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ORIGINAL ARTICLE

Biochar and wheat straw affecting soil chemistry and microbial biomass carbon countrywide

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Abstract

Indicating how different sources of organic matter (OM) may affect the properties of a wide range of soil types, at varying soil moisture (SM), is of significance in the agricultural fields. A large dataset of soil samples (0–30 cm) was collected from different parts of Iran (21 different agricultural regions, with a wide range of physical, chemical, and biological properties) to determine the effects of OM and varying SM on soil chemical (pH, salinity, and organic carbon) and biological (microbial biomass carbon, MBC) properties. The collected soil samples were incubated (9-month period) with the experimental treatments including OM (control (M1), 2% wheat straw (WS) (M2), and 2% biochar (BI) (M3)), at different SM levels (0.2 field capacity, FC (V1), 0.7 variable FC (V2), 0.7 constant FC (V3), and saturated moisture (V4)). Wheat straw was pyrolyzed (at 500°C) to produce BI, and their chemical properties were determined. BI salinity (3.1 dS/m) was significantly higher than WS (2.8 dS/m). The organic treatments, especially BI, significantly increased soil OM and MBC compared with the control treatment. The two sources of organic fertilization increased soil pH, OM, and MBC, though such effects were functions of varying soil moisture (drying and rewetting cycles). Due to higher C percentage (61%), the effects of BI, significantly affected by soil moisture, were more pronounced on soil parameters. The tested sources of organic matter (WS and BI), acting as functions of soil moisture, can strongly affect soil chemical and biological properties and contribute to higher efficiency of agricultural fields.

Keywords Field capacity · Organic matter · Pyrolysis · Soil acidity · Soil chemical and biological properties · Soil salinity

1 Introduction

With respect to the world increasing population and the necessity for increasing the production of agricultural fields, the improvement of soil proprieties, especially in the arid and semi-arid areas of the world, is of significance [48]. To enhance soil properties, different methods including chemical and biological fertilization have been so far tested and used [45, 46, 56]. Although chemical fertilization is a quick method of providing crop with its required nutrients, it is not economically and environmentally recommendable, as it is subjected to leaching and can negatively affect the environment [3, 32].

Accordingly, the use of organic fertilization including manure, organic matter, and soil microbes may be superior to chemical fertilization, as they can significantly enhance soil properties and are economically and environmentally recommendable [24, 35]. In the semi-arid and arid areas of the world, organic matter deficiency decreases plant growth and yield production [6]. For example, in most agricultural fields in Iran, the rate of organic carbon is less than 1% [43].

The accuracy of results and analyses may increase, if a wide range of soil types (different physical, chemical, and biological properties), as tested in this research, are subjected to the experimental treatments. Biochar (BI) and wheat straw (WS) are among the most prevalent sources of organic matter [27, 49]. WS as a source of organic matter (cultivating WS into the soil after harvest in reduced or no tillage) can considerably enhance soil nutrients including carbon. However, a major disadvantage of using WS is its high rate of carbon/nitrogen (C/N), which decreases the availability of soil N for plant use, due to N microbial immobilization [7].

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Biochar (produced by the pyrolyzation of agricultural residues) is an organic source of nutrients for plant use and can (1) improve different soil physical, chemical, and biological properties and (2) enhances carbon sequestration, which results in the mitigation of climate change. Biochar can absorb soil organic matter and hence preserve it from leaching. Due to its specific physical properties, especially its high porosity, BI can significantly enhance soil sorption and immobilization of organic matter [10, 37, 53]. Although it has not been the case for the present research, usually the rate of C/N in BI is less than WS, as BI contains higher N, preventing the deficiency of nutrients (faster rate of decomposition) including N in the soil [1, 23]. Carbon sequestration in the form of soil organic matter not only affects soil productivity but also increases atmosphere CO_2 (greenhouse gas) affecting the global climate [42].

Different parameters such as soil moisture (soil drying and rewetting) may affect soil N and C cycling and dynamic including microbial biomass carbon [30]. There is not much data, to our knowledge, on such processes in the soil. The significance of soil drying and rewetting cycles is due to affecting different soil processes including (1) formation of soil aggregates, (2) humus decomposition, (3) respiration of soil, (4) soil microbial population, and (5) nutrient cycling [20, 40]. Accordingly, it is important to investigate how the combination of different types of organic matter and soil moisture may affect soil physical, chemical, and biological properties.

Although there has been previous research on the use of biochar for the improvement of soil physical, chemical, and biological properties [4, 21, 22], it is yet a matter of question how biochar use may enhance soil properties, compared with the use of raw organic matter (wheat straw) at varying levels of soil moisture. Accordingly, because the investigation of soil chemical and biological properties affected by soil moisture dynamic (drying and rewetting) and sources of organic matter is of significance for the proper production of agricultural crops in the semi-arid and arid areas of the world, this research was proposed using a large set of soil data. The objective was to determine the effects of soil moisture levels and sources of organic fertilization (WS and BI) on soil chemical properties (pH, salinity, and organic matter) and soil biological properties (microbial biomass carbon) using a large dataset of soil samples collected countrywide.

2 Materials and methods

2.1 Sampling

The soil samples were collected from 21 different agricultural regions across Iran (Fig. 1), and their physical and chemical properties were determined (Table 1). The sampling regions, namely, (1) DarehBid, (2) Lenjan, (3) Talkhuncheh, (4) Darin, (5) Balestan, (6) Bushgan, (7) EmamZadeh, (8) GhasemKhani, (9) EbrahimAbad, (10) GonAbad, (11) NajmAbad, (12) Jazooshi, (13) Kharghani, (14) Sarvestan, (15) Dogh, (16) Shurjeh, (17) Ghadamgah, (18) CamSorkh, (19) SharifAbad, (20) TappehGhachi, and (21) Sahel, were used for the experiment. The samples were taken from the depth of 0–30 cm, air dried, and passed through a 2-mm mesh, and their physical and chemical properties including saturation percentage (SP), field moisture capacity, soil texture, salinity (EC, dS/m), pH, organic carbon (OC), calcium carbonate (CaCO3), available phosphorous (P), iron (Fe), zinc (Zn), and cation exchange capacity (CEC) were determined in the laboratory of Soil and Water Research Institute, Karaj, Iran, using the standard methods [33] (Table 1).

