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Does land use history have an influence on soil quality? A case study with agricultural lands of Rodh Mulazai, Pishin, Balochistan Pakistan

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Abstract

Rodh Mulazai is a small town in Pishin District, Balochistan, Pakistan. This study investigated the soil quality of agricultural lands in this region. The 20 field sites were sampled. All these sites had orchards (commonly apple), and three of them had tree-based intercropping systems with wheat or tomato. These agricultural lands were 7–25 years old and were commonly under conservation agriculture since the beginning. The concentration of soil organic matter in the upper 0–10 cm depth of these field sites ranged from 9.33 to 41 g kg^{-1}. A total of 13 soil macrofauna species were found, and the most common and abundant was the earthworm *Lumbricus terrestris*, followed by the earthworm *Lumbricus rubellus*. There was no relationship found between the total number of soil fauna and the concentration of soil organic matter at these field sites, nor did soil organic matter have a relationship with the concentration of soil clay contents. Likewise, the age of these sites with continuous conservation agriculture had no relation to the concentration of soil organic matter.

Keywords: soil macrofauna; land use history; conservation agriculture; tree-based intercropping; Pishin District.

Practical Application: The case study conducted in Rodh Mulazai, Pishin, Balochistan, Pakistan, explores the practical application of assessing the influence of land use history on soil quality in agricultural lands. By analyzing soil samples from different areas with varying land use histories, researchers aim to identify potential correlations between past land practices and current soil quality. Such investigations can help farmers and policymakers make informed decisions on sustainable land management practices, crop selection, and soil conservation strategies to improve agricultural productivity and environmental sustainability in the region.

1. Introduction

Land use history of agricultural lands in arid and semi-arid regions has an influence on soil quality. Various management practices have different influences on the soil quality of dry regions (Khan et al., 2022; Mason et al., 2015; Younas et al., 2022). Soil organic matter (SOM) is an important soil quality indicator and has a strong positive relationship with soil quality and crop productivity in dry regions (Sharma et al., 2013; Sithole & Magwaza, 2019). Management practices, such as type and frequency of tillage, cropping system (crop rotation, tree-based intercropping, and mono-cropping), and fertilizer management have a significant influence on the soil quality of agricultural lands in dry regions. For example, in a 13-year field trial in Winterton, Gourton Farm, KwaZulu-Natal, South Africa, with various tillage practices, Sithole and Magwaza (2019) found that, as compared to conventional tillage, fields under no-tillage practice had significantly greater organic carbon (27.1 t ha^{-1} in no-tillage fields versus 26.5 t ha^{-1} in conventional tillage fields) than fields under conventional tillage practice.

Crop diversification with shallow and infrequent tillage, coupled with organic fertilizer amendments, and mulching with crop residues tend to increase SOM and improve crop production in dry regions (Khan et al., 2022; Mason et al., 2015; Younas et al., 2022). Younas et al. (2022) found that the

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10-year-old agricultural field wheat-cabbage rotation, intercropped with almond trees under conservation agriculture (shallow tillage and the use of farm yard manure and inorganic fertilizer), had the highest concentration of SOM and soil organic carbon (SOC) and the highest number of soil macrofauna than the fields under mono-cropping systems in Loralai, Balochistan, Pakistan, with arid climatic conditions. Their results also demonstrated that orchards had a significantly higher concentration of SOM than croplands because orchards received shallow tillage while croplands received deep and more frequent tillage.

Soil macrofauna are important ecosystem engineers. They help structure soil by promoting soil aggregation, make channels for roots, microbes, and other creatures to grow and live, reduce soil bulk density, help retain soil nutrients, and promote soil aeration in agroecosystems (Lavelle et al., 2016; Sofo et al., 2020). Agricultural management practices have been reported to have a significant influence on the abundance and species diversity of soil macrofauna in dry regions (arid and semi-arid regions) (Younas et al., 2022; Zulu et al., 2022). In a 16-year-old field in Grouton farm, Winterton, KwaZulu-Natal, South Africa, Zulu et al. (2022) reported an approximately two times greater abundance of soil macrofauna under no tillage than a conventional tillage system. Kelly et al. (2021) reported an approximately two times increase in the abundance of soil macrofauna under a no-tillage and cover crop rotation system than conventional tillage with no cover crop in a 13-year-old field at the West Side Research and Extension Center, University of California, USA, with a Mediterranean arid climate. Sofo et al. (2020), in their literature review, reported a positive relationship between abundance of soil macrofauna, soil quality, and crop production in orchard agroecosystems.

Balochistan is the largest province of Pakistan by area (Panezai, 2012). Balochistan consists of an arid weather pattern (Rehman et al., 2019). The Pishin District is located in the north-west of Balochistan Province, Pakistan (Ashraf, 2019). This region lies between 66.13–67.50 longitudes and 30.04–31.17 north latitudes (Tareen et al., 2014). Rodh Mulazai is a rural agrarian area of this region. Local people in this region mostly rely on agriculture. The agricultural lands are mostly orchards of apples, plums, peaches, and few croplands. Till date, no data are available that demonstrates the soil quality of these agricultural lands from the perspective of agricultural management practices. The objective of this study was to evaluate soil quality and the abundance and number of species on soil macrofauna of agricultural lands in this region. A total of 20 agricultural fields and 3 barren adjacent sites (disturbed rangelands) were sampled in this regard.

