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FARMING SYSTEMS DIFFER FOR SOIL ORGANIC MATTER AND SOIL FAUNA IN COLD ARID REGIONS OF QUETTA DISTRICT, BALOCHISTAN

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Abstract
The soil organic matter concentration (SOM) is an important soil health indicator. It has a strong positive relationship with soil macrofauna, which are ecosystem engineers. Farming systems greatly influence the concentration of SOM and therefore the abundance of soil macrofauna. This study investigated the concentration of SOM and the abundance and number of soil macrofauna species of agricultural farms of two locations (separated by approximately 45 kilometers) in Quetta district, Balochistan, Pakistan. These farms were 1) orchards of apple, apricot, cherry and plum as monocrops or mix tree stands, 2) croplands of vegetables or cereals and 3) tree-based intercropping fields (TBI). Croplands and monocrop orchards were the oldest (12 to 26 yrs age for croplands and 16 - 25 yrs age for monocrop orchards); whereas, diversified orchards and tree-based intercropping fields were the youngest fields (since the lands were converted from rangeland to cropland; 6 - 14 yrs age for diversified orchards and 3 - 6 yrs age for TBI systems). The croplands were under conventional farming systems (deep tillage and one cropland also received synthetic fertilizers). The other fields (orchards and TBI systems) were under conservation agricultural practices (minimum tillage with the use of spade and the amendment of both manure and inorganic fertilizers). Despite being old, croplands had a significantly lower SOM concentrations than orchards (18.0±4.1 g kg^{-1} soil for croplands and 23.1±4.8 g kg^{-1} soil for orchards). The most diversified TBI field (4 yrs age) had significantly higher SOM concentration (23.2±3.9 g kg^{-1} soil) than the oldest (26 yrs age) wheat-fallow rotation system cropland (14.1±1.3 g kg^{-1} soil; $P<0.05$). Interestingly, the concentration of SOM to age ratio was 2 to 4 times significantly higher for TBI system and the diversified orchard than croplands and monocrop orchards ($P<0.05$). Moreover, out of four TBI systems, two fields (TBI1 with 14.8±1.5 g kg^{-1} soil SOM and TBI2 with 23.2±3.9 g kg^{-1} soil SOM) had two ant species co-existing and one TBI system (TBI3 with 18.19±3.5 g kg^{-1} soil SOM) had the highest number of soil macrofauna species (fire ants, snail, earthworm, brown rescue spider, ladybug, woodlice). This study shows that conservation tillage and diversified cropping system (TBI system) had a positive influence on the accrual of SOM in soil and the abundance of soil macrofauna species.
Keywords: *Conservation agricultural practices, Diversified cropping system, Soil macrofauna, Tree-based intercropping system, Soil organic matter.*

INTRODUCTION

Soil organic matter (SOM) controls many soil ecosystem services. For example, high concentration of SOM makes soil well-aggregated. Soil with bigger and stronger aggregates make it aerated, which is required for aerobic respiration of roots and soil microorganisms (1, 2). Furthermore, well-aggregated soil has low bulk density and has high capacity to retain air, water and nutrients (1, 2). Besides these functions SOM plays in soil, high concentration of SOM is an indicator of high abundance of microorganisms and therefore, it is an indicator of efficient nutrient cycling (3). The high concentration of SOM is therefore important for good soil health, which is in return required for high crop yield (4-6). The high concentration of SOM ensures that roots of crops get enough air, water and nutrients for their growth and development through making soil well-aggregated, reduces its bulk density, harbors diverse and abundant microbial genera, which help in nutrient cycling and provide defense to plant roots against pathogens (7).

