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LITER DECAY AND SOIL QUALITY OF OLIVE ORCHARDS OF BALOCHISTAN: AN INSIGHT INTO POTENTIAL FOR SEQUESTERING ORGANIC CARBON

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Abstract

Olive groves have found to be beneficial for soil quality and can play an important role in sequestering the organic carbon of soil of arid regions. The Pakistan Oil Seed Department, Government of Pakistan, have been promoting the cultivation of olive groves in various regions of Balochistan province of Pakistan. This study evaluated the quality of soils that were taken from the underneath of olive trees from four regions of Balochistan province, Pakistan; Zhob, Loralai, Kilasaifullah and Quetta. The olive stands of Zhob city are natural; whereas, the olive groves of other study sites have been cultivated. Soil samples from barren rangelands of each study site were also taken as a control. Results indicate 2-3 times significantly higher concentration of soil organic matter (SOM) and soil organic carbon (SOC) in olive grove sites than their control sites except for Zhob site. No difference between control and olive grove sites was observed for mineral nitrogen (nitrate) and Olsen phosphorus). The abundance of microbial biomass carbon showed a positive relation with the concentration of soil organic matter. The laboratory incubation study, which was related to the decomposition of twigs (taken from olive trees) buried in the soils that were taken from the study sites revealed significant differences. Results showed a positive relation of weight loss of twigs with the concentration of soil organic matter and microbial biomass carbon. However, weight loss of twigs:soil organic matter was significantly lower for the soils taken from olive groves than control site. Furthermore, number of soil macrofauna species was 2-3 times significantly higher in olive groves than control sites. Our findings indicate that the cultivation of olive groves improved the under-investigated soil quality parameters and exhibited a potential for the sequestration of soil organic carbon.

Keywords: *Litter decay, Microbial biomass carbon, Olive groves, Soil macrofauna, Soil organic matter*

INTRODUCTION

Soil carbon sequestration is defined as the natural process of uptake of carbon by plants through the process of photosynthesis and its subsequent storage in soil (via root exudations, residue or manure input etc.) as a component of soil carbon pool (1-3). There are five carbon pools; oceanic pool (38,000 peta gram (Pg), geologic pool (4000 Pg of coal, 500 Pg of oil and 500 Pg of gas), soil (2500 Pg of soil organic carbon and soil inorganic carbon (e.g. soil carbonates), atmospheric pool (760 Pg of CO2) and biotic pool (560 Pg) (1). Oceans and soils are the major sinks of organic carbon (1, 4). Soil being one of the major sinks of organic carbon is important for controlling the concentration of atmospheric CO2 (3). This sink can become a source of CO2 production and can add more severity to climate change when the rate of CO2 production from the microbial decomposition of soil organic matter (SOM) exceeds the rate of CO2 sequesters in soil (1, 3). There are many measures used for the assessment of carbon sequestration potential of a soil. Soil organic matter:litter decay rate, soil organic matter stocks, concentration of clay minerals in cultivated or undisturbed wild rangelands versus disturbed rangelands are some of the economically feasible measures that can be used to assess soil carbon sequestration potential of an agroecosystem or a rangeland/forest (5, 6, 7). Furthermore, macrofauna that dwell on soil surface or live in the top soil layer are very important soil ecosystem engineers. They help sequester soil organic matter through distributing the organic matter (plant or animal-based) in both horizontal and vertical directions in soil profile, and therefore they promote soil aggregation, which is an important indicator of the long-term storage of soil organic matter (1, 6-8).

The issue of climate change due to the increasing concentration of CO2 as well as nitrous oxide (N2O another potent greenhouse gas) in atmosphere can be resolved via increasing the carbon stocks of soil of agricultural lands through the proper management practices or utilizing abandoned marginal infertile lands for cultivation of proper plants that can grow well in those infertile soils (2, 9). Olive (Olea europaea L.) can grow well in marginal low productivity soils (hilly or mountainous areas) of Mediterranean regions (regions with cold climate and rainfall/precipitations usually occur in winter and spring seasons) (10). Furthermore, water requirement of olive groves is comparatively lower than other crops. Their production can rely on rainfall in mountainous areas; whereas, in plane areas, intensive systems including irrigation and tillage are in practice (10, 11, Personal observation). Olive groves have gathered attention of scientific community for their ability to sequester organic carbon in soil and woody parts (roots and stems) (12). For this reason, olive groves can be of great importance for economically feasible climate change mitigation option if are cultivated in the marginal soils of Mediterranean basin on large scale (10, 13).