2. Materials and Methods

2.1. Study area and sampling sites

The study was conducted in Rodh Mullazai, Pishin District, Balochistan, Pakistan. Rodh Mullazai is a rural agrarian area of Karezat Tehsil (Panezai, 2017) that covers approximately 35–38-km area (Figure 1). The study area is adjacent to Khanozai, which is the headquarter of Karezat Tehsil (Panezai, 2013). The environment is Mediterranean type (dry summers and cold, rainy winters). This region also receives snowfall in winter. The mean annual rainfall is less than 250 mm.

A total of 23 sampling sites were selected, of which 20 field sites were orchards (17 fields) or tree-based intercropping systems (3 fields), and 3 sites were barren areas (disturbed rangelands) (Figure 2). The coordinates of study sites are given in Table 1, and sampling sites are given in Figure 1.

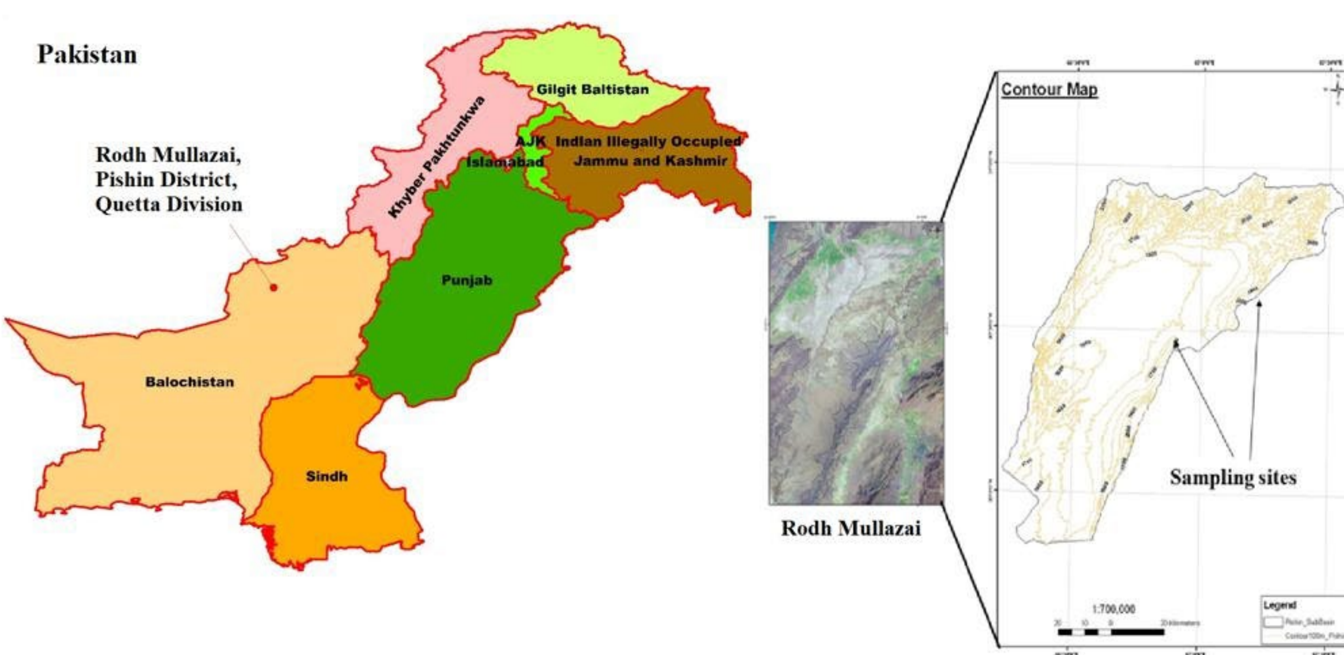
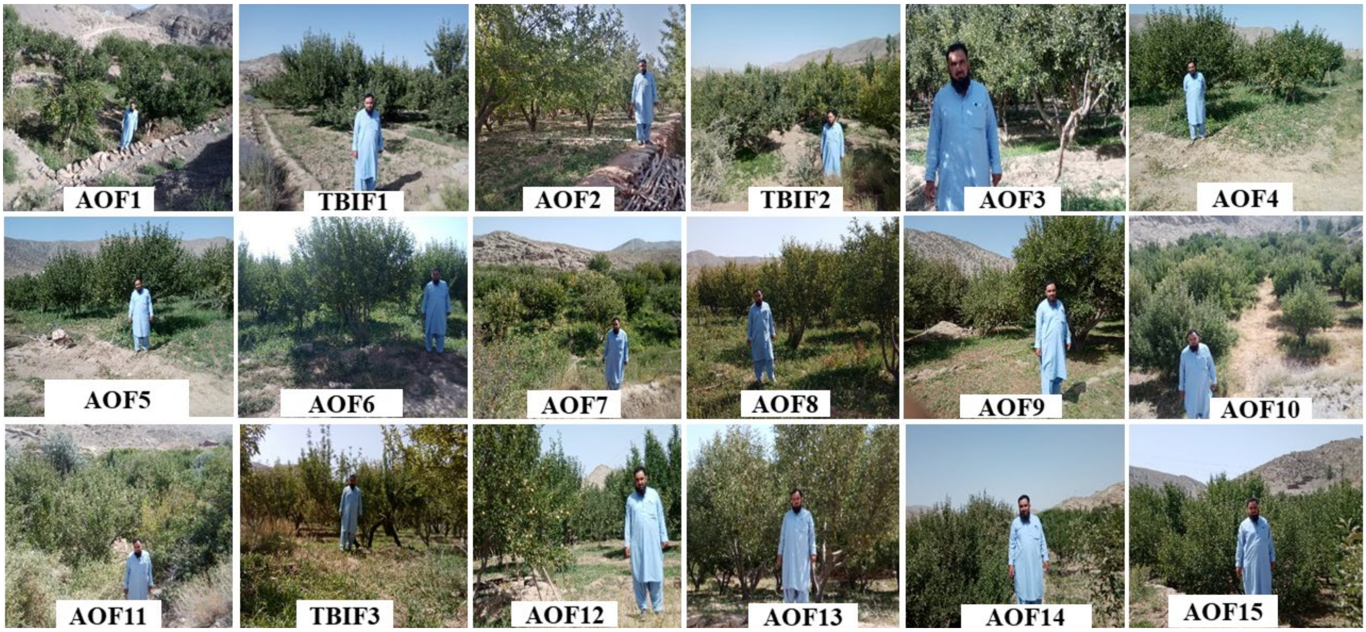