2.2 Biochar and wheat straw

For the production of BI, first wheat straw was precisely weighed, inserted in metal containers, and sealed with a lid and, to avoid air penetration, was covered with an aluminum seal. The container was then heated to 500°C [18] for 3 h using a furnace. The produced BI, which was without any ash, was weighed and meshed using a 2-mm mesh. WS salinity was also little, indicating that the straw was produced under anaerobic conditions [26]. WS and BI properties were determined using the standard methods [33]. The wheat straw had a pH and salinity of 5.74 and 4.96 (dS/m), respectively, and contained carbon (C) of 53.74%, hydrogen (H) of 3.53%, total nitrogen (N) of 0.61%, and total potassium (K) of 1.52%. The properties of BI were according to the following: C at 61%, H at 3.5%, and total N at 0.5%.The percentage of biochar yield (62%) was calculated using Eq. 1:

$$\text{Biochar yield } (\%) = \left(\text{weight of produced biochar } (\text{g})\right)/\left(\text{initial dry weight } (\text{g})\right) \times 100\Big) \tag{1}$$

2.3 Experimental design

The incubation experiment was a factorial on the basis of a completely randomized design including organic matter at three levels (control (M1), 2% WS (M2), 2% BI (M3)) and moisture levels (0.2 field capacity (FC) (V1), 0.7 variable FC (V2), 0.7 constant FC (V3), and saturated moisture (V4)) with three replicates in a constant temperature for the 21 regions. The moisture of the pots was kept constant on a weight basis. During the 9-month incubation period, the effects of organic matter and moisture levels on soil pH, salinity, organic carbon, and microbial biomass carbon were determined.

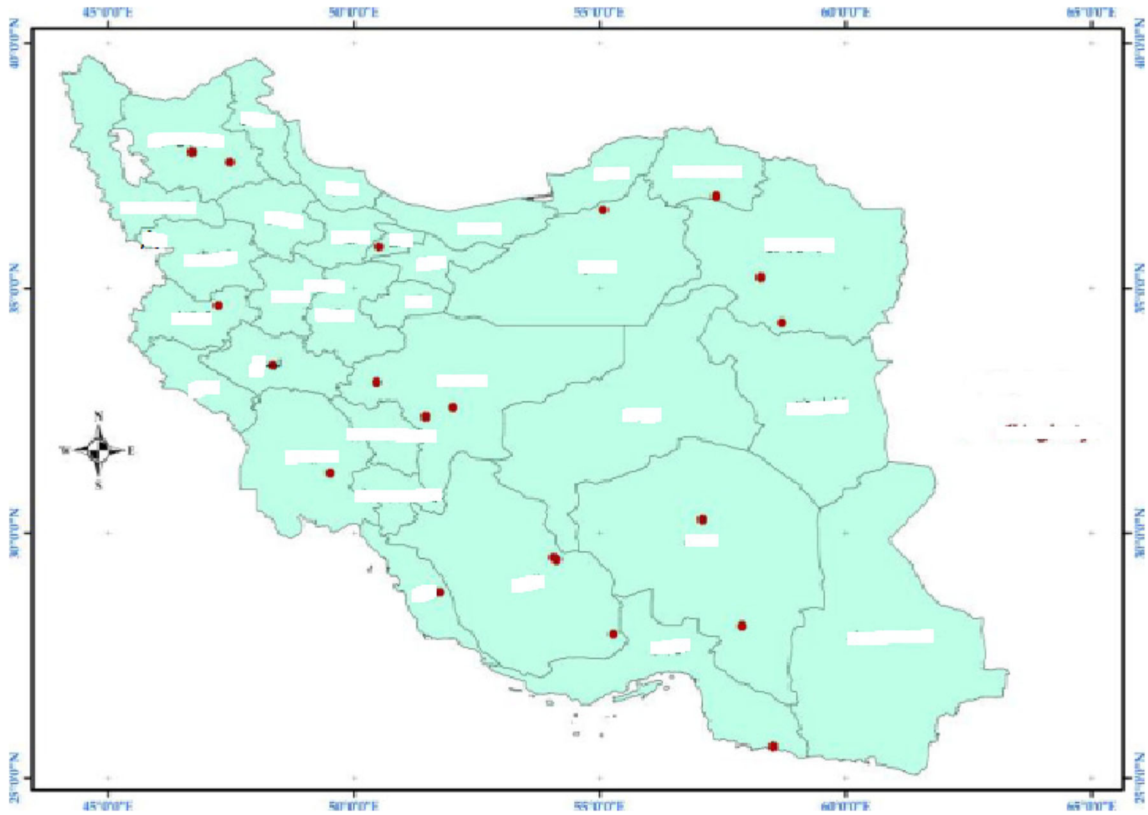

Fig. 1 The experimental sites

2.4 Measuring microbial biomass carbon

Microbial biomass carbon (MBC) was measured by the fumigation method using two 25-g soil samples. One sample was treated with 100-ml potassium sulfate (0.5 M) using a 250-ml Erlenmeyer, and the other one was poured into a 50-ml container and inserted in a desiccator covered with a filter paper at the bottom along with a container of soda lime and a container of 25-ml chloroform. The desiccator was connected to a vacuum pump boiling the chloroform for 2 min. The dedicator was placed in the dark for 24 h, and then the fumigated samples with chloroform were connected to the vacuum pump to evaporate the remaining of chloroform.

