$

where w_i= weight of the indicator and s_i=indicator score.


Figure 2. Soil samples analyses

A Principal component analysis (PCA) to the soil indicators. For each principal component (PC) the indicators with the highest absolute value were selected for inclusion in the Soil Quality Index (SQI). The selected indicators were bulk density (BD), pH, soil organic matter (SOM), soil available nitrogen (AN), available phosphorus (AP), and available potassium (AK). Indicator weights were calculated by dividing the proportion of variance explained by each PC by the total variance of all selected components. Each indicator was then standardized and scored accordingly.

RESULTS & DISCUSSION

The SQI was calculated by substituting the scored indicator means into Equation (2). The weights assigned to each principal component were PC1=0.595 and PC2=0.405, and these values were applied to the soil indicators selected from each corresponding component.

Eigenvalue	2.572	1.753	0.750	0.488	0.338	0.096
Proportion	0.429	0.292	0.125	0.081	0.056	0.016
Cumulative	0.429	0.721	0.846	0.927	0.984	1
Weight	0.595	0.405				

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Bulk density	0.164	0.468	0.828	-0.245	-0.082	0.032
SOM	0.528	-0.155	-0.046	0.173	-0.816	-0.017
pH	0.102	-0.586	0.506	0.563	0.27	-0.036
AN	-0.584	-0.072	0.132	0.13	-0.359	0.7
AP	-0.583	-0.091	0.157	-0.005	-0.356	-0.707
AK	0.047	-0.633	0.118	-0.759	-0.019	0.084

$$SQI = 0.595(SOM + AN + AP) + 0.405(AK + BD + pH) \quad (2)$$

Monoculture maize (FS1) showed a significant decline in SQI (13.8, P=0.001) compared with the more highly integrated systems, which averaged an SQI of 17.7) by the end of the evaluation period. Systems that included legumes (FS2 and FS4) consistently achieved higher SQI values, highlighting the beneficial role of legumes in enhancing soil health (Figure 3).

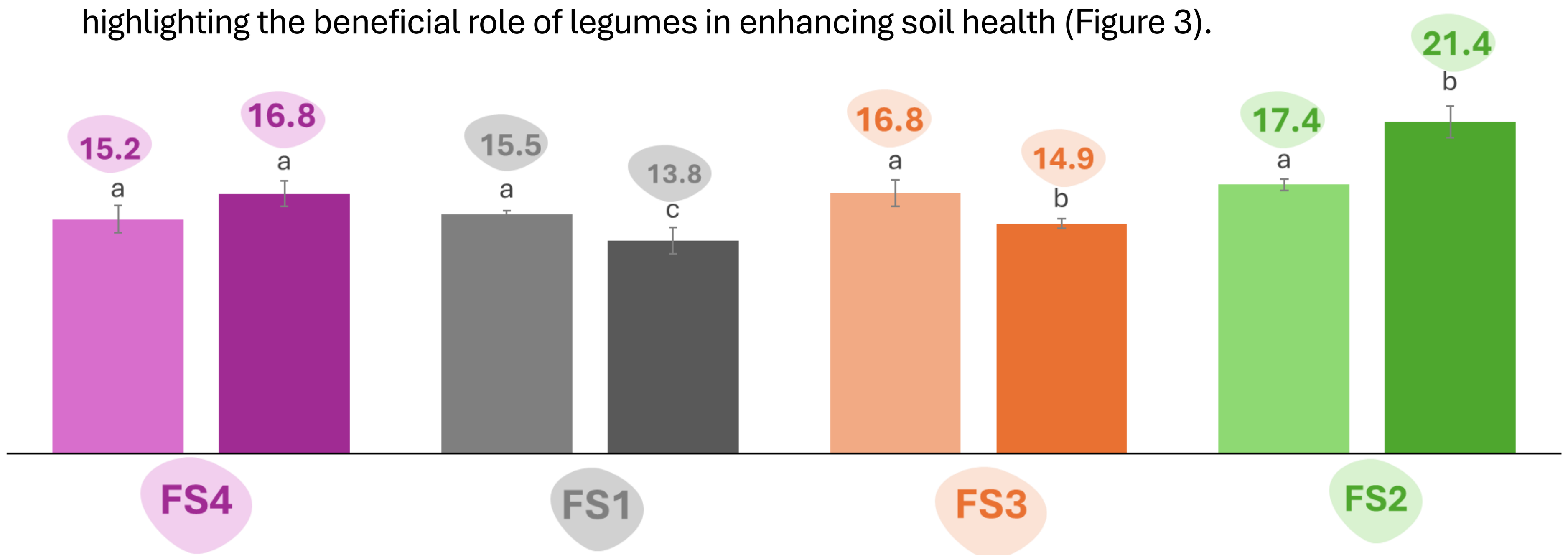

Figure 3. Soil Quality Index in Farming Systems

The SQI obtained in this study incorporates soil indicators such as organic matter and nutrient content, which are widely included in soil quality assessments [13–16] due to their strong contribution to soil sustainability and overall soil function [17]. The results clearly demonstrate the positive effects of integrated systems on soil quality. The increase in organic matter observed in FS4, along with the higher nitrogen and phosphorus levels found in FS3, underscores the importance of management practices that promote nutrient recycling, such as manure application and grazing [18]. Integrating maize with red clover, cover crops, mixed prairies, and livestock, enhances soil organic matter accumulation, improves soil fertility and water-holding capacity [5,19]. Additionally, maintaining continuous vegetative cover reduces erosion and contributes to overall soil quality improvement [20]. Increasing agrobiodiversity, particularly through the inclusion of forage crops, positively influences soil microbiological properties and crop yields [21]. The introduction of legumes further enhances both the quantity and quality of plant residues returned to the soil [22]. In contrast the MM system, characterized by a low degree of integration, exhibited a pronounced decline in organic matter content [6]. Although intensive conventional management may temporarily improve soil fertility through the application of chemical fertilizers, over the long term it contributes to soil compaction, erosion, and nutrient depletion, ultimately reducing soil quality [23]. These findings highlight the need to complement chemical fertilization with organic inputs, such as manure, and to adopt diversified management strategies that include legumes, cover crops, and grazing.

CONCLUSION

Integrated farming systems, particularly those incorporating legumes, significantly enhance soil quality by improving key indicators such as organic matter, nitrogen, and bulk density. In contrast, monoculture systems show marked soil degradation over time. The SQI proved to be a reliable tool for evaluating management impacts and guiding sustainable agricultural transitions. Overall, these findings highlight the importance of diversified crop-livestock systems for strengthening soil quality, improving long-term productivity, and supporting environmentally sustainable farming practices.

FUTURE WORK / REFERENCES

Long-term monitoring is necessary to evaluate the persistence of soil quality improvements and to detect cumulative effects on nutrient cycling and soil structure. Including biological indicators such as microbial biomass, enzymatic activity, and soil respiration, will help capture soil health processes not reflected in physical and chemical properties alone.

Acknowledgements: The authors wish to thank UNAM (Project: CI 2454) and the IPN for their financial and institutional throughout this study.

REFERENCES