Balochistan, Pakistan, one of the largest province of this country is considered as the most suitable region for the cultivation of olive because, more than 50% of land area of this province has Mediterranean climate (14). The Province Balochistan, Pakistan has gathered great interest on national and international level for the cultivation of olive groves (15). The Zhob District of Balochistan has wild forest of olive (16). In Balochistan, this crop has been successfully cultivated on large scale in Zhob, Loralai, Mastung, Harnai, Kila Saifullah and Quetta. As stated above, olive groves have been cultivated on large scale in many cold dry regions of this province (e.g. Zhob, Loralia, Harnai, Kila Saifullah, Quetta). No research to date has been published regarding the influence of these cultivations on soil quality, which is important to get an insight into the potential of these cultivations for sequestering organic carbon stocks in marginal infertile soils.

This research work will address following hypotheses; 1) organic matter is higher in the soil under cultivation of olive orchar than open rangelands that are under human disturbance; 2) litter decay is slower in soil that has high organic matter than the soil which has lower organic matter; 3) soil under cultivation of olive orchards have more soil macrofauna than the soils of open rangelands. This research will provide an insight into the potential of cultivating olive groves on marginal infertile lands of arid region for improving the quality of soil, which is directly related to the sequestration of organic carbon of soil. This preliminary research will open an avenue for future grant-winning research project to investigate soil carbon sequestration potential of these cultivated agroecosystems, which will be encouraging for the farmers of this region to cultivate this economically highly feasible crop on large scale. The objectives of the research were: to assess soil organic matter and soil organic carbon concentration of top-soil layer (0-10 cm depth) from tested study areas, to assess the abundance and diversity of soil surface and top soil layer macrofauna of tested study areas and to assess the litter decay rate in soil samples collected from tested study areas.

MATERIALS AND METHODS

STUDY SITES AND EXPERIMENTAL DESIGN

The field work of this study was carried out in October, 2022. For this study, four regions of Balochistan province, Pakistan were selected; Zhob, Loralai, Kilasaifullah and Quetta (Fig. 1). In an old growth forest of Zhob, where olive trees were present, three 100 m long transect lines, with the distance of 50 m, were marked. Along each transect line, at regular intervals of approximately 20 m, 5 x 5 m size plots were marked under the trunks of olive trees. From the center of each plot, soil samples were collected from 0-5 cm depth. Soil macrofauna found within plots were collected in zip lock, labeled plastic bags. For collection of soil fauna, method described in Khan *et al.* (17) and Younas *et al.*, (18) was used. Total of fifteen samples were collected from Zhob region. In Zhob, three more samples were collected from the open rangelands, where no olive tree was found. Those soil samples were considered as control (Fig. 2).

For other study locations, same procedure was followed but instead of 15 samples, five samples were collected from under the canopy of olive trees and three samples from open rangeland in the close vicinity of olive groves per study site.