The samples were then mixed with 100-ml potassium sulfate and along with a control sample (without chloroform) were shaken for 45 min using a reciprocal shaker at 40 round/min. The suspension was filtered with a Whatman paper #42. Microbial biomass carbon was determined using 8 ml of the extract treated with 2 ml potassium-dichromate and 15 ml concentrated sulfuric and phosphoric acid, under reflux conditions for 30 min. The sample was then treated with 25 ml water and, after adding ortho-phenanthroline iron (II) sulfate, was titrated with ammonium sulfate, and the remaining of potassium dichromate was measured [19].

2.5 Statistical analysis

Data were subjected to analysis of variance using SAS. Data were also subjected to a factorial analysis with the two factors of moisture and organic matter. The figures were accordingly plotted using SAS PROC PLOT. The normality of data was analyzed using Proc Univariate (Shapiro-Wilks tests). The homogeneity of variance was also tested using Levene's test. There was not any use of alternative analysis as the data were not subjected to any type of transformation. Means were compared using Duncan multiple range test at $P= 0.05$. The map of the experimental regions was drawn using ARC-GIS.

3 Results

3.1 Soil physical and chemical properties

The physical and chemical properties of the soils (Table 1), which were highly variable, were determined in the regions with the Eastern latitudes ranging from 25° 38′ to 65° 35′ and northern longitudes ranging from 38° 12′ to 59° 4′. The soils had different types of texture, with the SP ranging from 22 to 54%, and a wide range of salinity (0.11–23.6 dS/m) levels, and the pH values ranging from 7.57 to 8.33. The soils were

Table 1 The physical and chemical properties of the experimental soils

Ion	Altitude	Longitude	EC (1:5) (dS/m)	pH	S.P.	O.C. (%)	Avail. P. (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	CEC (meq/100g)	CaCO3 (%)	Avail. S (mg/kg)	Texture
1	33° 04′	50° 27′	0.11	7.83	38	0.54	20.2	8.8	0.5	23.4	14.9	2	S.C.
2	32° 34′	52° 00′	8.06	7.92	41	0.56	13	6.3	0.6	14.2	34.3	837.5	S.C.L.
3	32° 22′	51° 27′	0.16	7.98	17	0.06	6	5.8	1.9	7	84.2	10.25	L.S.
4	37° 34′	47° 29′	0.18	7.72	49	0.61	4	7.6	0.3	28.6	6.3	7.75	C.L.
5	37° 46′	46° 42′	0.15	7.61	28	0.68	10	7.3	0.4	13.6	0.96	4.25	S.L.
6	50° 57′	48° 48′	2.67	7.76	47	0.88	3.46	6	0.5	14.6	49.9	356.25	S.C.
7	28° 47′	51° 42′	1.08	7.66	34	0.84	7.2	3.7	0.8	9.2	63.4	194.25	L.
8	28° 47′	51° 44′	0.27	7.94	37	0.22	7.6	4	0.2	10.6	45.8	12.75	L.
9	52° 56′	40° 85′	12.66	7.57	39	0.22	13	6.3	0.6	14.2	21	8.7	C.L.
10	50° 83′	40° 90′	0.2	7.94	34	0.06	11.4	3.7	0.6	9.6	16.6	7.75	L.
11	65° 35′	38° 12′	0.18	8.18	22	0.08	3.6	5.9	0.2	7.4	8.4	9	L.S.
12	31° 13′	49o 31′	23.6	8.33	44	0.7	1.6	0.8	0.6	9.2	9.2	7.9	S.L.
13	36° 35′	55° 04′	3.99	7.81	36	0.77	10.6	11.4	0.5	15.2	32.4	511	S.C.
14	29° 29′	54° 03′	4.27	7.81	39	0.3	2	2.4	0.2	10.8	21.7	1110	S.L.
15	29° 27′	59° 04′	0.25	7.87	42	0.87	16.4	12.5	1	18.8	39.4	7.5	C.L.
16	27° 56′	55° 16′	0.23	7.74	30	0.81	5.8	5.5	0.3	9.2	37.5	10.5	S.L.
17	27° 45′	57° 01′	0.14	7.99	33	0.34	2.0	3.5	0.3	7.6	29.2	3.25	Si.L.
18	28° 06′	57° 53′	1.15	7.96	28	0.25	12.6	4.0	0.5	11.2	16.6	6.6	L.
19	34° 43′	47° 31′	0.23	7.63	41	0.87	15.4	6.1	0.4	23	43.6	1.75	Si.C.L.
20	33° 32′	48° 20′	0.21	7.76	54	0.98	9.6	18.2	0.3	38.4	1.2	4.0	C.
21	25° 38′	58° 31′	0.88	8.08	33	0.11	1.2	3.0	0.3	9.2	20.7	42.5	S.L.

Soil regions: (1) DarehBid, (2) Lenjan, (3) Talkhuncheh, (4) Darin, (5) Balestan, (6) Bushgan, (7) EmamZadeh, (8) GhasemKhani, (9) EbrahimAbad, (10) GonAbad, (11) NajmAbad, (12) Jazooshi, (13) Kharghani, (14) Sarvestan, (15) Dogh, (16) Shurjeh, (17) Ghadamgah, (18) CamSorkh, (19) SharifAbad, (20) TappehGhachi, and (21) Sahel. *E.C.* electrical conductivity, *S.P.* saturation percentage, *O.C.* organic matter, *Avail. P.* available phosphorus, *CEC* cation exchange capacity, *Avail. S.* available sulfur

not high in organic carbon, ranging between 0.06 and 0.98%, with the average organic carbon of 0.5%. CaCO3, clay, and cation exchange capacity (CEC) were in the range of 10–842 g/kg, 80–530 g/kg, and 7–38.4 cmol/kg soil, respectively. The available P and S were in the ranges of 2–20.2 and 2–837.5 mg/kg, and Fe and Zn ranged from 0.8 to 18.2 and 0.2–1 mg/kg, respectively (Table 1). Analyses of variance indicated the significant effects of soil moisture, organic matter, and their interactions on soil chemical properties including pH, EC, and OC in the experimental regions (Table 2).