Figure 1. Sampling location sites of study sites Rodth Mullazai, District Pishan, Quetta Division, Baluchistan, Pakistan.



AOF: apple orchard field, numbers (1–15) agricultural fields sampled; TBI: tree-based intercropping.

Figure 2. Study field sites of Rodh Mulazai, Pishin, Balochistan, Pakistan.

2.2. History data collection of sampling sites

The history of sampling field sites included the age of the fields, type of crop cultivated (trees or annual crops), type (deep with moldboard plowing or shallow with a spade) and frequency of tillage, and type and frequency of fertilizer used. The questions were asked to the local farmers of a given sampling field site.

2.3. Soil sampling and processing

On October 8, 2021, four soil samples were collected from each field site, from 0 to 10 cm depth, using a 10 cm diameter and 5 cm height soil corer (Khan et al., 2022; Younas et al., 2022). The soil samples were taken over a wide area to cover the complete sampling site. After collecting soil fauna (a description is provided below), soil samples were collected in labeled zip-lock plastic bags.

Soil samples were placed in the Soil Fertility Laboratory, Department of Botany, University of Balochistan, Quetta, for air-drying. Thereafter, samples were passed through a 2-mm mesh sieve to remove debris and decomposing plant residues, and samples were stored in a refrigerator at 4°C until analysis.

2.4. Soil fauna collection

During the inspection of the entire area for soil samples, soil surface macrofauna were gathered in plastic bottles. After collecting the soil, it was spread out on paper, and the macrofauna were collected in plastic bottles for the top soil layer (0–10 cm depth) macrofauna collection. The formalin solution used to preserve the macrofauna was diluted to 5%. The total number of soil fauna in each bottle was counted. Thereafter, identification of soil macrofauna was carried out in the Department of Zoology, University of Balochistan, Pakistan.

2.5. Soil chemical analysis

The chemical analysis of soil samples was carried out in the Soil Testing Laboratory, Agricultural Research Institute (ARI), Quetta, Pakistan. The Walkley-Black method was used to assess the soil's organic matter and organic carbon, according to the procedure outlined in Estefan et al. (2013). For the assessment of pH and electrical conductivity, soil samples were mixed with distilled water at a ratio of 1:2 soil:water (w:v) and analyzed according to the procedure given in Estefan et al. (2013). Following the methodology outlined in Estefan et al. (2013), texture of soil samples was examined.

2.6. Statistical analysis

The datasets of each tested parameter were analyzed for normality using the D'Agostino-Pearson K^2 test. The differences between treatments (sampling sites) were analyzed with one-way analysis of variance (ANOVA) followed by the least significant difference test (LSD). All statistical analyses were performed with the CoStat and Microsoft Excel software.

3. Results

3.1. History of sampling field sites

The field sites were 7–25 years of age. Mostly apple orchards were grown. Three fields were tree-based intercropping. Four field sites received only inorganic fertilizer input (synthetic NPK), and only one field site received only organic fertilizer. The rest of the other agricultural field sites received both inorganic and organic fertilizers, commonly once or twice per year. The manure from the farms of cows and buffalo were used as a source of organic fertilizer. Shallow tillage with a spade was practiced in all fields once or twice per year (Table 1).

Table 1. Land use history (age of agricultural land, tillage system, fertilizer management, and cropping system), SOM (g kg^{-1} soil), number of soil fauna per sampling spot, and total number of soil fauna*.