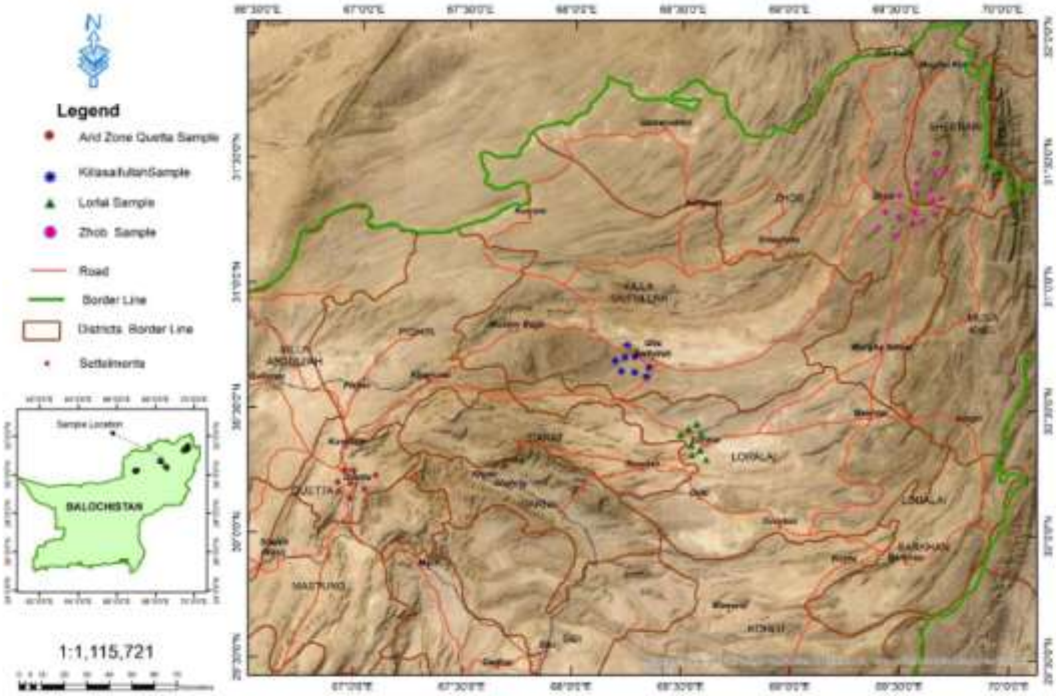

Fig. 1. Map of study sites (Zhob, Loralai, Kilasaifullah and Quetta)

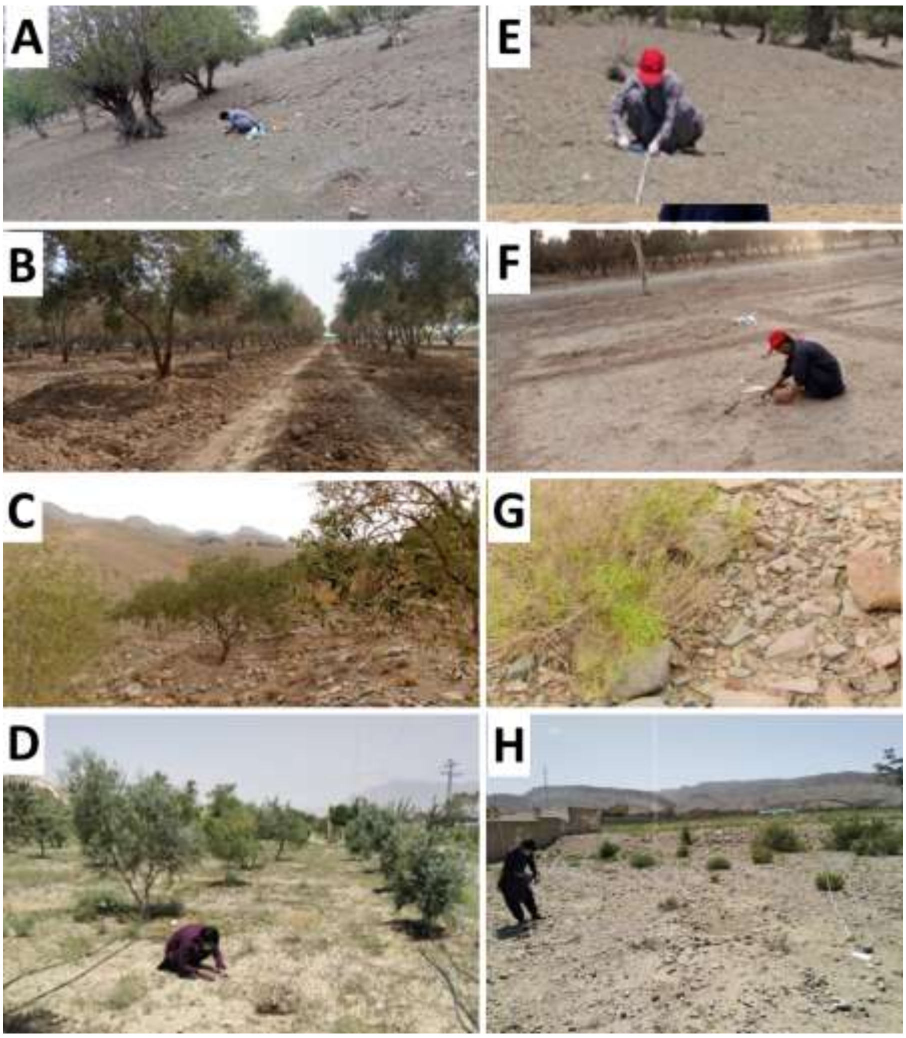

Fig. 2. Study sites; A-D are olive groves of Zhob, Loralai, Kilasaifullah and Quetta, E-H are the open rangelands of Zhob, Loralai, Kilasaifullah and Quetta

