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Effects of nine monoculture agricultural systems on the fertility of an agricultural soil

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ABSTRACT

Objective: Determine and evaluate the effect of monoculture practices on the levels of seven soil fertility indicators.

Design/Methodology/Approach: Nine monoculture agricultural systems were evaluated, in completely randomized blocks with four repetitions, during the 2012-2016 period. The plot was divided into 9 sections with four repetitions, giving a total of 36 plots where the 9 local systems studied were distributed until the conclusion of the experiment in 2020.The SAS VS 9 system was used for the statistical analysis of the results.

Results: The results indicated that the agricultural systems changed the chemical characteristics of the soil, highlighting four monoculture systems that included legumes (beans and fava beans) or the corn-bean (MF) and corn-fava bean (MH) combinations, which improved the organic matter (OM), total N (TN), and P content of the soil.

Study Limitations/Implications: The small plots that were contaminated by the tillage actions of continuous treatments, caused the conclusion of the experiment. Everything indicates that treatments can be reduced and the size of the plots increased.

Findings/Conclusions: The results indicated that the agricultural systems changed the chemical characteristics of the soil, highlighting four monoculture systems that included legumes (beans and fava beans) or the corn-bean (MF) and corn-fava bean (MH) combinations, which improved the organic matter (OM), total N (TN), and P content of the soil.

Keywords: crops, availability, nutrients.

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INTRODUCTION

Soil is the main agricultural resource for the daily production of food, fiber, and other products that are directly required by the growing needs of 8.104 billion human beings and indirectly by pets, livestock, and industries; human population will exceed 9.730 billion in 2050 (FAO and ITPS, 2015). All agricultural soils are part of the ecological environment in which they evolve. Human needs have modified the nature of the soil: cultivation impacts its physical and chemical characteristics, modifies its original biodiversity, and alters its original native state (FAO and ITPS, 2015). Acevedo and Barajas (2022) analyzed the soils of the humid jungle, acahuales (*Helianthus* spp. or *Simsia* spp.), pastures, and crops systems in Chiapas and determined that pastures and crops promoted the degeneration of the

original soil, compromising the functionality of the jungle ecosystem and altering the pH, organic matter, Phosphorus (P), and total Nitrogen (N) of the soil. For their part, Sellami and Terribile (2023) point out that agriculture-driven changes in land-use are usually negative, highlighting the intensity of tillage practices and inputs. Monocultures or low crop rotation cause the greatest deterioration in soil health and make agricultural activity more sensitive to climate change.

The Serdán Valley has sandy pumice-like soils, composed of albite and anorthite (with high Ca, Mg, and Na levels) of volcanic origin; their low fertility is not favorable for agricultural production (Pérez-Méndez, 2017). Therefore, local crops must be fertilized annually with N and P. However, the trend towards corn monoculture and the individual practices of producers makes it difficult to estimate the residual effect of chemical or organic additions from previous cycles. Therefore, the objective of this work was to determine and evaluate the effect of monoculture practices on the levels of seven soil fertility indicators.

MATERIALS AND METHODS

The study area consisted of plots located in the Instituto Tecnológico Superior of Ciudad Serdán, Chalchicumula de Sesma, Puebla. In the first 20 cm of depth, the local soils have an average apparent density of 2.4 g cm^{-3}, a cation exchange capacity (CEC) of 8 cmol kh^{-1}, a field capacity of 13%, and a wilting point of 7.2% (Pérez-Méndez, 2017). The organic matter of the soil is variable (0.5-2.5%), depending on the management employed by each producer. Corn monoculture predominates for environmental reasons (reduced rainfall and higher temperatures), incentives provided by government programs, and social and economic profitability.

Nine monoculture systems were studied from 2011 to 2016. The study consisted of completely randomized blocks with four repetitions and the following crops: corn (*Zea mays*), beans (*Phaseolus vulgaris*), fava bean (*Vicia faba*), and peas (*Psitium sativum*). The following treatments were used for this research: 1) ME (corn, 110 N-50 P_2O_5, 5 tons of cattle manure each year); 2) M135 (corn, 135 N-50 P_2O_5); 3) M110 (corn, 110 N-50 P_2O_5); 4) MC (control corn fertilized with 110 N-50 P_2O_5; this method is only applied in even years, because the crops grown on these local soils cannot be more than one cycle without fertilizer); 5) MF (corn-bean combinations fertilized with 110 N-50 P_2O_5); 6) MH (corn-fava bean combination fertilized with 110 N-50 P_2O_5); 7) bean (60 N-60 P_2O_5); 8) fava bean (40 N-40 P_2O_5); and 9) pea with 80 N and 40 P_2O_5 (Ps). The following varieties were used: Synthetic Serdán (corn) and local native varieties (other crops). The fertilization levels of the crops were those recommended in the area. Every year the treatments were applied in the same plots and with the same repetitions to ensure their effect on the soil. In 2011, one soil sample was taken and analyzed in the laboratory. In 2016, four soil samples were taken per treatment. Sampling depths in both periods were 0 to 20 cm and 20 to 40 cm. The NOM-021-RECNAT-2000 Official Mexican Standard (SEMARNAT. 2000) was used to determine the chemical parameters of pH, organic matter (OM), phosphorus (P, using the Bray 2 method), potassium (K), calcium (Ca), magnesium (Mg), and total nitrogen (TN). The statistical analysis of the results of the 2016 soil samples was carried out with the SAS VS 9 software, Tukey's mean differences