Soil macrofauna such as termites, ants, earthworms, centipedes, millipedes, spiders, isopods (e.g. woodlice), snails, scorpions, beetles act as ecosystem engineers and are indicators of soil health (8, 9). These creatures distribute plant litter (fallen leaves, stover of crops after harvest, other dead plant tissues) and animal remains in horizontal and vertical directions in soil (9). This factor helps make the soil fertile at greater distances, through providing microbes with organic residues to decompose and release nutrients in soil (9). Soil macrofauna has a great role in making soil well-aggregated (10). They make channels in soil, the earthworm castes are home to microbes, their movement and activities in soil reduces soil bulk density and provide microhabitats for soil flora (bacteria, archaea, actinomycetes, fungi) and fauna (nematodes, amoeba, colembola and other meso and macrofauna) (9). Therefore, soil macrofauna play great role in making soil fertile for crop yield. The concentration of SOM has a positive relationship with the abundance and species diversity of soil macrofauna (9, 11, 12). As stated above, SOM controls soil aggregation. Well-aggregated soil offers diverse microhabitats for soil fauna, where these organisms find ample of air, water and nutrients for their growth and reproduction (9, 11).

Agricultural practices are divided into two main classes; 1) conventional practices, which involves the use of deep tillage (mouldborad ploughing), use of synthetic fertilizers and pesticides, 2) conservation agriculture, which involves the use of minimum (or reduced) tillage (e.g. shallow ploughing using spade), use of both organic and inorganic fertilizers and crop diversification (e.g. tree-based intercropping, crop rotation, intercropping of cereals with vegetables) (13, 14). In general, conventional agricultural practices reduce the concentration of SOM and adversely influence the abundances of soil macrofauna and their diversity (15-18). The conservational agricultural practices tend to increase the concentration of SOM (19, 20) and the abundances of soil macrofauna (15-18).

Balochistan is the largest province off Pakistan that accounts for approximately 44% of total land area of the country. Approximately 50% of land of this province has cold Mediterranean climate (warm dry summer and cold rainy winter). The agricultural farms of these cold deserts are famous for the production of apple, cherry, apricot, peach, plum, watermelon and tomato. Other crops such as wheat, barley, zucchini, spinach, chili are also grown in these regions.

This study aimed to investigate the farming practices, concentration of SOM and abundances and number of soil fauna species in those agricultural farms. Three types of farms were surveyed; orchards, croplands and tree-based intercropping systems. We hypothesized that the farms, which receive organic fertilizers (e.g. manure), are under minimum (reduced) tillage practices and are more diversified (under crop rotation or tree-based intercropping systems) have more SOM concentration, high abundances of soil macrofauna and greater number of soil macrofauna species than the farms under conventional agricultural practices and under monocropping systems. We sampled agricultural farms at two locations with approximately similar climatic conditions but at approximately 45 kilometers distant.

MATERIALS AND METHODS

STUDY SITES

Two study sites; Barchor, Pishin and Hanna, Quetta were taken into account for this study. The reason for two study sites was to space out sampling to greater area with similar climatic conditions. These two areas are approximately 45 kilometers distant (Table I). The climate of these study sites is cold Mediterranean (warm dry summers and cold rainy winters). The total annual rainfall is less than 250 mm. Five agricultural fields were sampled from Barchor, Pishin and eight agricultural fields were sampled from Hanna, Quetta (Fig. 1). The agricultural fields were three croplands, three orchards with apple trees as monocrop, three diversified orchards with mix fruit trees (apple with cherry, apricot or plum) and four tree-based intercropping (TBI) systems (Fig. 2). All croplands were under deep tillage (conventional mouldboard tillage). The two croplands had been receiving both organic and inorganic fertilizers; one cropland was under conventional practices for both deep tillage and the use of only inorganic fertilizer (Table II). The orchards and tree-based intercropping systems were under conservation practices; minimum/shallow tillage with spade and the use of both manure and inorganic fertilizer (Table II). The manure used in these lands was mostly from the farms of cow and buffalo. Croplands and orchards were older than tree-based intercropping systems (Table II). The croplands were 12-26 yrs of age since the land was converted from rangeland to cropland. Orchards were 6-25 yrs of age since the land was converted to orchards from rangeland; whereas, TBI systems were 2-6 yrs of age (Table II). The TBI systems in this province are new compared to croplands and orchards (21- 23). The TBI system requires less water and more profitable crops (e.g. apple, plum, apricot, cherry, peach, watermelon, tomato and other vegetables) can be grown at one time in the agricultural fields of these cold deserts. The International Water Management Institute (IMWI) has been educating the local farmers for practicing the conservation agriculture, which involves the use of both organic and synthetic fertilizers, crop diversification and specifically tree-based intercropping systems. This may also be the reason for the existence of TBI agricultural system in this province. This experiment is designed as factorial. Due to age differences of selected agricultural fields, each field is considered as a treatment with five replications for SOM analysis.