SOIL SAMPLING AND COLLECTION OF SOIL MACROFAUNA AND THEIR IDENTIFICATION

After collection of soil samples, soils were spread on a plastic sheet to collect top-soil layer-dwelling macrofauna as well as the macrofauna found on the surface of soil within 5 x 5 m marked plots. The macrofauna were collected in labeled screw-capped plastic bottles, which had 5% formalin solution. Soil samples were collected in zip-lock labelled plastic bags. The macrofauna were identified by the Taxonomist from the Department of Zoology, University of Balochistan.

SOIL SAMPLE PROCESSING AND MEASUREMENT OF SOIL CHEMICAL PROPERTIES

The procedure described in Khan *et al.* (17) and Younas *et al.* (18) was used to process soil. Briefly, soils were air-dried in the Soil Fertility Laboratory, Department of Botany, University of Balochistan; thereafter, soils were passed from the sieve of 2 mm mesh (pore) size to remove pebbles and plant material. Thereafter, soil samples were stored at 4^{o}C before the processing for chemical analysis.

For the measurement of the concentration of mineral nitrogen and Olsen phosphorus, the protocol in Estefan *et al.* (19) was followed. Briefly, soil samples were dissolved in KCl solution at 1:5 w/v soil:KCl ratio in 250 ml labelled flasks. Thereafter, flasks were shacked for 1 hour on medium intensity on shaker. The soil extracts were collected in acid-washed screw-capped labelled plastic bottles using 41 grade Whatman filter paper (17, 19). Soil extracts were used to analyze ammonium (NH_4^+) and nitrate (HNO_3^-) with microtiter plate method (20). The concentration of bio-available phosphorus was measured of soil extracts with microtiter plate method (21).

The Walkley-Black chromic acid wet oxidation method (19) was used to quantify the concentration of soil organic matter and soil organic carbon of soil samples. Soil texture of soil samples was also measured (19) to analyze the concentration of clay, silt and sand. The method in Dupuis *et al.* (22) was adopted to measure electrical conductivity (EC) and pH of soil samples. Briefly, 40 g soil was dissolved in 80 ml distilled water. Soil samples were thoroughly mixed three times with clean stirrer at 30 minutes intervals. Thereafter, those samples were subjected to the analysis of pH and electrical conductivity.

SOIL MICROBIAL BIOMASS CARBON ANALYSIS

Air-dried soil samples were sent to the soil testing laboratory, Government College University, Faisalabad. Soil samples were incubated in dark for one week to allow microbes to grow. Thereafter, microbial biomass carbon was assessed using chloroform fumigation, extraction method (23). The extracts of soil samples were analyzed for dissolved organic carbon using total organic carbon (TOC) analyzer.

LITTER DECAY EXPERIMENT

The one year old twigs were collected from the olive tree from the olive farm at Balochistan Agricultural Research and Development Center, Quetta. The twigs were further cut into pieces of 5 cm length. Thereafter, those twigs were oven-dried at 60^{o}C for 48 hours. The initial weight of twigs after oven-drying was recorded.

50 g of air-dried soil samples collected from each study site were placed in sterilized screw-capped bottles of 100 ml capacity. In each bottle, one twig with known initial weight was placed in soil. 10 ml of distilled water was added in each bottle. The bottles were de-capped every week to allow gas exchange, which is required for aerobic decomposition. The water of bottles was adjusted at bi-weekly bases. After three months of decomposition trial, twigs were removed, washed carefully with tap water, oven-dried at 60^{o}C for 48 hours and the final weight was recorded. The percent loss of weight of twigs was measured as;

$$\%\text{ weight loss of twigs after decomposition} = \frac{initial\ weight - final\ weight}{initial\ weight}\ 100 \quad \ldots\ldots\ldots\ (1)$$

