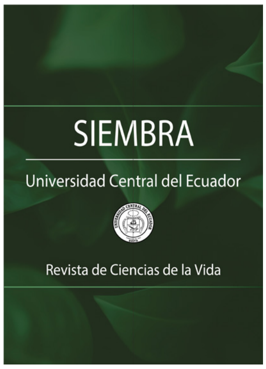
Understanding the effect of cropping system on soil health at the Northwestern Ontario Agricultural Research Station in Canada



Estudio del efecto del sistema de cultivo en la salud del suelo en la Estación de Investigación Agrícola del Noroeste de Ontario (Canadá)

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Siembra 11 (2) (2024): e6816

Received: 28/06/2024 / Revised: 07/08/2024 / 30/09/2024 / Accepted: 02/10/2024

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Abstract

Anthropogenic activities impact soil in varying degrees, from preserving natural landscapes to intensive agriculture which among the farm practices that impact the soil are the cropping systems. Information on cropping systems and soil impacts in northern territories is still missing. This study assesses the effect of different cropping systems on soil health - physical, chemical and biological soil properties and indicators of soil health - at the Lakehead Agricultural Research Station [LUARS] in northern Ontario, Canada. The study compares three cropping systems (perennial crops-pasture, grass, and annual crops-wheat, barley, corn, soybeans) and two forest areas (conifer plantation and naturally regenerating mixed wood forest) at LUARS. Soil samples were collected at different depths and analyzed for various indicators using the Cornell Soil Health Assessment framework. The results showed the soil health scores varied among cropping systems, with natural forest and perennial crops-pasture having higher scores compared to annual crops-wheat, barley, corn, soybeans. Soil organic matter was found to be lowest in annual crops-wheat, barley, corn, soybeans, while aggregate stability was highest in natural forests. The study also identifies the soil health gap, which represents the difference between the health of a particular cropping system and a benchmark. The soil health gap analysis can help farmers implement practices to improve soil health and increase the resilience and sustainability of agroecosystems. Overall, this study emphasizes the importance of understanding the effect of cropping systems on soil health and provides insights into potential strategies for improving farm practices.

Keywords: annual cropping system, assessment, organic matter, pasture, soil health, soil indicators.

SIEMBRA
https://revistadigital.uce.edu.ec/index.php/SIEMBRA
ISSN-e: 2477-8850
Frequency: half-yearly
vol. 11, núm 2, 2024
siembra.fag@uce.edu.ec
DOI: https://doi.org/10.29166/siembra.v11i2.6816

Resumen

Las actividades antropogénicas afectan el suelo en diversos grados, desde la conservación de los paisajes naturales hasta la agricultura intensiva, entre cuyas prácticas agrícolas se encuentran los sistemas de cultivo. Pero, aún falta información sobre los sistemas de cultivo y su impacto en el suelo en los territorios del norte de Canadá. En este estudio se evaluó el efecto de diferentes sistemas de cultivo en la salud del suelo (propiedades físicas, químicas y biológicas, e indicadores de la salud del suelo) en la Estación de Investigación Agrícola de Lakehead [LUARS], en el norte de Ontario (Canadá). Se comparó tres sistemas de cultivo (cultivos perennes - pastos, pastizales y cultivos anuales - trigo, cebada, maíz y soya) y dos zonas forestales (plantación de coníferas y bosque mixto de regeneración natural) en LUARS. Se recogieron muestras de suelo a distintas profundidades y se analizaron diversos indicadores utilizando el marco de evaluación de la salud del suelo de Cornell. Los resultados mostraron que las puntuaciones de la salud del suelo variaban según los sistemas de cultivo. Los bosques naturales y los cultivos perennes-pastos tuvieron puntuaciones más altas en comparación con los cultivos anuales (trigo, cebada, maíz y soya). Se observó que la materia orgánica del suelo era más baja en los cultivos anuales (trigo, cebada, maíz y soya), mientras que la estabilidad de los agregados era más alta en los bosques naturales. El estudio también identificó la brecha de salud del suelo, misma que representa la diferencia entre la salud de un sistema de cultivo concreto y un punto de referencia. El análisis de la brecha de salud del suelo puede ayudar a los agricultores a aplicar prácticas para mejorar la salud del suelo y aumentar su resiliencia.