3.2 Soil acidity

The effects of both experimental treatments were significant on soil acidity. There were not clear trends of experimental treatments on soil pH. However, in the V1 treatment, BI significantly decreased soil acidity, in V2 there were not any effects of organic matter, in V3, BI significantly increased soil pH, and in V4, WS significantly decreased soil acidity, while the effect of BI was not significant. The trend of pH variation was not significant at the field capacity (FC) moisture. The effects of experimental treatments were highly variable on soil acidity as the least pH value was related to treatment M2 at V4 (Fig. 2). S8 at V4 had the highest soil pH (8.80), and S6 at V1 had the least soil pH (7.74).

With respect to the properties of the experimental soils, the effects of organic matter at different soil moisture levels appeared differently. Accordingly, the least pH's were related to region 6 at V1, and the highest pH's were related to region 8 affected by soil moisture levels and sources of organic matter. In most cases, the use of WS significantly increased soil pH compared with control and BI treatments (Fig. 2a–d). BI resulted in the least pH (7.84) in S6, and WS resulted in the highest pH (8.87) in S8.

3.3 Soil salinity

The results indicated that the effects of different sources of fertilization including control (2.9 dS/m) and WS (2.8 dS/m) on soil salinity were not significantly different; however, soil salinity by BI was significantly (3.1 dS/m) higher than the other treatments. The effects of soil moisture on soil salinity

Table 2 Organic carbon, salinity, and acidity of the experimental soils affected by the sources of organic matter

Soil	S.V.	d.f.	S.S.		
			OC	EC	pH
1	M.	3	0.2	0.017**	0.14
	O.M.	2	0.2	0.09**	0.64**
	M. * O.M.	6	0.08	0.01**	0.11
	Error	12	0.09	0.003	0.055
	C.V. (%)	–	3.7	7.2	37.6
2	M.	3	0.05**	0.49*	0.05**
	O.M.	2	0.05**	0.19	0.85**
	M. * O.M.	6	0.02**	0.11	0.02**
	Error	12	0.006	0.09	0.002**
	C.V.(%)	–	0.97	4.4	5.2
3	M.	3	0.017	0.0007	0.10**
	O.M.	2	2.07**	0.05**	0.09*
	M. * O.M.	6	0.02	0.0005	0.06*
	Error	12	0.009	0.0003	0.01
	C.V. (%)	–	16.18	4.8	1.4
4	M.	3	0.06**	0.02**	0.2
	O.M.	2	0.6	0.06**	0.1
	M. * O.M.	6	0.01	0.006**	0.1
	Error	12	0.005	0.0003	0.09
	C.V. (%)	–	7.3	6.2	3.7
5	M.	3	0.4**	0.02**	0.04
	O.M.	2	0.07*	0.1**	0.8**
	M. * O.M.	6	0.2**	0.007**	0.02
	Error	12	0.01	0.001**	0.02
	C.V. (%)	–	1.3	14.7	15.2
6	M.	3	0.006	0.2**	0.17**
	O.M.	2	0.8**	0.3**	0.09**
	M. * O.M.	6	0.01	0.06	0.05**
	Error	12	0.02	0.02	0.007
	C.V. (%)	–	13.2	5.5	1.11
7	M.	3	0.05**	0.18**	0.05
	O.M.	2	0.9**	0.15**	0.05
	M. * O.M.	6	0.01*	0.02	0.01
	Error	12	0.004	0.01	0.03
	C.V.(%)	–	5.9	11.1	2.3
8	M.	3	0.004	0.016**	0.04
	O.M.	2	0.67**	0.07**	0.37**
	M. * O.M.	6	0.01*	0.009**	0.04
	Error	12	0.004	0.001	0.02
	C.V.(%)	–	10.2	9.4	1.7
9	M.	3	0.3**	0.35	0.02
	O.M.	2	0.7**	0.01	0.13**
	M. * O.M.	6	0.02*	0.68*	0.01
	Error	12	0.005	0.17	0.01
	C.V.(%)	–	11.4	3.4	1.2
10	M.	3	0.019	0.005*	0.004
	O.M.	2	0.8**	0.081**	0.04**
	M. * O.M.	6	0.008	0.003**	0.019
	Error	12	0.006	0.001	0.003
	C.V.(%)	–	16.8	10.36	0.73
11	M.	3	0.1**	0.001	0.05
	O.M.	2	1.6**	0.13**	0.005
	M. * O.M.	6	0.01*	0.0036	0.021
	Error	12	0.005	0.0033	0.024
	C.V.(%)	–	10.33	19.58	1.84
12	M.	3	0.2**	21.7	0.08**
	O.M.	2	1.3**	0.53	0.09**
	M. * O.M.	6	0.03**	9.4	0.01*
	Error	12	0.002	8.1	0.006
	C.V.(%)	–	4.5	12.56	0.96
13	M.	3	0.02*	0.6**	0.03*
	O.M.	2	0.9**	0.64**	0.0009
	M. * O.M.	6	0.012	0.28**	0.03**
	Error	12	0.005	0.05	0.006
	C.V.(%)	–	6.16	6.06	0.99
14	M.	3	0.3**	0.08	0.031
	O.M.	2	0.89**	0.3**	0.0005
	M. * O.M.	6	0.03**	0.04	0.006
	Error	12	0.003	0.03	0.01
	C.V.(%)	–	7.3	4.7	1.26
15	M.	3	0.29**	0.32**	0.055*
	O.M.	2	0.8**	0.08**	0.007
	M. * O.M.	6	0.009**	0.01	0.033
	Error	12	0.001	12.07	0.01
	C.V.(%)	–	3.8	–	1.29
16	M.	3	0.02	1.22**	0.05**
	O.M.	2	0.8**	1.17**	0.02*
	M. * O.M.	6	0.004	0.05	0.003
	Error	12	0.01	0.08	0.006
	C.V.(%)	–	11.4	15.5	0.96
17	M.	3	0.03*	0.038*	0.085
	O.M.	2	0.62**	0.17**	0.098
	M. * O.M.	6	0.01*	0.016	0.05
	Error	12	0.005	0.009	0.04
	C.V.(%)	–	10.7	19	2.58
18	M.	3	0.01*	0.04	0.033
	O.M.	2	0.64**	0.06*	0.047*
	M. * O.M.	6	0.01*	0.03*	0.014
	Error	12	0.002	0.01	0.010
	C.V.(%)	–	8.0	13.3	1.21
19	M.	3	0.02**	0.07**	0.012
	O.M.	2	0.64**	0.05**	0.01
	M. * O.M.	6	0.01**	0.01**	0.005
	Error	12	0.003	0.001	0.025
	C.V.(%)	–	4.8	11.7	1.92
20	M.	3	0.083*	0.12**	0.01
	O.M.	2	1.18**	0.1**	0.01
	M. * O.M.	6	0.02	0.01**	0.01
	Error	12	0.01	0.001	0.01
	C.V.(%)	–	10.4	12.8	1.4
21	M.	3	0.016	0.01	0.02*
	O.M.	2	0.71**	0.12**	0.03**
	M. * O.M.	6	0.006	0.03	0.04**
	Error	12	0.004	0.014	0.004
	C.V.(%)	–	12.7	8.5	0.77