Sampling sites	Age (years)	Land use history	Cropping system	SOM	Number of fauna	Number of species of fauna
AOF1	14	Shallow tillage once per year, use of inorganic and organic fertilizers	Apple orchard since beginning	10.8 ± 2.0^{ij}	2 ± 1.41^{gh}	2
TBIF1	7	Shallow tillage once per year, use of inorganic and organic fertilizers	Maize as crop between apple trees stands	15.3 ± 3.0^{ghi}	8.25 ± 1.26^{a}	3
AOF2	25	Shallow tillage once per year, inorganic fertilizer twice per year and organic fertilizer was not used for last 10 years	Apple orchard since beginning	9.33 ± 2.2^{j}	4.25 ± 1.71^{def}	2
TBIF2	17	Shallow tillage twice per year, no inorganic fertilizer used, organic fertilizer is used once per year	Maize crop in between apple trees	29.1 ± 4.3^{b}	4.5 ± 2.38^{cdef}	4
AOF3	15	Organic and inorganic fertilizers are used once per year. Shallow tillage is used once per year	Apple trees since beginning	25.5 ± 2.7^{bcd}	3 ± 1.15^{fg}	2
AOF4	18	Organic and inorganic fertilizers are used once per year. Shallow tillage is used once per year	Apple orchard, since beginning	27.1 ± 3.9^{bc}	3.5 ± 2.38^{defg}	3
AOF5	22	Only inorganic fertilizers are used and shallow tillage once per year	Apple orchard since beginning	30.1 ± 10.2^{b}	5.5 ± 1.29^{bcd}	1
AOF6	17	Organic and inorganic fertilizers are used once per year. Shallow tillage is used once per year	Apple orchard since beginning	30.4 ± 3.5^{b}	5.25 ± 1.71^{bcde}	2
AOF7	13	Inorganic fertilizer is used every year, organic fertilizer is used every 3–4 years and shallow tillage is used once per year	Apple orchard since beginning	22.2 ± 3.6^{cdef}	6.5 ± 1.00^{abc}	3
AOF8	19	Inorganic fertilizer is used every year, organic fertilizer is used every 3–4 years and shallow tillage is used once per year	Apple orchard since beginning	19.3 ± 1.7^{efg}	4 ± 1.41^{defg}	4
AOF9	20	Both organic and inorganic fertilizers are used once every year and shallow tillage is used every year	Apple orchard since beginning	14.4 ± 7.2^{ghij}	3.25 ± 2.06^{efg}	4
AOF10	16	Both organic and inorganic fertilizers are used once every year. Shallow tillage once per year	Apple orchard since beginning	41.0 ± 1.3^{a}	4 ± 0.82^{defg}	1
AOF11	12	Both organic and inorganic fertilizers are used once every year and shallow tillage is used every year	Apple orchard since beginning	12.1 ± 3.7^{hij}	4 ± 1.41^{defg}	3
TBIF3	8	Only inorganic fertilizers are used once per year and shallow tillage once per year	Tomato cropping in between apple trees stands	16.4 ± 3.4^{fghi}	4.5 ± 1.73^{cdef}	2
AOF12	16	Only inorganic fertilizers are used once per year and shallow tillage once per year	Apple orchard since beginning	11.3 ± 2.6^{ij}	3 ± 1.83^{fg}	4
AOF13	18	Inorganic fertilizer is used every year, organic fertilizer once in 2 years, shallow tillage once per year	Apple orchard since beginning	18.6 ± 1.2^{efg}	4.25 ± 1.26^{def}	2
AOF14	13	Both organic and inorganic fertilizers are used once every year and shallow tillage is used every year	Apple orchard since beginning	22.5 ± 2.3^{cde}	4.5 ± 1.00^{cdef}	3
AOF15	9	Both organic and inorganic fertilizers are used once every year and shallow tillage is used every year	Apple orchard since beginning	27.7 ± 2.9^{bc}	7 ± 2.45^{ab}	3
ACAOF1	10	Both organic and inorganic fertilizers are used once every year and shallow tillage is used every year	Apricot and apple trees	21.9 ± 0.9^{cdef}	3.75 ± 0.96^{defg}	4
AOF16	8	Both organic and inorganic fertilizers are used once every year and shallow tillage is used every year	Apple orchard since beginning	25.8 ± 3.7^{bc}	4.25 ± 0.50^{def}	1

*Within column, values with different letters are significantly different at $p<0.05$. Manure from the farms of cows and buffalo are used as organic fertilizer in these agroecosystems; AOF: apple orchard field, numbers (1–15) agricultural fields sampled; TBI: tree-based intercropping.

3.2. Soil chemical properties

The SOM concentration of sampling sites ranged from 9.3 to 41.0 g kg^{-1} (Table 2). The concentration of SOC of sampling sites ranged from 5.4 to 23.8 g kg^{-1} (Table 2). The pH of soil samples of study sites ranged from 7.2 to 8.2 (Table 2). The soil electrical conductivity of study sites ranged from 0.18 to 0.72 dS m^{-1} (Table 2). The soil texture ranged from clay loam to sandy loam (Table 2).

Significant differences in the concentration of SOM between sampling sites were observed (Table 2). The highest concentration of SOM was observed in AOF10, followed by AOF5, AOF6, and TBIF2, whereas the least concentration was observed in AOF2 (Table 2).

No correlation between concentration of SOM with number of soil fauna or concentration of SOM and clay contents of soil was observed (Figure 3).

Table 2. Soil organic matter (g kg^{-1}), soil organic carbon (g kg^{-1}), soil pH, soil electrical conductivity (dS m^{-1}), soil phosphorus (mg kg^{-1}), soil potassium (mg kg^{-1}), sand (g kg^{-1}), silt (g kg^{-1}), and clay (g kg^{-1}) of study sites. Values are mean±SD (except for sand, silt clay which have n=1)*.