Palabras clave: sistema de cultivo anual, evaluación, materia orgánica, pasturas, salud del suelo, indicadores del suelo.

1. Introduction

Anthropogenic disturbances to soil range from maintenance of pre-settlement conditions (preserving natural landscapes) to intensive agriculture, consuming resources at the expense of the environment (DeFries et al., 2004). Intensive agriculture changes soil functions such as water balance, organic matter, and nutrient inputs and outputs. Conventional single cropping systems deteriorate soil structure, increase soil compaction and erosion, alter the organic carbon cycle, and change soil pH (Wei et al., 2014).

Several soil health indicators define the level of soil degradation. They include physical properties (water holding capacity, water aggregate, soil penetration), chemical properties (extractable P, K, Mg, Fe, Mn, Zn contents and total C and total N), and biological properties (active carbon, soil respiration, soil protein, and organic matter), according to the Cornell Assessment Soil Health [CASH] framework (Moebius-Clune et al., 2016). Soil health "is the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity and promote the quality of soil and water environments, and maintain plant, animal and human health" (Doran & Parkin, 1994). The assessment's main objective is to evaluate soil health as a result of anthropogenic disturbances such as cropping systems, crop rotation, and intercropping that use in agriculture at different spatial and temporal scales and can be monitored (Yang et al., 2020).

Comparing cropping systems is difficult due to soil variability and temporal dynamics. However, experimental study areas can assist in comparing different agricultural areas (Karlen et al., 2019). Any cropping system, including crop rotation, plant diversity, and intercropping, is an adaptation to maximize crop yield, but intensification of any of these practices can be harmful to the environment. Consequently, soil health assessment can be used to monitor an agroecosystem's long-term sustainability (Agomoh et al., 2020; Yang et al., 2020).

On the other hand, crop rotation can improve soil structure, reduce soil-borne pathogens, increase disease suppression, facilitate nutrient intake, reduce synthetic inputs, and improve yields. Also, crop rotation can increase soil organic matter, microbial biomass, and microbial activity (Agomoh et al., 2020; Reicosky, 2018, p. 165). Furthermore, plant diversity can improve soil microbiota, increase nutrient efficiency, and maintain soil physical structure. It also increases crop yield by balancing chemical input at different scales (Yang et al., 2020). In addition, intercropping meliorates pest control, increases nutrient cycling, and improves water and soil conservation (Tilman et al., 2002). It can improve microorganisms' functionality and nutrient uptake efficiency and reduce the costs of fertilizers and pesticides (Sahota & Malhi, 2012), enhancing plant root functions and reducing soil's artificial chemical contamination (Yang et al., 2020).

Studies were conducted to understand how soil has been degraded over time and to explore the potential to increase soil health. As we know, intensive agriculture causes losses to soil function, and determining a soil health benchmark by comparing cropping systems could help define goals for improving farm practices. In general, undisturbed lands have higher soil health indicators than cultivated areas, and the gap between the health of undisturbed or native soil and the soil of a particular cropping system is defined as the soil health gap (Maharjan et al., 2020). The concept of the soil health gap supports decision-making to improve soil health, and it can be scaled to regional or national areas (Maharjan et al., 2020).

Since 2003, the Thunder Bay Agricultural Research Station has been conducting studies in plant nutrition, new crop varieties, crop protection, and farm management practices, which have benefitted farm communities in the Thunder Bay District. However, understanding how cropping systems affect soil functions was not assessed. The purpose of this study is to assess soil health under different cropping systems and determine its soil benchmark related to soil organic matter at the Lakehead Agricultural Research Station.