*, **: significant at P= 0.05 and 0.01, respectively

were significantly higher in V2 (variable soil moisture of field capacity) (3.16 dS/m) compared the moisture levels (ranging from 2.84 to 2.93 dS/m). S5 and V4 resulted in the least EC (0.17 dS/m), and S12 and V2 had the highest EC (24.67 dS/m). S3 and the control treatment of OM resulted in the least EC (0.16 dS/m), and S12 and BI resulted in the highest EC (23.04 dS/m).

3.4 Soil organic matter

The effects of experimental treatments on soil organic matter were significant, and both organic treatments (WS (0.89%)

and BI (1.20%)) significantly increased soil organic matter (0.49%) compared with the control treatment. However, according to the results, the effects of BI were more pronounced on enhancing soil organic matter, than the WS treatment. The combination of S21 and V3 resulted in the least (0.20%) and S16 and V4 in the highest (1.47%) OC. S10 and control treatment of OM had the least (0.06%) OC and S16 and BI had the highest (1.64%) OC.

3.5 Microbial biomass carbon

According to the analysis of variance, the effect of organic fertilization was significant on MBC in different experimental regions (Table 3). Similar to the effects of the organic fertilization treatments on soil organic matter, the use of WS (524.9 mg/kg) and BI (885.1 mg/kg) significantly increased MBC, compared with the control treatment (221.5 mg/kg), and the effects of BI were more pronounced than the effects of WS in the soils of different experimental regions (Fig. 3a–d). S17 and the control treatment of organic matter resulted in the least (43.1 mg/kg) and S16 and BI resulted in the highest (2947.4 mg/kg) MBC.

4 Discussion

4.1 Soil physicochemical properties

Investigating soil properties affected by varying soil moisture (drying and rewetting cycles) and different sources of organic matter is of significance for the optimum production of agricultural crops. In this research, different parts of Iran, with a high variation of soil physical, chemical, and biological properties were selected so that the obtained results can be broadly interpreted and used. The significant effects of the experimental treatments and their interactions on soil pH, salinity, organic matter, and MBC indicated that it is possible to alter such soil properties in a favorable way, so that the efficiency of agricultural fields is enhanced. Luo et al. [31] also found that the use of biochar significantly increased soil organic carbon and total N, and as a result, biochar can be used for the optimization of fertilizer use.

According to Li et al. [25], the addition of biochar, similar to our results, increased soil pH and increased the efficiency of water and soil for crop production. Although researchers have indicated that it is possible to mitigate the negative effects of soil salinity on plant growth using the optimum rates of biochar, the increased solubility of different elements such as Ca^{2+}, Mg^{2+}, and K^{+} (their presence in the soil solution) in