The weight loss of twigs:soil organic matter (SOM) or the weight loss of twigs:soil organic carbon (SOC) ratio was also calculated by using following formula;

$$\text{Weight loss of twigs: SOM (or SOC)ratio} = \frac{\%\text{ weight loss of twigs after decomposition}}{Concentration\ of\ SOM\ (or\ SOC)} \quad \ldots\ldots\ldots\ (2)$$

STATISTICAL ANALYSIS

D'Agostino-Pearson K^2 test was applied to assess if data sets have normal distribution, followed by Analysis of Variance (ANOVA) and least significance difference (LSD) tests. The non-parametric data was log transformed before ANOVA analysis (all data sets showed non-parametric distribution). The Kruskall-Wallis test (specific for non-parametric data) was applied on the data of weight loss of twigs buried in soil samples. The same test was also applied on the data, which were related to weight loss of twigs: SOM or SOC ratio measurements. The Microsoft Excel and CoStat softwares were used for statistical analysis.

RESULTS

Results of our study show a significant difference in the concentration of SOM and SOC between study sites. Interestingly, concentration of SOM was significantly higher for the soil taken from the under canopy of olive grows than open rangelands (except Zhob site) (Table I; $p<0.05$). The highest concentration of SOM and SOC was found in the soil from the under canopy of olive grows of Quetta city (Table I, $p<0.05$). A positive relationship of SOM can be seen with the concentration of silt and clay of soil (Table I). The electrical conductivity was also higher of the soils taken from the under canopy of olive grows than the open rangeland site (except for Quetta city site, Table I; $p<0.05$).

Table I. Study sites, age of olive trees, concentration of soil organic matter (SOM), types of soil macrofauna found during soil sampling, number of a given soil macrofauna found during soil sampling and total number of soil macrofauna species of a given study site

Study site	Age of olive trees (yrs)	SOM	Type of soil macrofauna	Number of a given soil macrofauna	Number of soil macrofauna species
Zhob	Wild	11.2 ± 6.81^{bc}	Grasshopper	2	6
			Carpenter ant	Innumerable	
			Meadow ant	Innumerable	
			Acrobat ant	Innumerable	
			Fire bug	1	
			Rove beetle	1	
Zhob_CK	Protected rangeland	5.59 ± 5.55^{d}	Locust	2	2
			Meadow ant	Innumerable	
Loralai	10 - 31	17.0 ± 9.01^{ab}	Carpenter ant	Innumerable	4
			Common ant	Innumerable	
			Acrobat ant	Innumerable	
			Yellow grasshopper	1	
Loralai_CK	Open rangeland	9.96 ± 5.24^{bc}	*armadilium maculatum*	6	2
			Common ant	Innumerable	
Kilasaifullah	9 - 17	20.9 ± 19.0^{ab}	*Anacridium aegyptium*	1	8
			Acrobat ant	Innumerable	
			Amblyomma americanum	1	
			Red carpenter ant	Innumerable	
			Black carpenter ant	Innumerable	
			Carolina grasshopper	1	
			Wood louse	1	
			Stenocara gracilipes	1	
Kilasaifullah_CK	Open rangeland	6.64 ± 4.86^{cd}	Red carpenter ant	Innumerable	2
			Black carpenter ant	Innumerable	
Quetta	5 - 19	35.9 ± 19.9^{a}	Grasshopper	1	8
			Spider	1	
			Acrobat ant	Innumerable	
			Common ant	Innumerable	
			Darling beetle	2	
			Stenocara gracilipes	1	

			Locust	1	
			Oriental homet	3	
Quetta_CK	Open rangeland	10.6 ± 2.12^{bc}	Acrobat ant Carpenter ant	Innumerable Innumerable	2

*Values of SOM are maean ± SD. Values with different letters are significantly different at $p<0.05$

The microbial biomass carbon (MBC) was significantly higher in the soil taken from the canopy of olive grove of Quetta farm than the soil from open rangelands of Zhob, Kilasaifullah and Quetta and the soil taken from under canopy of olive trees of Kilasaifullah (Fig. 3; $p<0.05$). The weight loss of twigs due to decomposition was also higher for the soils taken from under canopy of olive trees from Loralai, Kilasaifullah and Quetta than for the soil taken from under canopy of olive trees from Zhob and from open rangeland of Kilasaifullah (Fig. 3; $p<0.05$).