Study sites	Soil organic matter	Soil organic carbon	Soil pH	Soil electrical conductivity	Phosphorus	Potassium	Sand	Silt	Clay	Number of soil fauna
AOF1	10.8 ± 2.0^{ij}	6.3±1.2	7.83 ± 0.16^{abcde}	0.19 ± 0.04^{c}	4.91 ± 0.81^{efg}	55.44 ± 7.7^{def}	10	77.5	12.5	2 ± 1.41^{gh}
TBIF1	15.3 ± 3.0^{ghi}	8.9±1.8	7.31 ± 0.43^{cdefg}	0.20 ± 0.10^{c}	4.57 ± 0.84^{efg}	59.36 ± 2.7^{def}	10	60	30	8.25 ± 1.26^{a}
AOF2	9.33 ± 2.2^{j}	5.4±1.3	7.21 ± 0.24^{k}	0.25 ± 0.03^{c}	2.98 ± 0.67^{gh}	53.38 ± 1.7^{ef}	15	45	40	4.25 ± 1.71^{def}
TBIF2	29.1 ± 4.3^{b}	16.9±2.5	8.21 ± 0.44^{fghij}	0.18 ± 0.08^{c}	7.18 ± 2.41^{bcd}	52.35 ± 3.1^{ef}	15	47.5	37.5	4.5 ± 2.38^{cdef}
AOF3	25.5 ± 2.7^{bcd}	14.8±1.6	7.86 ± 0.30^{ebcde}	0.28 ± 0.08^{c}	5.55 ± 1.79^{cde}	47.80 ± 1.8^{f}	22.5	32.5	45	3 ± 1.15^{fg}
AOF4	27.1 ± 3.9^{bc}	15.1±2.3	7.56 ± 0.09^{fghij}	0.31 ± 0.05^{c}	4.91 ± 0.57^{efg}	62.67 ± 12.0^{cdef}	10	72.5	17.5	3.5 ± 2.38^{defg}
AOF5	30.1 ± 10.2^{b}	17.4±5.9	7.43 ± 0.21^{jk}	0.31 ± 0.07^{c}	1.92 ± 0.48^{h}	57.09 ± 4.7^{def}	20	37.5	42.5	5.5 ± 1.29^{bcd}
AOF6	30.4 ± 3.5^{b}	17.7±2.1	7.71 ± 0.18^{hijk}	0.34 ± 0.13^{c}	4.32 ± 1.47^{efg}	109.7 ± 10.1^{a}	12.5	55	32.5	5.25 ± 1.71^{bcde}
AOF7	22.2 ± 3.6^{cdef}	–	7.52 ± 0.13^{fghij}	0.44 ± 0.05^{abc}	2.24 ± 0.81^{h}	75.05 ± 3.1^{cd}	17.5	57.5	25	6.5 ± 1.00^{abc}
AOF8	19.3 ± 1.7^{efg}	11.2±1.0	7.82 ± 0.26^{jk}	0.25 ± 0.02^{c}	1.93 ± 0.51^{h}	59.57 ± 4.7^{def}	12.5	75	12.5	4 ± 1.41^{defg}
AOF9	14.4 ± 7.2^{ghij}	8.4±4.2	7.99 ± 0.04^{abcde}	0.33 ± 0.13^{c}	2.22 ± 0.48^{h}	117.1 ± 8.6^{a}	12.5	77.5	10	3.25 ± 2.06^{efg}
AOF10	41.0 ± 1.3^{a}	23.8±0.8	7.81 ± 0.04^{defgh}	0.35 ± 0.06^{c}	3.34 ± 0.55^{fgh}	82.49 ± 30.1^{bc}	12.5	77.5	10	4 ± 0.82^{defg}
AOF11	12.1 ± 3.7^{hij}	7.0±2.2	7.78 ± 0.09^{efghij}	0.45 ± 0.04^{abc}	1.90 ± 0.44^{h}	99.8 ± 51.9^{ab}	12.5	75	12.5	4 ± 1.41^{defg}
TBIF3	16.4 ± 3.4^{fghi}	9.5±2.0	8.14 ± 0.12^{abcd}	0.24 ± 0.04^{c}	1.93 ± 0.43^{h}	61.22 ± 10.7^{def}	17.5	60	22.5	4.5 ± 1.73^{cdef}
AOF12	11.3 ± 2.6^{ij}	6.5±1.6	7.96 ± 0.08^{bcdef}	0.33 ± 0.04^{c}	4.79 ± 1.17^{efg}	68.45 ± 8.4^{cdef}	17.5	57.5	25	3 ± 1.83^{fg}
AOF13	18.6 ± 1.2^{efg}	10.8±0.7	8.26 ± 0.13^{a}	0.40 ± 0.05^{bc}	5.55 ± 0.66^{cde}	61.43 ± 3.9^{cdef}	20	45	35	4.25 ± 1.26^{def}
AOF14	22.5 ± 2.3^{cde}	13.0±1.3	8.09 ± 0.05^{abc}	0.32 ± 0.06^{c}	8.11 ± 1.71^{b}	71.96 ± 18.2^{cde}	20	70	10	4.5 ± 1.00^{cdef}
AOF15	27.7 ± 2.9^{bc}	16.1±1.7	7.43 ± 0.26^{ijk}	0.72 ± 0.52^{a}	7.25 ± 2.24^{bc}	59.98 ± 4.7^{def}	25	37.5	37.5	7 ± 2.45^{ab}
ACAOF1	21.9 ± 0.9^{cdef}	12.7±0.5	8.11 ± 0.02^{ab}	0.42 ± 0.05^{bc}	4.52 ± 0.60^{efg}	54.62 ± 8.4^{def}	17.5	40	42.5	3.75 ± 0.96^{defg}
AOF16	25.8 ± 3.7^{bc}	15.0±2.1	7.66 ± 0.14^{ghij}	0.25 ± 0.01^{c}	10.45 ± 4.52^{a}	70.10 ± 11.1^{cde}	22.5	37.5	40	4.25 ± 0.50^{def}
RL1	19.9 ± 3.6^{defg}	11.6±2.1	7.83 ± 0.06^{efghi}	0.66 ± 0.78^{ab}	4.44 ± 0.76^{efg}	59.78 ± 8.9^{def}	10	47.5	42.5	0
RL2	15.6 ± 3.4^{ghi}	9.0±2.0	7.88 ± 0.07^{bcdef}	0.29 ± 0.17^{c}	5.13 ± 0.14^{def}	58.54 ± 7.1^{def}	10	65	25	0
RL3	17.8 ± 7.4^{efgh}	10.3±4.3	7.61 ± 0.09^{fghij}	0.3 ± 0.07^{c}	5.50 ± 1.34^{cde}	56.89 ± 12.1^{def}	15	60	25	0