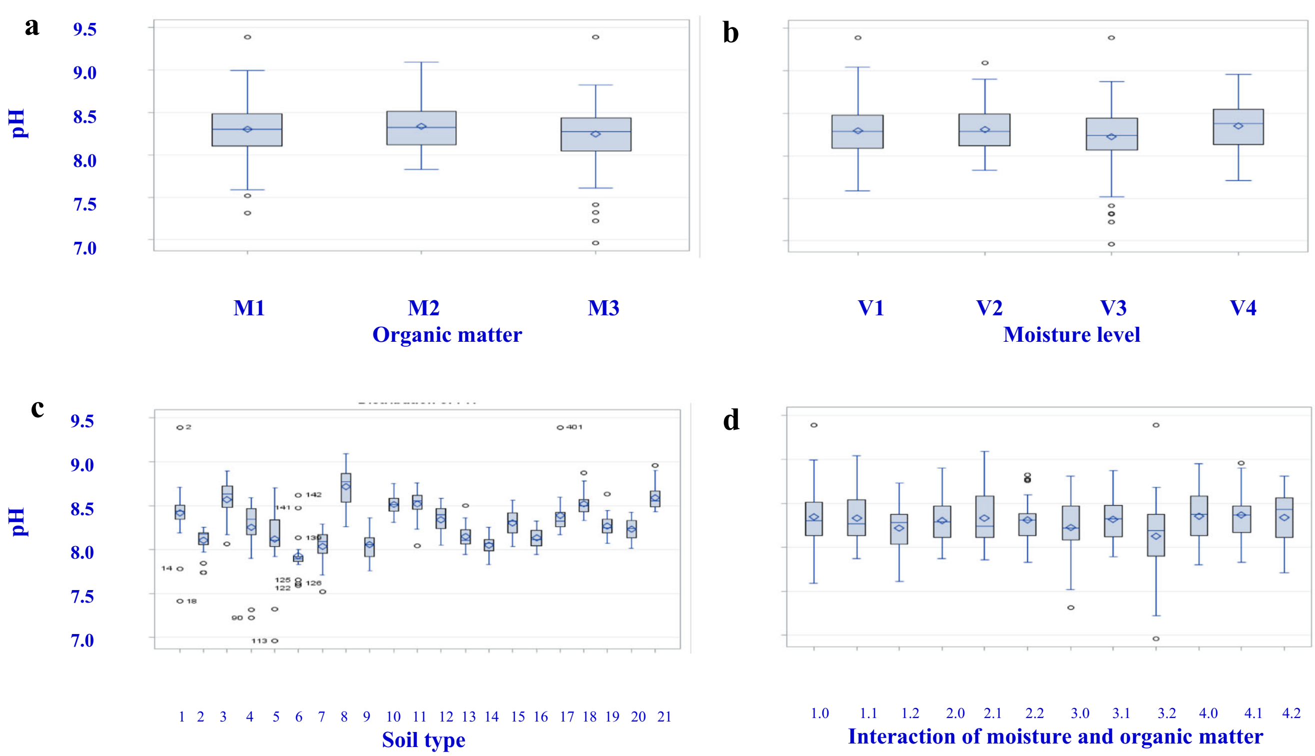

Fig. 2 Soil pH affected by (**a**) organic matter (M), (**b**) soil moisture (V), (**c**) soil type, and (**d**) interaction of organic matter and soil moisture. Levels of organic matter (M1= 1 (control), M2= 2 (2% wheat straw(, M3= 3 (2% biochar)) and moisture levels (V1= 1 (0.2 FC), V2= 2 (0.7 variable FC), V3= 3 (0.7 constant FC), and V4= 4 (saturated moisture)). The numbers in **d** stand for the combination of soil moisture (1, 2, 3, and 4) and organic matter (0, 1, and 2)

Table 3 Microbial biomass carbon affected by the sources of organic matter

Soil	S.V.	d.f.	MBC
1	O.C.	2	92398**
	Error	3	243.9
	C.V.	–	4.5
2	O.C.	2	200379**
	Error	3	647.2
	C.V.	–	4.5
3	O.C.	2	117409**
	Error	3	645.1
	C.V.	–	4.9
4	O.C.	2	344871**
	Error	3	5194.6
	C.V.	–	9.2
5	O.C.	2	93381**
	Error	3	220
	C.V.	–	3.5
6	O.C.	2	100381**
	Error	3	759
	C.V.	–	5.2
7	O.C.	2	186165**
	Error	3	1540.7
	C.V.	–	6.8
8	O.C.	2	347054**
	Error	3	456.3
	C.V.	–	3.8
9	O.C.	2	57392**
	Error	3	361.1
	C.V.	–	7.8
10	O.C.	2	174531**
	Error	3	365.3
	C.V.	–	3.8
11	O.C.	2	304199**
	Error	3	1438
	C.V.	–	4.9
12	O.C.	2	514104**
	Error	3	1376.3
	C.V.	–	4.5
13	O.C.	2	327738**
	Error	3	797.4
	C.V.	–	4.1
14	O.C.	2	45683**
	Error	3	809.6
	C.V.	–	5.4
15	O.C.	2	86069**
	Error	3	928.5
	C.V.	–	6.8
16	O.C.	2	68199**
	Error	3	385
	C.V.	–	3.8
17	O.C.	2	23094**
	Error	3	2543
	C.V.	–	35.4
18	O.C.	2	354758**
	Error	3	1009
	C.V.	–	5.7
19	O.C.	2	32279**
	Error	3	5112
	C.V.	–	12
20	O.C.	2	16330**
	Error	3	1641.1
	C.V.	–	7500.7
21	O.C.	2	60307**
	Error	3	3668.4
	C.V.	–	25.3

S.V. source of variation, *d.f.* degree of freedom, *MBC* microbial biomass carbon, *C.V.* coefficient of variation. Soil regions: (1) DarehBid, (2) Lenjan, (3) Talkhuncheh, (4) Darin, (5) Balestan, (6) Bushgan, (7) EmamZadeh, (8) GhasemKhani, (9) EbrahimAbad, (10) GonAbad, (11) NajmAbad, (12) Jazooshi, (13) Kharghani, (14) Sarvestan, (15) Dogh, (16) Shurjeh, (17) Ghadamgah, (18) CamSorkh, (19) SharifAbad, (20) TappehGhachi, and (21) Sahel. *O.C.* organic matter; *, **: significant at $P = 0.05$ and 0.01, respectively

the soil when treated with BI, at the higher rates, can be the most important reason increasing soil salinity [17, 52] in our research.

Another important aspect about the present research is the high variability of the selected soil properties, including salinity, pH, saturation percentage, organic C, available, P, Fe, Zn, CEC, and $CaCO_3$, which can also significantly affect the productivity of the tested soils. Due to the presence of a wide range of soil textures, it can be the important source of variation. The texture of soil affects different soil chemical properties including the availability of nutrients. In the meanwhile, the interaction of such properties with the tested treatments can also determine the response of the soils to the use of different sources of organic matter at varying soil moistures. Dai et al. [8], by a meta-analysis, indicated that plant response to biochar is determined by the physicochemical properties of biochar and soil [11–13]. Similar to our results, Li et al. [25] found that with increasing the rate of biochar, soil salinity increased.