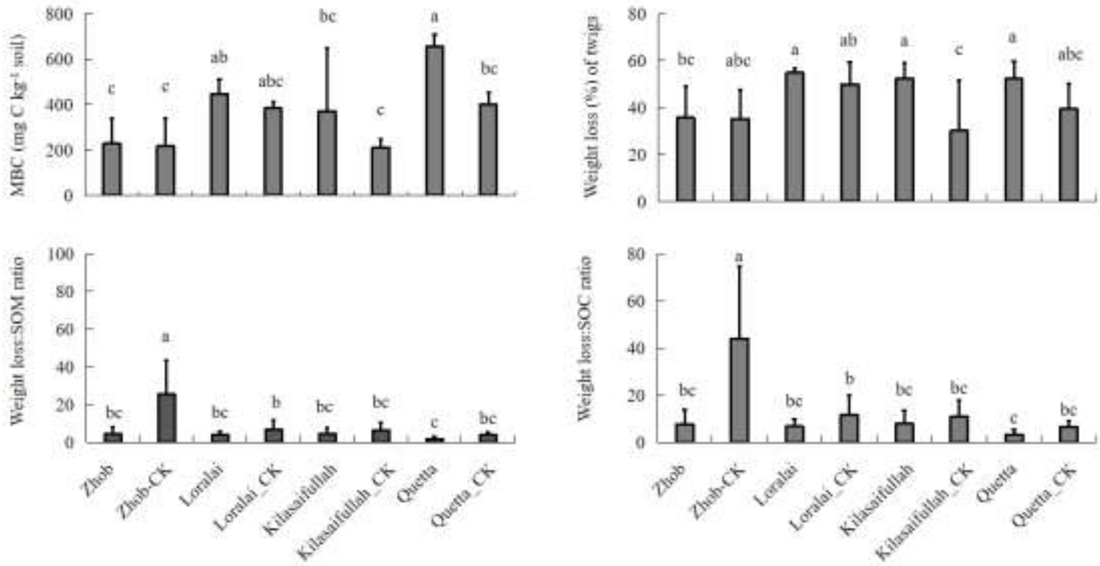

Fig. 3. Microbial biomass carbon (MBC), weight loss of twigs buried in soils taken from study sites, weight loss of twigs: SOM and SOC ratio. Bars with different letters are significantly different at $p<0.05$

The weight loss of twigs: SOM and weight loss of twigs:SOC ratio was lower in the soils taken from under canopy of olive trees from Quetta olive farm than the open rangelands of zhobe and Loralai (Fig. 4; $p<0.05$).

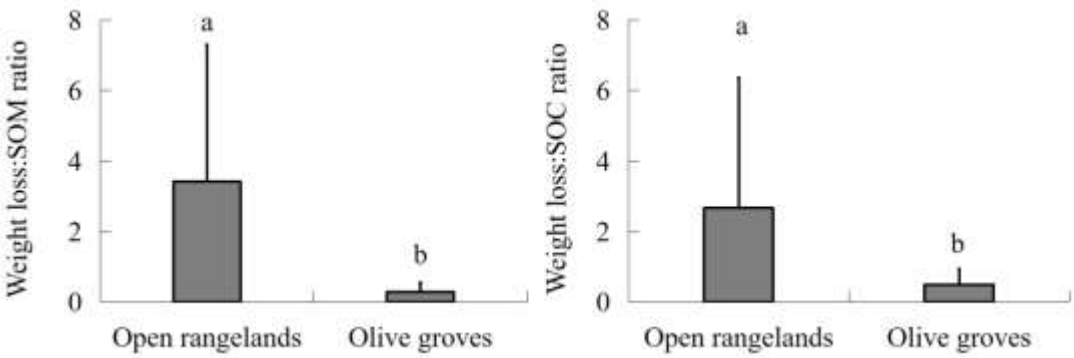

Fig. 4. Weight loss of twigs (buried in soils taken from study sites):SOM or SOC ratio. The values are mean ± SD of data of open rangelands versus olive groves. Bars with different letters are significantly different at $p<0.05$.