2. Materials and Methods

The study was conducted at Lakehead University Agricultural Research Station [LUARS] in Thunder Bay, Ontario, Canada, in 2019. LUARS is part of the Slate River area, where soils have been influenced by proglacial streams and subsequent deglaciation (Baldwin et al., 2000). The mean annual precipitation ranges from 700-850 mm, and the mean annual temperature ranges from -26 °C to -22 °C in January and 21 °C to 25 °C in July (Environment Canada, 1991).

At LUARS, three cropping systems were chosen (perennial crops-pasture, grass, and annual crops-wheat, barley, corn, soybeans) plus two reference forested areas (a conifer plantation and adjacent naturally regenerating mixed wood forest) (Figure 1). Soil samples were collected in July 2019 using a split-core sampler (AMS Soil Samplers, Inc., American Falls, Idaho). In each area, three random plots were chosen, and at each corner and in the center of each plot, five samples were collected to form one composite sample at two depths (shallow, 0-5 cm, and deeper, 5-15 cm). Soil samples were stored at low temperatures to transport to Lakehead University Laboratory and sent to the Cornell Soil Health Laboratory in Ithaca, New York. Detailed protocols and procedures are available for the CASH framework (Moebius-Clune et al., 2016). Descriptive statistics and a split-plot design were used for the study to compare the soil health indicators for the three cropping systems and two forested areas.