Different types of soils revealed distinct range of properties. The soils differed from non-saline to saline, the pH's were

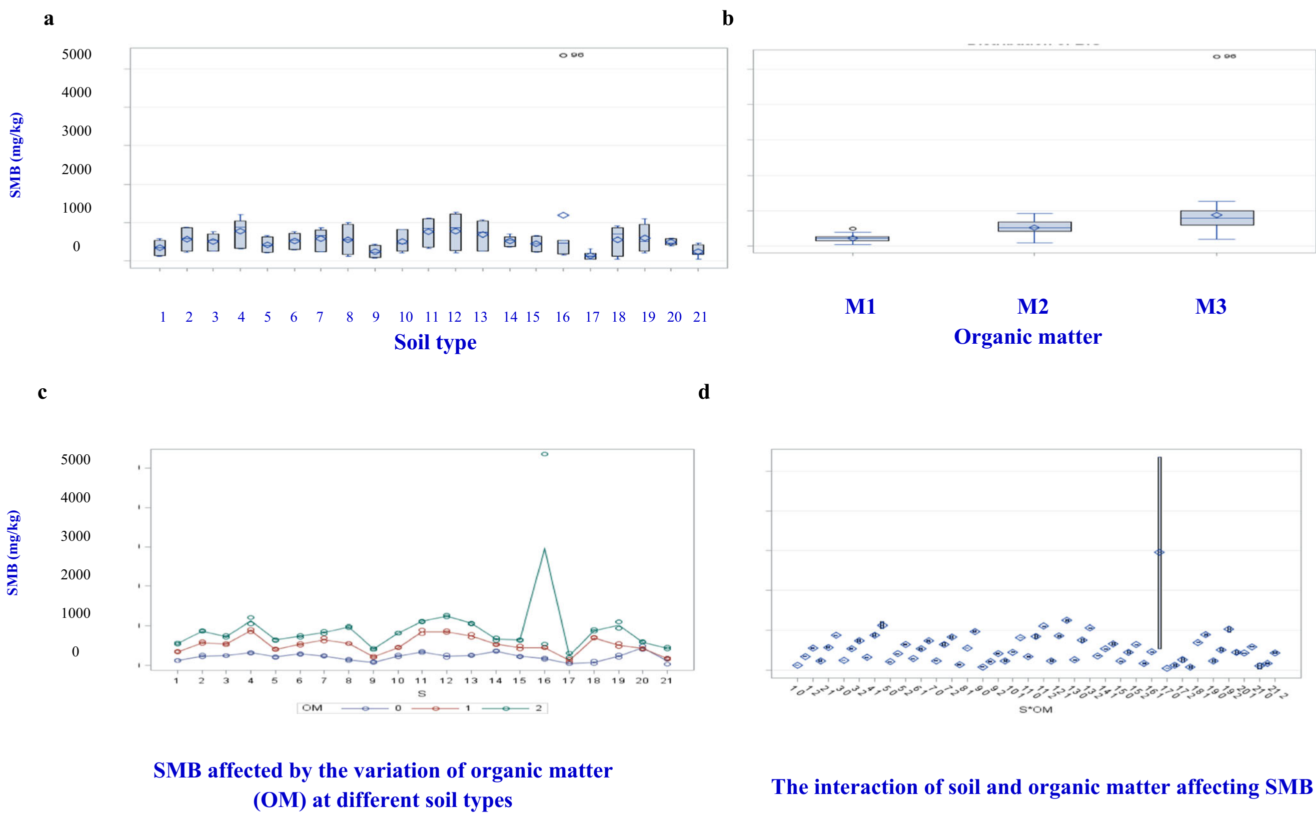

Fig. 3 Soil microbial biomass (SMB) affected by (**a**) soil type, (**b**) organic matter, (**c**) the variation of organic matter (OM) at different soil types, and (**d**) the interaction of soil type and organic matter. Levels of organic matter (M1= 1 (control), M2= 2 (2% wheat straw(, M3= 3 (2% biochar)) and moisture levels (V1= 1 (0.2 FC), V2= 2 (0.7 variable FC), V3= 3 (0.7 constant FC), and V4= 4 (saturated moisture)) of the soil regions: (1) DarehBid, (2) Lenjan, (3) Talkhuncheh, (4) Darin, (5) Balestan, (6) Bushgan, (7) EmamZadeh, (8) GhasemKhani, (9) EbrahimAbad, (10) GonAbad, (11) NajmAbad, (12) Jazooshi, (13) Kharghani, (14) Sarvestan, (15) Dogh, (16) Shurjeh, (17) Ghadamgah, (18) CamSorkh, (19) SharifAbad, (20) TappehGhachi, and (21) Sahel. The numbers in **d** are the combination of soil type (1–21) and organic matter (0, 1, and 2)

alkaline, and high variability of soil saturation, which definitely affects availability of water for plant use and the redox potential of soil. However, organic carbon was deficient in the soils. Although soil texture significantly affects different soil physical and chemical properties, including the availability of nutrients, water holding capacity and CEC, organic matter is also an important factor significantly affecting the such properties. The deficiency of organic matter in the tested soils is an indicator confirming the need for treating the soils with WS and BI.