When comparing between soils taken from under canopy of olive trees versus open rangelands, weight loss of twigs:SOM or SOC ratio was higher for the soils taken from open rangelands than from the under canopy of open rangelands. The number of species of soil macrfauna was significantly higher under the canopy of olive trees than open rangelands (Table II). The types of soil macrofauna collected from study locations are given in Fig. 5.

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Table II. Soil texture, concentration of soil organic matter (SOM), soil organic carbon (SOC), pH, electrical conductivity (EC), Olsen phosphorus and nitrate (NO_3^--N) of study sites. Values are mean ± SD

Field sites	Clay (g kg⁻¹ soil)	Sand (g kg⁻¹ soil)	SOM (g kg⁻¹ soil)	SOC (g kg⁻¹ soil)	pH	EC (µS m⁻¹)	Total dissolved salts (ppm)	Olsen Phosphorus (g kg⁻¹ soil)	NO_3^--N (mg kg⁻¹ soil)
Zhob	25	800	11.2 ± 6.81^{bc}	6.17 ± 4.19^{bc}	7.63 ± 0.23^{b}	236.5 ± 382^{bc}	69.76 ± 14.75^{c}	3.20 ± 0.75^{c}	13.79 ± 7.36^{a}
Zhob_CK	--	--	5.59 ± 5.55^{d}	3.24 ± 3.22^{c}	7.68 ± 0.16^{ab}	135.3 ± 33.2^{c}	67.06 ± 16.77^{c}	3.16 ± 0.35^{c}	12.55 ± 9.98^{ab}
Loralai	25	125	17.0 ± 9.01^{ab}	9.88 ± 5.22^{ab}	7.62 ± 0.16^{b}	653.0 ± 451^{a}	632.2 ± 607^{a}	3.71 ± 0.52^{c}	8.46 ± 4.91^{ab}
Loralai_CK	--	--	9.96 ± 5.24^{bc}	5.77 ± 3.04^{bc}	7.90 ± 0.11^{a}	544.9 ± 489^{ab}	810.1 ± 863^{a}	8.72 ± 1.23^{ab}	6.49 ± 4.83^{ab}
Kilasaifullah	225	300	20.9 ± 19.0^{ab}	12.1 ± 11.0^{ab}	7.77 ± 1.16^{ab}	506.2 ± 204^{a}	253.7 ± 99.0^{ab}	7.02 ± 2.39^{bc}	13.73 ± 7.12^{ab}
Kilasaifullah_CK	--	--	6.64 ± 4.86^{cd}	3.85 ± 2.82^{bc}	7.77 ± 0.10^{ab}	155.8 ± 20.1^{bc}	76.4 ± 10.4^{c}	7.26 ± 3.63^{abc}	11.63 ± 8.09^{ab}
Quetta	50	400	35.9 ± 19.9^{a}	20.8 ± 11.59^{a}	7.84 ± 0.06^{ab}	257.4 ± 67.6^{ab}	128.4 ± 36.3^{bc}	10.7 ± 7.72^{ab}	7.45 ± 2.38^{ab}
Quetta_CK	--	--	10.6 ± 2.12^{bc}	6.18 ± 1.23^{bc}	7.85 ± 0.03^{ab}	263.5 ± 34.64^{ab}	115.4 ± 25.3^{bc}	12.03 ± 3.49^{a}	5.71 ± 4.21^{b}

Within column, values with different letters are significantly different at $P<0.05$. -- represents no data

Fig. 5. Soil macrofauna collected from various field sites

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DISCUSSION

In present study, SOM and SOC concentrations of various sites ranged between 5.59 - 35.9 g kg^{-1} soil for SOM and 5.77 - 20.8 g kg^{-1} soil for SOC. The concentration of SOC from the clay loam soil taken from the under canopy trees of olive grow in Matasanos Southern Spain was reported to be between 5.8 to 10 g kg^{-1} soil (24). The concentration of SOM and SOC was higher in the soil taken from Quetta olive farms (20.8 g kg^{-1} soil). The possible reason is the fine texture of soil of Quetta olive farm. Our results indicated that olive groves increased the concentration of SOM than open sites of nearby rangelands in the underneath of tree canopy. The increase in SOM was approximately 2 - 3 times than the open rangeland sites. Olive groves are well known in increasing the carbon stock in soil (25, 26) and are also confirmed from our study. The Zhob study site has wild stands of olive trees and is protected from anthropogenic disturbances. Despite of being natural olive stands of Zhob village, concentration of SOM and SOC was lower than the samples collected from olive farms of Quetta site. We attribute this reason to the high concentration of sand (80%) in the soil of Zhob site. The litter fromleaves and twogs and turnover of roots of olive trees are the major contributors of organic matter accumulation in soil (27). However, soil properties play major role in organic matter storage in soils planted with olive trees (27). As is observed in this study, soil of Quetta olive farm had low sand fraction than the soil of Zhob natural olive stands and had the highest concentration of SOM and SOC.