(DSH) were determined with an α=0.05 probability and a Pearson correlation analysis was performed between the variables.

RESULTS AND DISCUSSION

The statistical analysis of the agricultural systems analyzed showed differences in the increase or decrease of the fertility variables under study. The results were compared with the differences in the means resulting from Tukey's test. The correlation is mentioned according to its importance as a covariate.

Organic matter, total N, pH

Organic matter (OM) had a high correlation with the electrical conductivity (EC, r=0.81) and total N (TN, r=0.93) variables. For this reason, only the OM variable was discussed (Table 1). In this Table 1, shows that the organic matter (T8, T5, T7, T9, and T6) and total N (T8, T7, T5, and T9) variables tend to increase in agricultural systems with legumes by themselves or in association with corn at the two depths studied. Organic matter (OM) was notably lower in the second layer of soil with treatments T6 and T8 (bean by itself or associated with corn) than in the first 20 cm of depth (Table 1). Therefore, the greatest OM increase in these two systems is caused by the loss in the superficial foliage layer (mainly of fava bean). The smallest increase in OM in the second soil layer occurs in T1, indicating that manure application only benefits the surface layer (although it was applied annually).

Phosphorus (P)

Soluble P was analyzed independently, considering the effect of legumes by themselves or combined with other crops on the availability of this nutrient in the soil (Table 2). An increase in soluble P was observed in the plots with the MF (T6) and MH associated crops, with P levels up to 100% higher than the rest of the plots, where corn monocultures predominated.

Table 1. Statistical analysis of the means of the soil fertility variables (pH, OM, and TN) that were studied in Serdán, Puebla (2016).

Variable	Unit	Initial value	Cultivation system studied								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
			ME	M135	M110	MC	MF	MH	F	H	Ps
			Soil depth 0-20 cm								
pH	%	6.6	6.55 abc	6.55 abc	6.43 d	6.41 d	6.51 cd	6.75 ab	6.51 cd	6.67 abc	6.81 a
OM	g^{-Kg}	8.1	14.5 b	8.52 c	9.15 c	9.95 c	16.0 b	14.1 b	15.3 b	22.6 a	15 b
TN	%	0.1	0.13 b	0.08 d	0.08 d	0.08 cd	0.12 b	0.11 bc	0.12 b	0.18 a	0.12 b
Variable	Unit	Initial value	Soil depth 20-40 cm								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
pH	%	6.6	6.85 bc	6.85 bc	6.84 bc	6.94 a	6.75 cd	6.5 e	6.79 bc	6.56 e	6.59 de
OM	g^{-Kg}	3.4	8.2 c	8.8 c	8.4 c	10.6 ab	16 a	9.8 ab	16 a	9.5 c	12.9 b
TN	%	0.06	0.08 c	0.08 c	0.09 c	0.10 bc	0.14 a	0.12 ab	0.14 a	0.09 c	0.14 a

Table 2. Statistical analysis of the means of the Phosphorus variable within the agricultural systems studied in Serdán, Puebla (2016).

Variable	Unit	Initial value	Cultivation system studied								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
			ME	M135	M110	MC	MF	MH	F	H	Ps
			Soil depth 0-20 cm								
P	ppm	19.8	16.5 cd	5.5 d	15.7 cd	16.1 cd	30.7 bc	34.4 ab	45 ab	20.9 bc	46.1 a
			Soil depth 20-40 cm								
		8.96	20 c	8.7 c	19.8 c	21.4 bc	38.6 b	39.2 b	38.1 b	68.7 a	67.13 a

This study recorded a higher P availability in bean (T7) and pea (T9) monocultures. Soil P showed the greatest decrease with T2 in both soil layers, because a high N dose caused a greater removal of this nutrient from the crop. Therefore, not all corn biomass should be removed, given the potential deterioration in soil P levels.