*Within column, values with different letters are significantly different at p<0.05; AOF: apple orchard field, numbers (1–15) agricultural fields sampled; TBI: tree-based intercropping; RL: rangeland (barren area).

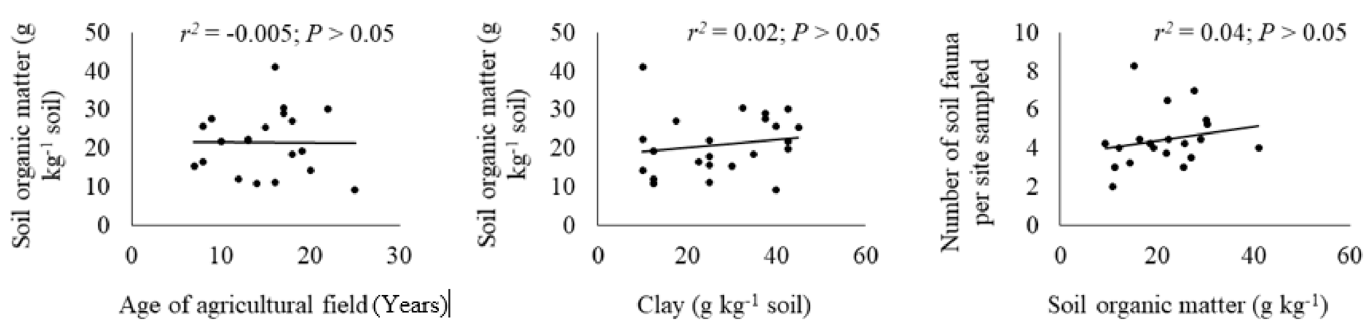


Figure 3. Correlation between SOM and age of agricultural land, SOM with clay contents of soil, and SOM with number of soil fauna found from a sampling site (agricultural field).

3.3. Soil fauna

A total of 13 soil macrofauna species were found, out of which 12 were identified (Figure 4; Table 3). The identified species were *Melolontha melolontha*, *Operophtera brumata*, *Lumbricus terrestris*, *Aporrectodea calignosa*, *Lumbricus rubellus*, *Octolasion tyrtaeum*, *Hirudo* spp. (leech), *Trachelipodidae trachelipus*, *Arion* spp., *Eisenia fedida*, *Aporrectodea calignosa*, and *Amynthas agrestis*. The most commonly found soil macrofauna in these agricultural fields was the earthworm *Lumbricus terrestris* (Table 2).

4. Discussion

The concentration of SOM of sampling field of the present study ranged from 9.3 to 41.0 g kg^{-1} soil, whereas the concentration of SOC in the agricultural field ranged from 5.4 to 23.8 g kg^{-1} soil. The concentration of SOC in our study fields is in agreement with previous reports by Moussa-Machraoui et al. (2010), which showed the concentration of SOC in the upper 0–20 cm depth of soils from agricultural fields in the Mediterranean semi-arid regions of Mahassen and Krib, Tunisia, as 9–17 g kg^{-1} soil. Likewise, approximately 7–13 g kg^{-1} SOC have been reported