The microbial biomass carbon was also different between soil samples collected from study sites.The higher MBC was observed in the soils collected from underneath of canopy trees of olives from Loralai and Quetta study sites than Zhob site. Interestingly, MBC was 39% higher in the soils from Quetta olive farm than Quetta open rangeland site. This indicates that the olive groves of Quetta city significantly increased SOM, SOC and MBC of soil than the barren area.Microbial biomass carbon is an important indicator for soil carbon sequestration. Microbes play the major role in sequestring organic matter in soil aggregates via their secretions and cellular turnover (2). Approximately 3 times greater SOM and 39% more MBC in the soil from underneath of olive canopy of Quetta olive farm than barren area indicates that the cultivation of olive trees have great protential in increasing the soil organic matter stock.

The twigs buried in soils taken from study sites for decomposition, showed significant variation. The highest decomposition of twigs as estimated from the weight loss was observed in soil taken from the olive farms of Loralai, Kilasaifullah and Quetta city as compared to the soil taken from Zhob olive stands and Kilasaifullah rangeland control site. This showed to some extent a positive relation between the concentration of SOM and the weight loss of twigs from decomposition. The concentration of microbial biomass carbon was also lower in the soils from Zhob and Kilasaifullah control sites. The low decomposition in the soils taken from these sites (Zhob and Kilasaifullah control sites) than the soil taken from Quetta olive farm can be attributed to the low concentration of microbial biomass carbon and low concentration of SOM. Our results are in agreement to the general finding that the rate of decomposition has a positive relationship with the concentration of microbial biomass carbon (2). However the interesting finding is that, weight loss of twigs to SOM ratio was significantly lower for the soil taken from olive farms of Quetta city than the control sites of Zhob and Loralai sites. Furthermore, weight loss of twigs due to decomposition to SOM ratio for the soil from Zhob natural olive stand was not different than the soil taken from Quetta sites despite of having the lowest concentration of SOM. This indicates that the rate of litter decomposition was lower in soils taken from olive stands. This finding suggests high microbial carbon use efficiency of the soils (2) taken from olive stands and indicates high soil carbon sequestration potential of these soils than the control sites.

Another finding of this study is the almost 2 - 3 times higher number of soil macrofauna species found in olive groves sites than control. Soil macrofauna are important soil ecosystem engineers and play positive role in structuring soil and sequestring soil organic carbon. The high number of species of soil macrofauna is an indication that olive groves can play role in sequestering soil organic carbon. This phenomenon merits further investigation.

The analysis of soil samples for chemical properties was carried out in the soil testing laboratory, Agricultural Research Institute following the standard protocols of Estefan *et al.* (2013). The microbial abundance as measured from the microbial biomass carbon of soil samples was measured in the soil testing laboratory, Government College University, Faisalabad using standard protocols. Therefore, the validity of results associated with this study becomes unquestionable. However, more replications instead of five per agricultural field would offer more precisions to the findings specifically regarding species and abundance of soil fauna.

CONCLUSION

Soils were taken from underneath of olive trees from four different sites; Zhob natural olive stand, olive farms from Loralai, Kilasaifullah and Quetta and from open rangeland sites of each city. These soils revealed that SOM was significantly higher in the soils taken from olive stands (11.2 g kg^{-1} to 35.9 g kg^{-1} SOM) than control sites (5.59 g kg^{-1} to 10.6 g kg^{-1}). The weight loss of twigs due to decomposition in soils taken from study sites showed lower decomposition:SOM ratio for the soils from olive stands than control. Furthermore, number of soil macrofauna species was also 2 - 3 times higher in olive stands (4 – 8 species per sampling location) than their control sites (2 species per sampling location). Our results indicate high potential of olive stands to sequester soil organic carbon.

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