Mohammed *et al.* (2018) pointed out that legumes require large amounts of energy provided by Phosphorus (P) to fix N, particularly in intercropping systems. Therefore, the activity of their root exudates (citrate, phosphatic acid, and release of $H+$ protons) stimulates microbial activity around them and contributes to the solubilization of P from the soil. According to Ibrahim *et al.* (2022), the availability of Phosphorus and other nutrients can be limited or favored by the interaction between the crop and its effect on biological activity, production systems, and cultivation practices. Despite what Lulu Wei *et al.* (2020) point out, the P available in the soil as a result of the application of manure (T1) was below the levels reached with the treatments with legumes by themselves or associated with corn (T5, T6, T7, T8, T9). This result implies the possibility of establishing more profitable corn-legumes-corn rotations or associations (such as MH and MF) to improve P availability.

K, Ca, and Mg

The analysis of means showed differences between the values of these three nutrients (Table 3). Pea (T9) recorded the greatest loss of this three nutrient in the soil: approximately

Table 3. Statistical analysis of the means of the K, Ca, and Mg variables that were studied in Serdán, Puebla (2016).

Variable	Unit	Initial value	Cultivation system studied								
			Soil depth 0-20 cm								
			T1	T2	T3	T4	T5	T6	T7	T8	T9
			ME	M135	M110	MC	MF	MH	F	H	Ps
K	pmm	931	473 ab	475 cb	530 ab	600 a	428 c	509 bc	548 ab	504 bc	301 d
Ca		2634	788 a	652 bcd	689 ab	673 ab	461 e	398 e	539 cd	523 cd	509 de
Mg		1888	538 bc	562 abc	591 abc	642 ab	421 de	349 e	428 ed	669 a	470 cd
			Soil depth 20-40 cm								
K	pmm	695	469 cd	396 d	514 bcd	591 b	585 bc	575 bcd	590 b	713 a	508 bcd
Ca		1139	764 b	729 b	679 b	704 b	1306 a	922 b	1434 a	667 b	1255 a
Mg		888.7	675 cd	575 d	617 d	706 bcd	914 abc	599 d	1015 a	528 d	941 ab

37% less than the original level. According to Akter *et al.* (2020), the flowering and grain filling of peas require adequate levels of K, Ca, and Mg; consequently, these nutrients showed the greatest reduction in this treatment. Therefore, a high availability of P in the soil was observed in the analysis (solubility effect of the roots and less removal by the crop).

In contrast, T9 had a greater loss of the K available in the soil, because this nutrient was not applied during the development of the experiment. The control (T4) recorded the lowest decrease in K, because it achieved the lowest development and yield; the demand for K was reduced, probably the plot was fertilized only once every two cycles. The ME treatment (T1) showed the greatest Ca increases with respect to the rest of the treatments and recorded one of the five best OM increases (Table 3). According to Lulu Wei *et al.* (2022), the continuous application of composted manure provides both nutrients to the crop and soil, improving other physical properties such as moisture retention.

Mg was relevant only for the fava bean monoculture (T8). The soluble Mg difference between beans (T7) and fava beans (T8) shows genetic mechanisms (*e.g.*, the metabolism of each species) that apparently modify the behavior of the roots of these two legumes, releasing this alkaline earth nutrient.

Correlation between P and K

The Ca, Mg, and K correlations were negative, with P/Ca, P/Mg, and P/K ratios of $r=-0.54$, $r=-0.49$, and $r=-0.34$, respectively. Individually, each of these correlations is not decisive, but their effect on the P immobilization in the soil is both individual and collective. Rodríguez-Camacho *et al.* (2021) point out that P moves in the soil solution mainly as primary orthophosphate (H_2PO_4), and secondary orthophosphate (H_2PO_4)= PO_4^{3-} . As organic phosphates enzymes, they are absorbed by the roots; therefore, the availability of this nutrient will be very likely reduced when its free electrons react with the positive charge of Ca or Mg in local soil minerals —including anorthite ($CaAl_2Si_2O_8$), albite ($NaAlSi_3O_8$), and other materials with abundant Ca, K, and Mg.

Comparison with other studies

Sangines *et al.* (2019) studied the long-term effects (1967-2016) on soil properties in an experiment in Agroscope, Switzerland, determining that changes were influenced by series of long wheat, turnip, and corn monoculture periods. Meanwhile, a higher organic matter content was recorded when these crops were grown in constant rotation.

CONCLUSIONS

The agricultural systems under study changed the chemical characteristics of the soil. Four agricultural systems stood out, both in bean and fava bean monocultures and the corn-bean (MF) or corn-fava bean (MH) combinations, improving the organic matter (OM), total N (TN), and soil P (P) content. Corn monoculture systems (T1 to T4) caused the greatest reduction in fertility variables. In conclusion, local monoculture practices will make corn yields increasingly dependent on the external application of nutrients, which is not beneficial, neither for soil nor producer health.

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