Table I. Coordinates of study sites

Location	Agricultural field code	Longitude	Latitude
Barshor, Pishin	Cropland 1	30°77′24″ N	67°20′33″ E
	OM 1	30°77′40″ N	67°20′37″ E
	TBI 1	30°81′66″ N	67°29′71″ E
	DO 1	30°76′24″ N	67°20′73″ E
	DO 2	30°75′10″ N	67°20′07″ E
Hanna, Quetta	Cropland 2	30°23′68″ N	67°10′58″ E
	Cropland 3	30°24′96″ N	67°12′84″ E
	OM 2	30°26′37″ N	67°14′53″ E
	OM 3	30°16′06″ N	67°09′48″ E
	TBI 2	30°27′32″ N	67°18′39″ E
	TBI 3	30°27′15″ N	67°16′31″ E
	TBI 4	30°25′64″ N	67°14′43″ E
	DO 3	30°24′66″ N	67°12′02″ E

Table II. Age of agricultural field (yrs) and management practices of study field sites in Barshor and Hanna Valley, Quetta District, Balochistan

Farming system	Age of agricultural field	Management practices	Cropping system
Cropland1	26	Deep tillage (mouldboard ploughing) yr^{-1}, amendment of urea	Wheat-fallow rotation
Cropland2	15	Minimum tillage (shallow tillage using spade) yr^{-1} farmyard manure and inorganic synthetic fertilizer	Potato-fallow rotation
Cropland3	12	Mouldboard ploughing yr^{-1} amendment of farmyard manure and sequesterne fertilizer	Pumpkin and green beans
OM1	25	Minimum tillage twice yr^{-1} and the amendment of inorganic fertilizer and farmyard manure	Orchard of apple
OM2	22	Minimum tillage yr^{-1} and the amendment of farmyard manure	Orchard of apple
OM3	16	Minimum tillage yr^{-1} no amendment of fertilizers	Orchard of apple
DO1	14	Minimum tillage yr^{-1} and the amendment of inorganic fertilizer and farmyard manure	Orchard of plum and apple
DO2	6	Minimum tillage yr^{-1} and the amendment of inorganic fertilizer and farmyard manure	Orchard of apricot and apple
DO3	14	Minimum tillage yr^{-1} and the amendment of inorganic fertilizer	Orchard of apricot, apple and plum
TBI1	2	Mouldboard tillage twice yr^{-1} and the amendment of farmyard manure and inorganic fertilizer	Potato field intercropped with apple trees
TBI2	4	Minimum tillage yr^{-1} once in a year and the amendment of farmyard manure	Orchard of apricot, apple and cherry intercropped with mix vegetables
TBI3	3	Minimum tillage yr^{-1} and the amendment	Orchard of apricot

		of farmyard manure and white and black mix inorganic fertilizer	intercropped with mix vegetables
TBI4	6	Minimum tillage yr^{-1} and the amendment of NSP inorganic fertilizer	Orchard of apple intercropped with barely

OM; orchard monocrop, DO; diversified orchard, TBI; tree-based intercropping; 1, 2, 3, 4; field sites