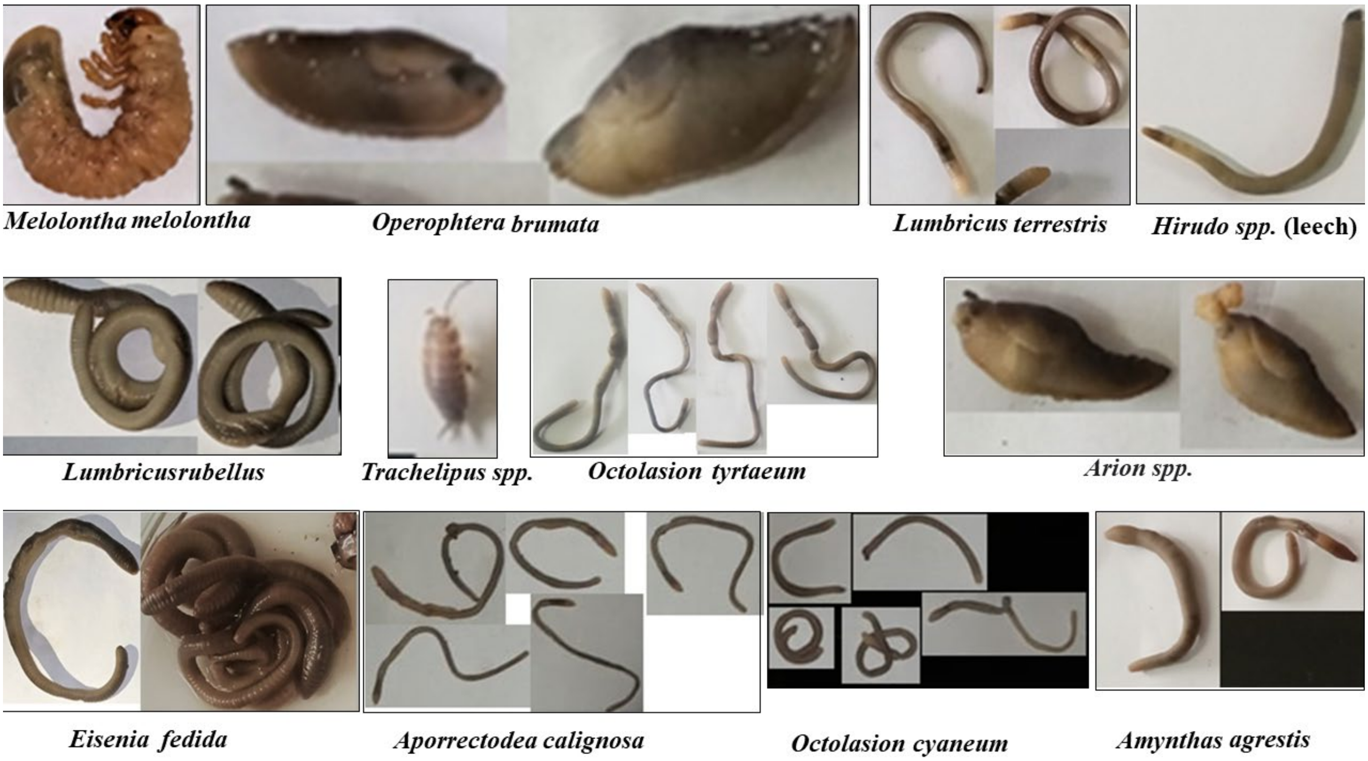


Figure 4. Types of soil fauna found from agricultural lands (sampling sites) in the study region.

for the agricultural soils of temperate Mediterranean regions of Peninsular Spain (Romanya & Rovira, 2011). A study conducted in the Alt Emporda, Figueres, North-Eastern Iberian Peninsula, which has a Mediterranean climate, showed the concentration of SOC in the upper 0–20 cm depth of soils from agricultural fields cultivated with *Vitis vinifera*, *Olea europaea, Pinus halepensis*, *Quercus suber*, and *Cistus monspeliensis* had SOC concentrations in the range of 2.95–37.7 g kg^{-1} soil (Emran et al., 2022).

The highest concentration of SOM was found in AOF10 (41.0 g kg^{-1} soil), followed by AOF5 (31.0 g kg^{-1}), AOF6 (30.4 g kg^{-1}), TBIF2 (29.1 g kg^{-1}), AOF 15 (27.7 g kg^{-1}), and AOF4 (27.1 g kg^{-1}). These agricultural fields were more than 15 years old (except for AOF4, which was 11 years old) and were under conservation agriculture. However, the oldest field, AOF2, with 25 years of age, had the lowest SOM and SOC concentrations (9.33 g kg^{-1} SOM and 5.5 g kg^{-1} SOC, respectively). Likewise, AOF9 with 20 years of age had 14.4 g kg^{-1} SOM. The AOF2 field did not receive organic amendments for the past 10 years, and only inorganic fertilizer was used; this may explain the lower concentrations of SOC and SOM in this field. However, other fields such as AOF9 and AOF12 receive both organic and inorganic fertilizers, and these fields had lower concentrations of SOM and SOC despite more than 15 years of agricultural practice. We unfortunately do not have information about the quantity of organic and inorganic amendments in these fields to better explain the lack of relationship between the age of field and SOM concentration. The TBIF2 was 17 years of age with conservation agriculture and had 29.1 g kg^{-1} SOM. In our previous published report about SOM in the Mediterranean region, Loralai, Balochistan, Pakistan, agricultural fields, a 10-year-old field under tree-based intercropping with conservation agriculture and crop diversification, had the highest concentration of SOM (26.07 g kg^{-1} soil) than the fields with monocropping systems and/or conventional farming systems (Younas et al., 2022). Our results regarding the positive influence of crop diversification as tree-based intercropping under conservation agriculture are in agreement with the meta-analysis of Morugan-Coronado et al. (2020) on agricultural fields in Mediterranean regions. The concentration of SOM in arid to semi-arid agricultural systems has a positive relationship with the concentration of clay in the soil (Morugan-Coronado et al., 2020); however, our results are not in agreement with the general trend in this regard. It shows that in our field sites, management systems were stronger controllers of SOM than soil texture. Our results are in agreement with the findings of our previously published report about the agricultural fields of the Mediterranean region of Loralai, Balochistan, Pakistan (Younas et al., 2022).

In the agricultural lands of Rodh Mulazai, a total of 13 soil macrofauna species were found (one species was unidentified). However, only 1–4 species were found in a given field. The earthworm *Lumbricus terrestris* was the most commonly found macrofauna and was found in almost all fields except AOF1, AOF13, and AOF14. Not only was this species found in most fields, but it was also the most abundant species among others. Interestingly, the second most common and abundant species was earthworm, *Lumbricus rubellus*. In our previously published articles, no earthworm was found in the agricultural lands of Loralai, Balochistan, Pakistan (Khan et al., 2022; Younas et al., 2022). We attribute the absence of earthworms in that area to the closeness to extensive fluoride mining activities

Table 3. Total number of individuals, total number of species, species types, and number of individuals of each species type found from a given agroecosystem sampled.