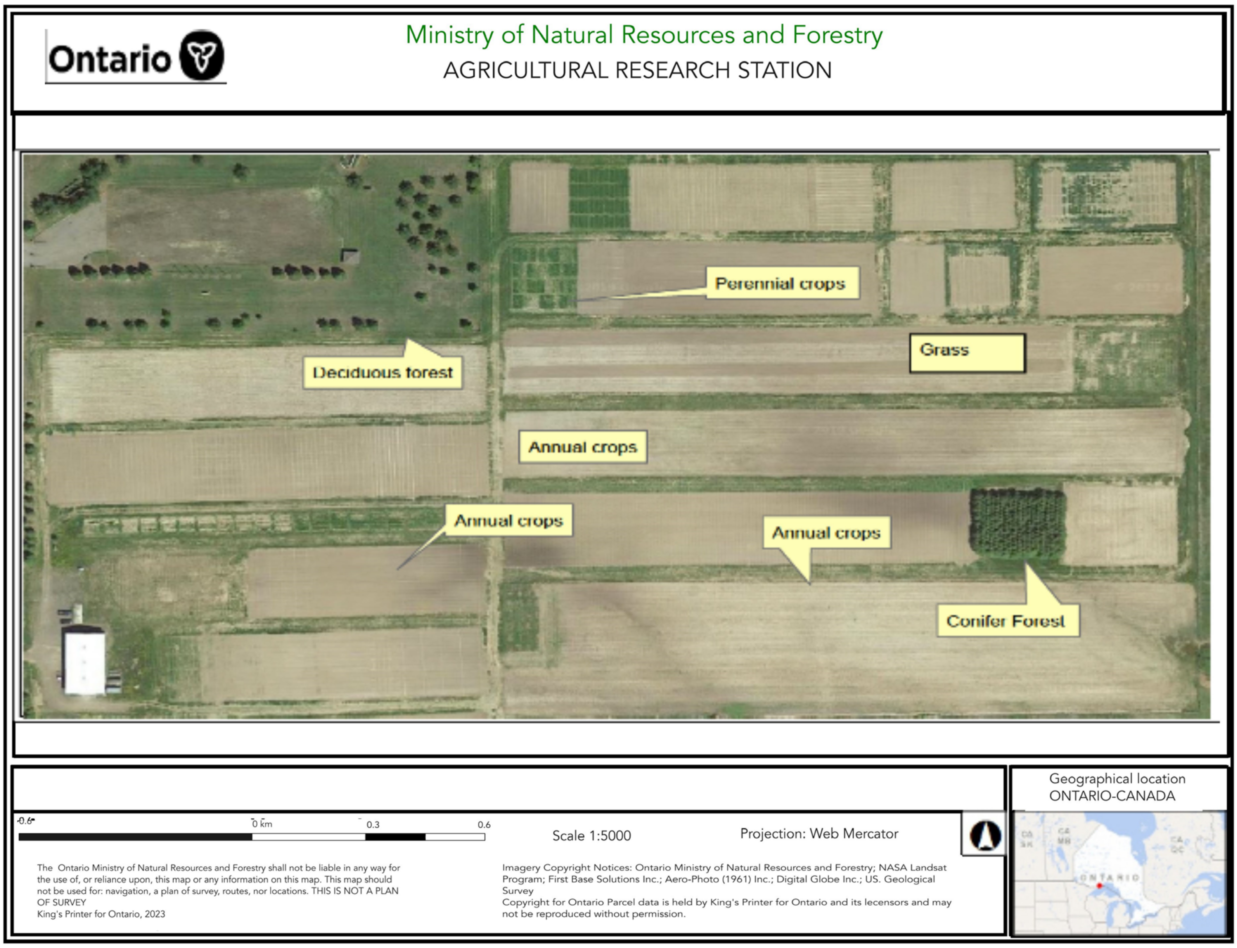

Figure 1. Assess the effect of disturbance on soil health, including triplicate sites of annual crops-wheat, barley, corn, soybeans; perennial crops-pasture, relatively undisturbed grass, deciduous forest, and conifer forest treatments.

3. Results and Discussion

The soil health scores were high to low in the following order: natural forest < grass < conifer forest < annual crops-wheat, barley, corn, soybeans < perennial crops-pasture for the shallow soil samples (Table 1). For the deeper soil samples, the order was natural forest < conifer forest < annual crops-wheat, barley, corn, soybeans < grass < perennial crops-pasture. We can also expect the soil health indicators for the cropping systems to change with the different stages of the crops. For example, SOM decreases, then increases, then decreases for annual crops-wheat, barley, corn, soybeans under intensive management, an effect associated with tillage practices (Congreves et al., 2015; Magdoff & Es, 2000; Magdoff & Weil, 2004), but the absence of soil disturbance in perennial crops-pasture and conifers forest suggests increases only in SOM over a growing season (Magdoff & Es, 2000).

Soil aggregate stability was high in natural forests and low in annual crops-wheat, barley, corn, soybeans for the shallow soil samples, and pasture had the lowest aggregate stability in the deeper soil samples. Low levels of disturbance provide the opportunity for microorganisms to create micro aggregates and increase soil stability (Das et al., 2014). Areas with low machine intervention are expected to have low soil compaction (Afzalinia & Zabihi, 2014). Shallow soils were acid in the conifer plantation and pasture, but acid soil occurred in the deeper samples only in the conifer forest. Low pH decreases NH_4^+ immobilization and N mineralization rates (Cheng et al., 2013). Low pH f 3.2 to 3.8 is associated with pine needles (Oregon State University, 2017). Microelements such as Mn, Fe, and Zn were variable among the cropping systems.

Fertilization levels are ideally directly proportional to the crop system's requirement. Micronutrients such as Mn, Fe, and Zn are required for some cropping systems, but rarely are deficiency symptoms widespread (Magdoff & Es, 2000). Nitrogen fertilizer helps microorganisms increase soil organic matter [SOM] decomposition rates (Benalcazar et al., 2024; de Clercq et al., 2015) and make P available for the plant to use. Mycorrhizal fungi increase P uptake in low-P soils. However, high levels of N or P can harm the environment (Carpenter et al., 1998; Magdoff, 2007; Torstensson et al., 2006). More than 50% of fertilizer can be lost to the atmosphere or through percolation or filtration.