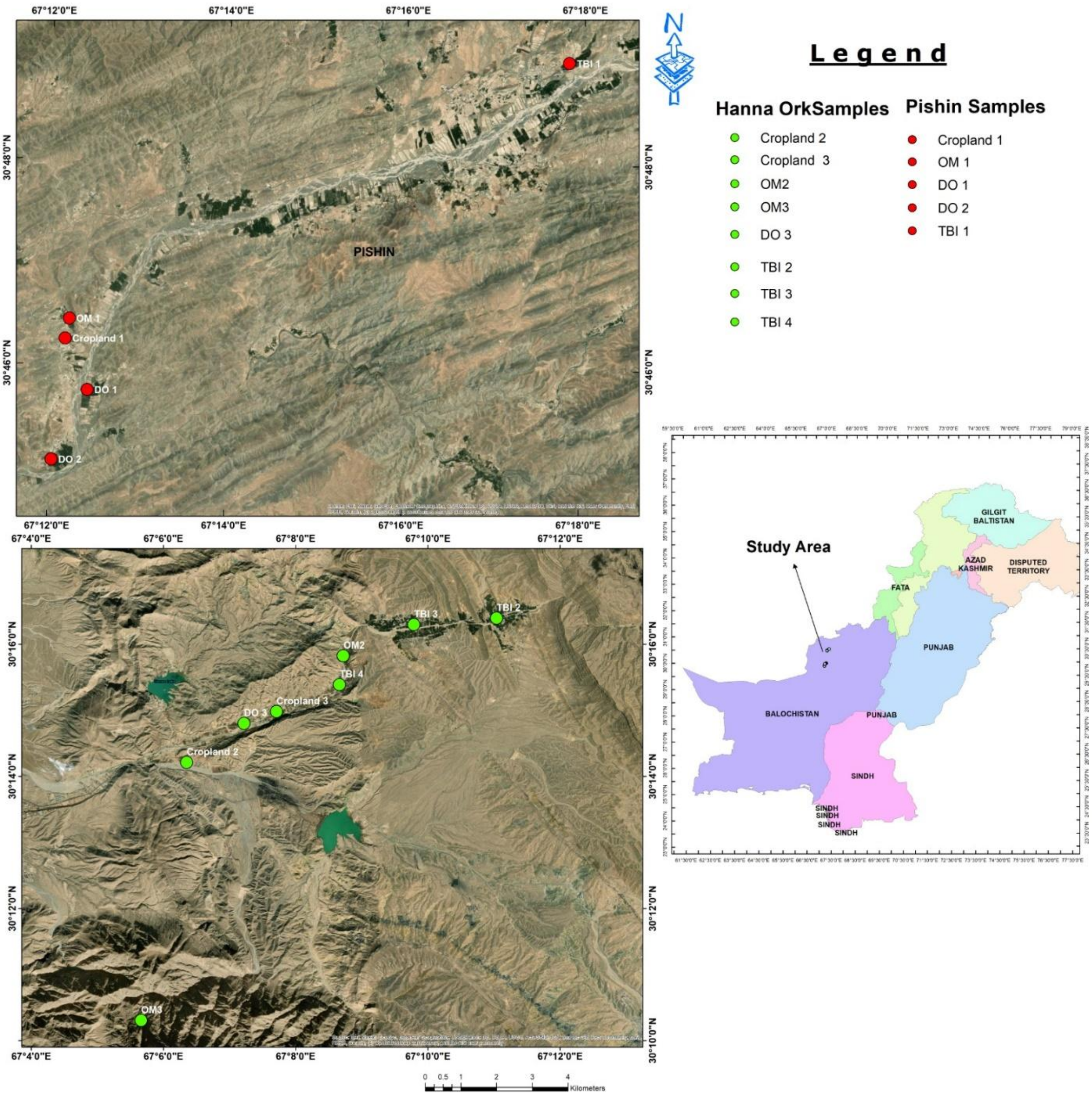

Fig. 1. Map showing study field sites

COLLECTION OF INFORMATION REGARDING FARMING PRACTICES

The local farmers of each sampling field site were questioned for the following information 1) age since the agricultural field was grown on a barren rangeland, 2) type of crop(s) grown, 3) type and frequency of tillage, 4) type of fertilizer applied.