Sampling site	Total number of soil fauna	Number of soil fauna species	Types of soil fauna	Number of types of soil fauna
AOF1	9	2	*Melolontha melolontha* (white grub cockchafer)	6
			Operophtera brumata (winter moth (Pupa))	3
TBIF1	20	3	*Lumbricus terrestris* (earthworm)	12
			Hirudo spp. (leech)	3
			Lumbricus rubellus (earthworm)	5
AOF2	12	2	*Melolontha melolontha* (white grub cockchafer)	1
			Lumbricus terrestris (earthworm)	11
TBIF2	9	4	*Operophtera brumata* (winter moth (Pupa))	1
			Lumbricus terrestris (earthworm)	4
			Hirudo spp. (leech)	3
			Lumbricus rubellus (earthworm)	1
AOF3	11	2	*Lumbricus terrestris* (earthworm)	9
			Lumbricus rubellus (earthworm)	2
AOF4	11	3	*Operophtera brumata* (winter moth (Pupa))	5
			Lumbricus terrestris (earthworm)	4
			Hirudo spp. (leech)	2
AOF5	17	1	*Lumbricus terrestris* (earthworm)	17
AOF6	16	2	*Lumbricus terrestris* (earthworm)	12
			Hirudo spp. (leech)	4
AOF7	14	3	*Lumbricus terrestris* (earthworm)	10
			Hirudo spp. (leech)	1
			Lumbricus rubellus (earthworm)	3
AOF8	14	4	*Operophtera brumata* (winter moth (Pupa))	1
			Lumbricus terrestris (earthworm)	10
			Hirudo spp. (leech)	2
			Trachelipodidae Trachelipus (wood lice)	1
AOF9	13	4	*Melolontha melolontha* (white grub cockchafer)	1
			Lumbricus terrestris (earthworm)	5
			Hirudo spp. (leech)	2
			Octolasion tyrtaeum (earthworm)	5
AOF10	14	1	*Lumbricus terrestris* (earthworm)	14
AOF11	13	3	*Lumbricus terrestris* (earthworm)	10
			Operophtera brumata (winter moth (Pupa))	1
			Arion spp. (slug juvenile stage)	2
TBIF3	12	2	*Lumbricus terrestris* (earthworm)	8
			Arion spp. (slug juvenile stage)	4
AOF12	11	4	*Lumbricus terrestris* (earthworm)	5
			Lumbricus rubellus (earthworm)	3
			Phyllophaga (May beetle (grub))	1
			Eisenia fedida (red wiggler earth worm)	2
AOF13	12	2	*Aporrectodea calignosa* (gray earthworm)	10
			Arion spp. (slug juvenile stage)	2
AOF14	14	4	*Operophtera brumata* (winter moth (Pupa))	2
			Arion spp. (slug juvenile stage)	2
			Octolasion cyaneum (blue gray worm)	1
			Unknown	1
AOF15	20	3	*Lumbricus terrestris* (earthworm)	16
			Arion spp. (slug juvenile stage)	2
			Amynthas agrestis (crazy worm)	2
ACAOF1	17	4	*Lumbricus terrestris* (earthworm)	7
			Lumbricus rubellus (earthworm)	5
			Arion spp. (slug juvenile stage)	2
			Aporrectodea calignosa (gray earthworm)	3
AOF16	12	2	*Lumbricus terrestris* (earthworm)	7
			Lumbricus rubellus (earthworm)	5

AOF: apple orchard field, numbers (1–15) agricultural fields sampled; TBI: tree-based intercropping.

(Khan et al., 2022). There are, however, no mining activities in the region of Roth Mulazai, Pishin, Balochistan, and this may be the reason that this important earthworm was found in the agricultural fields of this region. The other reason for the presence of this earthworm in these soils may be the use of organic fertilizers and reduced and shallow tillage, which is reported to have a positive influence on the abundance of this earthworm in agricultural lands of Mediterranean climate (Baldivieso-Freitasa et al., 2018). The positive relationship between SOM and the abundance of earthworms in agricultural lands is frequently reported (Guo et al., 2016; Teixeira et al., 2021; Treder et al., 2020). We, however, did not find any relationship between the concentration of SOM or SOC and the abundance of earthworms in these fields, as is evident from Tables 1–3. Unfortunately, we do not have any possible explanation for this finding. However, as earthworms are important ecosystem engineers of agricultural lands in dry regions, their presence in these lands indicates the soil health of these fields, which mostly practice conservation agriculture. Future research is needed to evaluate the influence of earthworms and the abundance of soil macrofauna on their potential role in sequestering organic carbon in soil.

5. Conclusion

The 20 agricultural field sites in Rodh Mulazai sampled were mostly under conservation agriculture with shallow and reduced tillage (once per year) and amendment of both organic (manure from cows and buffalo) and synthetic fertilizers. The concentration of SOM in the upper 0–10 cm depth of these field sites ranged from 9.33 to 41 g kg^{-1} soil. A total of 13 soil macrofauna species were found, and the most common and abundant was the earthworm *Lumbricus terrestris*, followed by the earthworm *Lumbricus rubellus*. There was no relationship found between the total number of soil fauna and the concentration of SOM at these field sites, nor did SOM have a relationship with the concentration of soil clay contents. Likewise, the age of these sites with continuous conservation agriculture had no relationship with the concentration of SOM. It merits further investigation to observe the soil carbon sequestration potential of these sites in relation to the abundance of soil macrofauna.

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