Biological indicators including SOM were lowest for the annual crops-wheat, barley, corn, soybeans in shallow soil samples. For the deeper soil samples, pasture, perennial and annual cropping systems had very similar levels of SOM. Similar patterns occurred for soil protein, soil respiration, and active carbon, since these indicators have a close relationship with SOM. Soil organic matter is one of the most vital components which influences almost all the above indicators and impacts several soil functions such as managing pests, water holding capacity, and nutrient retention; higher SOM improves soil aggregation, reduces compaction, and has a beneficial effect on soil biota (Lal, 2011; Magdoff & Es, 2000; Wiesmeier et al., 2019, Yang et al., 2024).

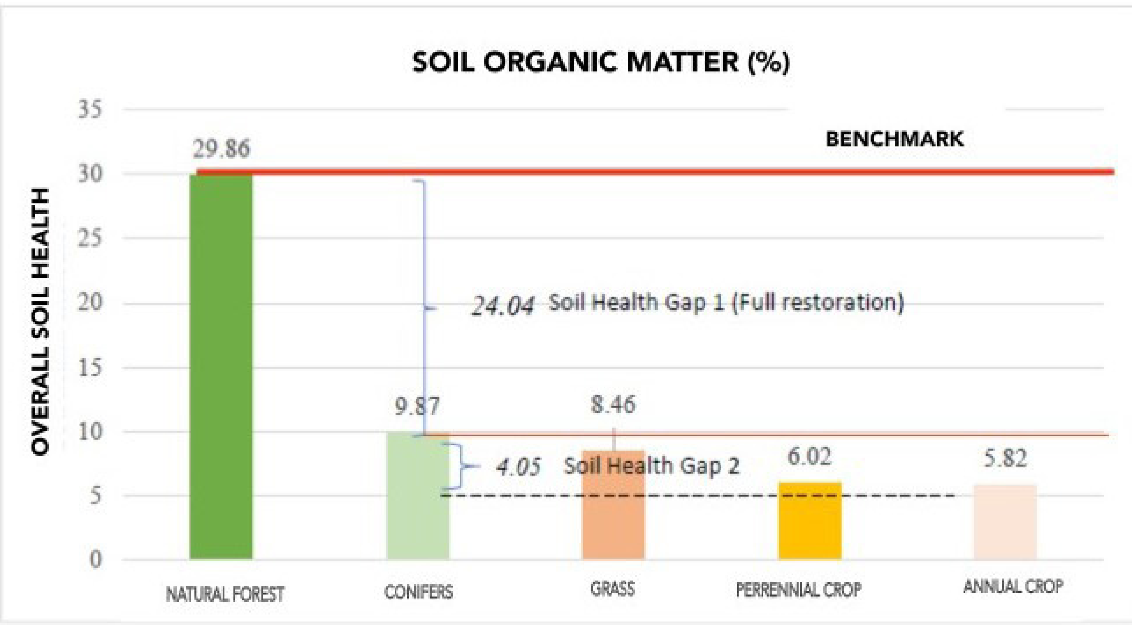

Figure 2. Cropping Systems and benchmark measures of soil organic matter toIllustrate the soil health gap and the potential to improve farm management (adaptedfrom Maharjan 2020).

Table 1. Effect of cropping systems on soil physical, chemical and biological soil health indicators.