SOIL AND MACROFAUNA COLLECTION

Using 5 cm diameter and 10 cm height soil corer (open from both sides) was used to collect soil from the top 0-10 cm depth. From each field site, 5 samples of soil were collected with random walk technique. Soil samples were spread over a plastic sheet to collect soil fauna. Soil macrofauna that was found in the vicinity of soil sampling within eye site limit were also collected in a screw-capped plastic bottle containing 5% formaline solution (23). After collecting soil fauna, soil samples were collected in labelled ziplock plastic bags. Soil samples were air-dried in Soil Biology and Fertility Laboratory, Department of Botany, University of Balochistan. The soil macrofauna samples were identified using services from the Department of Zoology, University of Balochistan. The samples of soil fauna were pooled of each sampling field site.

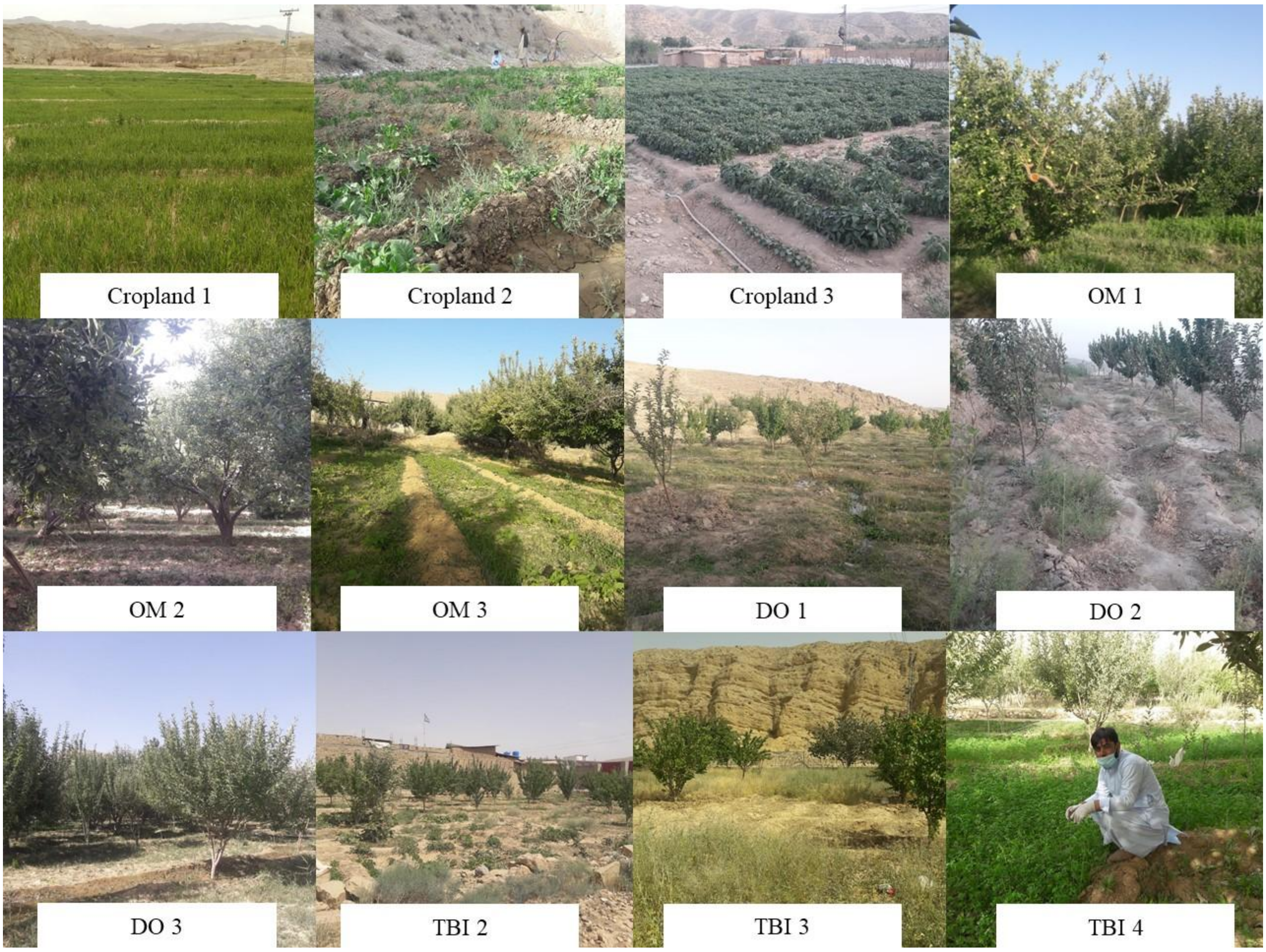

Fig. 2. Field sites at Barshor and Hanna valley, Quetta District, Balochistan, Pakistan. OM; orchard monocrop, DO; diversified orchard, TBI; tree-based intercropping; 1, 2, 3, 4; field sites

SOIL ORGANIC MATTER ANALYSIS

Air-dried soil samples were further analyzed for the concentration of SOM according to the procedure of Walkley and Black rapid titration method as described in Estefan *et al.,* (24).

STATISTICAL ANALYSIS

The data sets for concentration of SOM were subjected to normality test using D'Agostino-Pearson K^2 test. The fields were considered as treatments and the sample size for each field site (treatment) was five. This research was a factorial experiment. The Analysis of Variance (ANOVA) followed by least significance difference test (LSD) was used to analyze data. The comparison was made between fields (treatments) for average values. To better visualize the relationship between age of an agricultural field and the concentration of SOM and between the concentrations of SOM with the number of soil macrofauna, these results were combined in figure form. The concentration of SOM to age ratio was also quantified based on the average values of fields to measure the differences between agricultural systems i.e. croplands, orchards (monocrop), diversified orchards and TBI systems.

RESULTS AND DISCUSSION