4.2 Soil physicochemical properties affected by biochar and wheat straw

According to our results, although the two sources of organic fertilization including WS and BI significantly affected different soil properties including pH, salinity, organic matter, and soil MBC, the effects of BI were more pronounced. This can be due to the higher percentage of C in BI (61%) than WS (53.74%) affecting plant use and microbial activities. It is because the process of pyrolysis significantly increases the degradation rate of organic matter in BI, and as a result, the present N and C can be more easily used by plants and microbes. Similarly, Sun et al. [50] found that although the effects of manure were more pronounced on soil properties such as microbial abundance and diversity, WS was also able to increase bacterial population, but not diversity, by increasing soil pH and the availability of different soil nutrients including C, N, and P [44]. Similar to our results, Pokharel et al. [38], conducting a global meta-analysis, found that biochar can significantly increase soil microbial biomass C and enzymatic activities. They accordingly indicated that the use of biochar is a suitable method for reviving the fertility of soils and increasing plant productivity, especially in areas with not sufficient amount of organic matter [2].

4.3 Drying and rewetting affecting soil physicochemical properties

The effects of drying and rewetting (moisture fluctuation) on soil physical, chemical, and biological properties have been investigated by researchers. The fluctuation of soil moisture is a function of rainfall, irrigation, and temperature, which are more inconsistent under arid and semi-arid conditions [14, 16, 41]. Due to rewetting. (1) the availability of food and bacterial activity increases quickly, and (2) the degradation of soil aggregates releases the immobilized organic matter, mineralized by soil microbes [55]. The higher the number of drying and rewetting cycles, the less the microbial biomass and activity, which is due to higher microbial decomposition and carbon reduction by the soil microbes during the rewetting process. Microbial activity, subjected to drying and rewetting, is a function of soil type affecting soil moisture, organic matter, and aggregation as well as their interactions. Drying and rewetting may also decrease microbial population and subsequent nutrient release [15, 41, 55].

4.4 Biochar affecting soil pH

According to the results, the use of BI at V1 significantly increased soil pH, which is similar to the results by Smebye et al. [47]. However, at the higher levels of soil moisture, soil pH was not increased by BI indicating that soil moisture is a determining factor in the alteration of soil pH by BI (analysis of variance indicated significant interactions between soil moisture and BI). This can be due to the alteration of soil oxidation/reduction potential under higher moisture levels, because with increasing the soil moisture, and due to less oxygen, the conditions are more favorable for the reduction of the elements in the soil decreasing soil pH.

The use of BI increases soil pH and the availability of soil organic matter absorbed onto soil particles affecting different soil properties including soil microbial activities [47, 51]. The strong binding of BI with cations such as Ca^{2+} and Mg^{2+}, compared with the monovalent cations such as Na^+ and K^+, can explain pH increase in the soil treated with BI, resulting in the higher absorption of cations by soil colloids. Similarly, [5] found that the use of biochar increases soil pH. Wu et al. [54] indicated that biochar is more effective than lime to enhance soil pH in acidic soil and improve fruit quality.

4.5 Biochar and soil organic C

Carbon presence in BI increases soil organic carbon, which can be available for plant and microbes in different forms such as dissolved organic carbon (in water, acidic and basic), affecting (1) plant and microbial growth, (2) soil properties, and (3) soil carbon and pollutant sequestration [9, 28, 39]. BI colloidal property is one important aspect affecting soil chemistry such as nutrient absorption and release or cation exchange capacity (CEC) and soil pH as well as soil physics such as water holding capacity, soil porosity, and hydraulic conductivity. Such soil physical characteristics affect water movement containing nutrients and dissolved organic compounds into the soil micro- and macropores [28, 29, 36].

4.6 Biochar and soil microbial properties

Biochar as a source of carbon can stimulate soil microbial activities affecting respiration of soil (increased production of CO_2) as well as the biodegradation of soil organic compounds [34]. Although the analyses of phospholipid fatty acids indicated that during the first 16 weeks of the incubation study the microbial population decreased compared with control, it increased from week 16–24 indicating the gradual adoptability of soil microbes with the addition of BI. There was a shift in the soil microbial population toward the Gram-positive bacteria as the ratio of soil bacteria/soil fungi as well as Gram-negative bacteria/Gram-positive bacteria decreased. In conclusion the authors indicated that BI can increase the population and activity of some bacterial species, affecting carbon sequestration (the increased production of CO_2) and biodegradation of labile organic matter [34].

Such types of research are important due to the fluctuations of different soil properties such as moisture and salinity in the field, which are not constant in time and space affecting soil microbial properties. Interestingly, the use of organic matter can improve the properties of saline soils because the production of osmolytes requires a high amount of energy [55].

5 Conclusion

The effects of soil moisture (four different levels ranging from 0.2 field capacity to saturation) and organic matter (wheat straw and its biochar) on soil pH, salinity, organic matter, and microbial biomass carbon were investigated in a 9-month incubation study using a wide range of soil types across Iran. There is not much data, to our knowledge, in this context. The results indicated that it is possible to alter such soil properties using wheat straw and biochar and make the conditions more favorable for plant growth and microbial activities. However, just WS was able to decrease soil salinity. BI salinity (3.1 dS/m) was significantly higher than WS (2.8 dS/m). Due to a higher percentage of C the organic treatments, especially, BI (61%) significantly increased soil OM and MBC compared with the control treatment. The two sources of organic fertilization, as sources of food for the soil microbes, and due to having colloidal properties, increased soil pH, OM, and MBC, though such effects were functions of varying soil moisture (drying and rewetting cycles). The important parameters of CEC and nutrient availability of soil colloids including organic matter determine soil pH. The effects of BI, significantly affected by soil moisture, were more pronounced on soil parameters. The use of organic matter such as the ones tested in this research is strongly suggested, for improving the properties and increasing the production of agricultural fields. The combined use of WS and BI is recommendable for the improvement of soil chemical and biological properties in the arid and semi-arid areas of the world.

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Author contribution All authors contributed equally to the manuscript.

Data availability The authors selected not to share data.

Declarations

Animal research Not applicable

Consent to participate Not applicable

Consent for publication Not applicable

Conflict of interest The authors declare no competing interests.

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