		Soil depth									
		5 cm					15 cm				
		Natural Forest	Conifer forest	Grass	Perennial crop	Annual crop	Natural Forest	Conifer forest	Grass	Perennial crop	Annual crop
Physical indicator	Aggregate stability (%)	71.08	68.33	45.38	48.08	37.21	46.18	69.69	26.3	41.71	33.92
	Subsurface hardness 30 com (psi)	200	300	200	350	200	200	300	200	350	200
	Surface hardness 15 cm (psi)	150	200	150	300	150	150	200	150	300	150
Chemical indicators	pH	6.31	5.47	5.87	6.45	6.18	6.36	5.58	6.13	6.76	6.53
	P (ppm)	7.39	7.29	8.89	10.56	16.92	2.84	4.05	2.89	2.66	9.67
	K (ppm)	220.61	239.35	236.23	184.35	373.18	170.44	163.07	138.36	82.88	272.50
	Mg (ppm)	1,551.15	771.74	608.5	882.58	787.11	1,140.32	818.51	799.49	888.27	933.10
	Mn (ppm)	10.39	13.50	8.33	3.54	10.92	6.59	10.87	4.77	2.26	4.64
	Fe (ppm)	8.71	14.69	14.68	5.78	8.47	24.80	16.82	18.04	6.89	6.06
	Zn (ppm)	3.11	1.12	2.60	0.94	1.00	1.43	0.88	1.43	0.16	0.73
Biological indicators	Organic matter (%)	29.86	9.87	8.46	6.02	5.82	10.24	7.76	4.60	4.62	4.66
	Soil protein	37.04	19.30	10.28	12.14	10.29	17.39	16.20	6.95	8.98	6.32
	Soil respiration	2.00	1.31	1.48	0.91	0.88	1.11	0.95	0.55	0.62	0.58
	Active carbon ($mg.mg^{-1}$)	4,266.98	1,360.55	1,051.84	1,038.17	1,064.22	1,402.47	1,157.94	749.41	887.81	830.57
Overall score		94,46	81.91	88.13	83.04	83.56	90.43	81.17	75.08	69.85	78.60

LUARS area soils could be described as having two levels of soil health gap. The first corresponds to recovery from annual crop systems to a benchmark, where 24 % improvement in SOM is required. The second soil health gap compares the conifer plantation to annual crop systems and requires 4 % of SOM increase, which could be a realistic soil health goal (Figure 2). Having this kind of soil health gap analysis helps farmers implement different practices to increase an agroecosystem's resilience and sustainability. Examples of best management practices that could be implemented are application of different crop residues or mulch with high levels of organic matter. Planting cover crops protect against wind erosion and extreme temperatures while minimizing soil disturbance, improves soil structure, and managing soil fertility maintains optimal pH values so microflora and microfauna benefit the soil ecosystem (Acton & Gregorich, 1995; Doran & Parkin, 1994; Magdoff & Es, 2000).

4. Conclusion

Different cropping systems have varying effects on soil health at the Lakehead Agricultural Research Station [LUARS]. The soil health scores were found to be highest in natural forests and perennial crops-pasture, while annual crops-wheat, barley, corn, soybeans had lower scores. Soil organic matter [SOM] was lowest in annual crops-wheat, barley, corn, soybeans, indicating potential degradation of soil quality. The study also identified the soil health gap, which represents the difference between the health of a particular cropping system and a benchmark. This analysis can help guide farmers in implementing practices to improve soil health and increase the resilience and sustainability of agroecosystems. Overall, this study highlights the importance of considering soil health indicators and implementing appropriate management practices to maintain and enhance soil quality in agricultural systems.

Acknowledgement

We are grateful to The Canadian Queen Elizabeth II Diamond Jubilee Advanced Scholars Program, made possible with financial support from the International Development Research Centre and the Social Sciences and Humanities Research Council. Thanks to the Canadian Agricultural Police Institute, MITAC, and Lakehead University Agricultural Research Station (LUARS) for providing funds to conduct this research, and the Cornell Soil Health Laboratory, Robert Schindelbeck, Kirsten Kurtz, and the Cornell team for sharing their experience and knowledge related to soil health. Also, thanks to all the farmers who granted access to their lands to conduct this study.

Funding

The Canadian Queen Elizabeth II Diamond Jubilee Advanced Scholars Program, made possible with financial support from the International Development Research Centre and the Social Sciences and Humanities Research Council.

Contributor roles

- Paul Benalcazar: conceptualization, investigation, methodology, resources, software, validation, writing – original draft, writing – review & editing.

Ethical implications

Ethics approval not applicable.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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