Significant differences between type of cropping and the concentration of SOM were found (Fig. 3). The cropland 1 that was under deep tillage practice and in that field only inorganic fertilizer was amended had the least concentration of SOM (14.1 g kg^{-1} soil). The highest concentration of SOM was found in apple orchard (OM2), which was under conservation agricultural practices for minimum tillage and the amendment of both manure and inorganic fertilizer (32.8 g kg^{-1} soil) (Fig. 3). The apple orchards OM1 and

OM2 as monocropping systems and diversified orchards DO1 and DO2 and the TBI2 had significantly higher concentration of SOM than the cropland 1, TBI1 and TBI4 fields. The cropland 1 was grown with wheat as monocrop with fallow period every year. The deep tillage every year and the use of no organic fertilizer may be the reason why the concentration of SOM was significantly lower than most of the orchards and TBI2 field. Our results are in agreement with other reports that croplands under monocropping system with fallow period and conventional tillage practice has significantly lower concentration of SOM than the soil under conservation agriculture with trees (21, 22, 25, 26). Another interesting finding w as that the TBI2 field was the most diversified with trees of apricot, apple and cherry intercropped with mix vegetables. This TBI2 system was only 4 years old since it was converted from rangeland to an agricultural field. Other conservation agricultural practices such as the amendment of farmyard manure as organic fertilizer and shallow tillage might also played role in improving the concentration of SOM in this field. This may be the reason that the concentration of SOM was comparable to the concentration of SOM in orchards and was significantly higher than the concentration of SOM in cropland 1 (Table II). Another interesting finding is the significant differences between the cropping systems regarding the ratio of concentration of SOM to age (Fig. 4). The concentration of SOM:age ratio was significantly higher by 2-4 times for diversified orchards and the TBI system than croplands and the monocrp orchards ($P<0.05$). This indicates that crop diversification help in SOM accrual. The TBI system has been reported frequently for its positive role in increasing the concentration of SOM than croplands (27, 28).

As was observed for the concentration of SOM in these fields, cropping systems showed an influence on the abundances and the number of soil macrofauna species (Table III). The two TBI systems; TBI1 (SOM = 14.8±1.5 g kg^{-1} soil) and TBI2 (SOM = 23.2±5.7 g kg^{-1} soil) had two ant species that were coexisting. This was however not observed for the other cropping systems such as monocrop orchards, diversified orchards and croplands. Likewise, the TBI3 field (SOM = 18.2±3.5 g kg^{-1} soil) had the highest number of soil macrofauna (except for cropland 2 field) such as fire ants, snail, earthworms, woodlice, ladybug, Brown recuse spider. The positive influence of TBI system and diversified cropping systems on the abundances and species diversity of soil biota is frequently reported (29-31). The diversity of soil macrofauna is an indication of soil health (9). Ants are important soil-dwelling organisms, which play a significant role in structuring soil (promoting soil aggregation) and promoting soil fertility (32, 33).

The highest number of soil macrofauna was also observed for cropland 2 (seven different macrofauna species as were observed for TBI3). The types of macrofauna species in this field was however different than what was found in TBI3. In this field, fire ant, brown slug, fire bug, isopod, Red cooton bug and Cran fly larva were found (Table III). We attribute this high number of soil fauna in this cropland to the management practice. In this field, the amendment of farmyard manure as fertilizer and reduced tillage were practiced. This may be the reason for high number of soil fauna found in this field. Our results are in alignment of published reports that the amendment of organic fertilizers and reduced tillage increases the abundance and diversity of soil macrofauna (9, 34, 35).

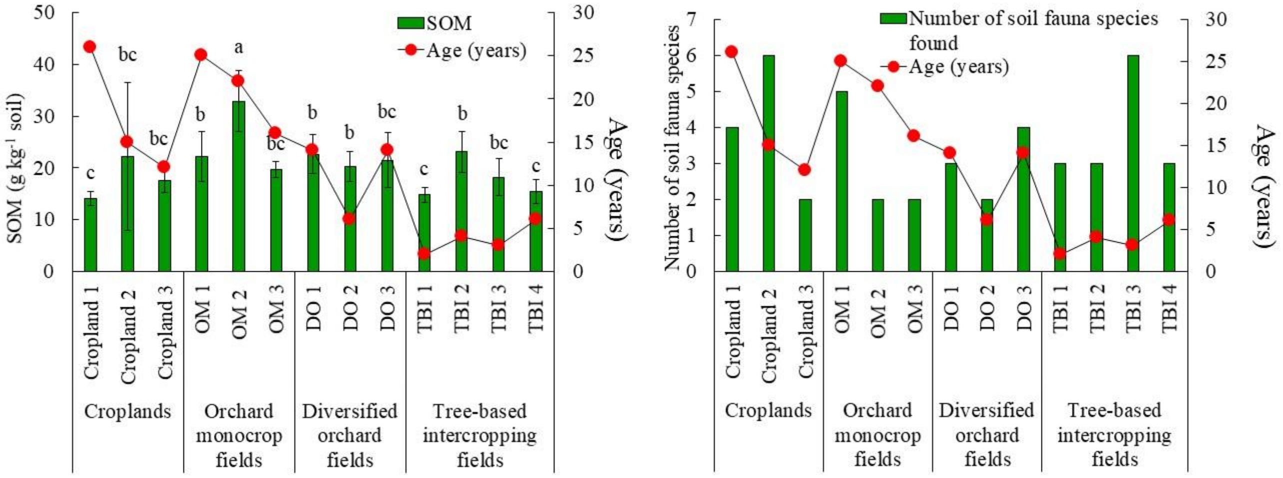

Fig. 3. Mean (± standard deviation) of soil organic matter (SOM) in the upper 0-10 cm depth of soil of agriculture fields of various age (years). Bars with different letters are significantly different at $p<0.05$

Table III: Soil surface-dwelling and upper soil layer-dwelling macrofauna of study field sites

Sampling site	Types of soil fauna	Number of soil fauna
Cropland 1	Small black ants	Uncountable
	Short-horned grasshopper	1
	Hermit beetle	1
	Scarab beetle	1
Cropland 2	Fire ant	Uncountable
	Brown slug	1
	Fire bug	1
	Isopods	1
	Red cooton bug	1
	Cran fly larva	1
Cropland 3	Carpenter ant	Uncountable
	Fire bug	2
OM 1	Small black ants	Uncountable
	Brown slug	7
	Drugstore beetle (bread beetle)	1
	Tiny black bug	1
	Earthworm	1
OM 2	Snail	2
	Earthworm	3
OM 3	Isopods	1
	unidentified	1
DO 1	Isopod	2
	Earthworm	1
	Slug	2
DO 2	Large-headed small ants	Uncountable
	Darkling beetle	1
DO 3	Fire ant	Uncountable
	Snail	1
	Isopods	1
	Earthworm	1
TBI 1	Small black ants	Uncountable
	Carpenter ants	Uncountable
	Carpet beetle	1
TBI 2	Carpenter ants	Uncountable
	Fire ants	Uncountable
	Fire bug	1
TBI 3	Fire ants	Uncountable
	Snail	2
	Earthworm	1
	Brown recuse spider	1
	Ladybug	2
	Woodlice	2
TBI 4	Snail	3
	Earthworm	1
	Ladybug	2

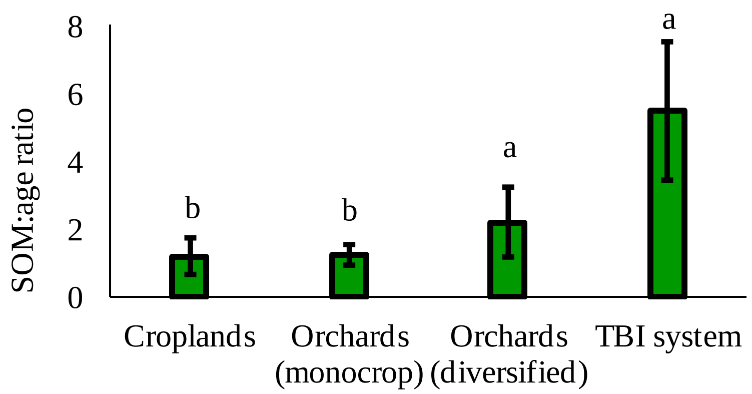

Fig. 4. The concentration of soil organic matter to age of field ratio. Bars with different letters are significantly different ($p<0.05$)

CONCLUSION

Cropland under conventional practices (deep tillage, monocroping with fallow period per year and the use of only inorganic fertilizer) tend to reduce the concentration of SOM and number of species of soil fauna. Contrary to this, orchards under conservation agricultural practices (amendment of both manure and inorganic fertilizer and shallow tillage) and the TBI system tend to increase the concentration of SOM. The significantly higher SOM:age ratio for TBI system and diversified orchard indicates that crop diversification enhances the accrual of SOM in soil. The interesting finding of this study was the co-existence of two ant species in two out of four TBI fields sampled in this study. Our findings suggest that the TBI system despite of being younger than monocrop orchards and croplands, was better in increasing the species diversity of soil macrofauna.

Conflict of Interest:

Authors have no conflict of interest.

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