Medium-term effects of clay-based mineral biochar on plant performance and soil properties

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Abstract

There is no detailed information about the effect of mineral biochar (MB) on soil properties and plant performance. Here, MB levels of 0, 5, … and 25% in three application methods; including mixed with the topsoil (MTS), subsoil (MSS), whole soil (MWS) were used through cultivating the *Fortuynia bungei* (bush), *Calligonum comosum* (shrub) and *Ziziphus spina-christi* (tree) in holes based on a completely randomized factorial design for two consecutive years in an arid region. Based on the results, even using 5% MB, a relative improvement in soil and plant properties was observed, but there was no significant difference between 20 and 25% MB application. Plant performance was significantly influenced by specie type, MB levels and application method. Using 20% MB under MWS, shrub *C. comosum* had the highest height and biomass production. OM, EC and pH showed the most changes, which were mostly influenced by the level of MB used (Sig.<0.001). Also, soil respiration, urease, b-glucosidase, dehydrogenase, and acid phosphatase showed an increase of 34.4, 79.1, 100.0, 65.3 and 22.5%, respectively, in comparison to its control (MB = 0). The Pearson-Kendall correlation through PCA also showed significant ecological relationships between soil-plant characteristics improvements by 15–20%MB application.

1 Introduction

Improving the performance of plants in low-income countries located in arid and semi-arid regions is one of the important challenges to ensure food security (Farrar et al. 2019; Kangoma et al. 2017). On one hand, the increasing use of artificial and chemical inputs to increase agricultural products has led to the increase of various environmental problems i.e. soil and water contamination (Noori et al. 2021; Semida et al. 2019). Therefore, over the last two decades, application of biochar in soil has attracted the attention of the scientific community (Chi et al. 2021), and has been exploited as the eco-friendly materials to conserve natural resources and reclaim depleted or contaminated soil and water resources (Ahmad et al. 2021).

In general, due to unique characteristics such as high surface area, porosity and surface charges (Chrysargyris et al. 2020; Hossain et al. 2020), biochar has high stability and is produced to manage waste, reduce climate change, produce energy and improve soil properties and its performance (Biederman et al. 2017). Therefore, biochar affects physical (i.e. specific gravity), chemical (i.e. pH) and biological (microbial activity) properties of soil that increases plant performance (Khadem and others 2017; Leng et al. 2021). Biochar also is effective in removing chemical elements from the soil including various types of metal ions (Wittwer et al. 2017).

However, in large-scale, global implementation of biochar need to be done in a cost-effective manner (Buss et al. 2022). Moreover, biochar production can be a costly process depending on the economy and the geographical location. In fact, the production process requires resources and costs, especially in arid and semi-arid countries with low income. At the first step, it needs plant materials to produce biochar. Furthermore, controlling the temperature, pressure, and biomass composition play a vital role in the production of biochar (Chi et al. 2021; Noori et al. 2021). Finally, there is a direct relationship between biochar production technologies, biochar properties and biochar performance in agriculture and forestry systems (Wang et al. 2020). Therefore, exiting fertilizers such as mineral biochars (MBs) can be considered as a suitable/effective method for soil/plant improvement.

Compared to chemical fertilizers, MBs, have many economic and environmental benefits (Arif et al. 2021). In addition to being economical, MBs cause the stability of soil resources and its fertility, maintain production capacity in the long term, break down agricultural waste and detoxify contaminated soils as well (Hossain et al. 2020). Therefore, if MB is available, the cost of their preparation and use is low.

Generally, there are two major types of MB (Ahmad et al. 2021; Yang et al. 2021), including clay-based MB and phosphate-based MB use in different scale (Wang et al. 2022a). Clay-based MB possess higher specific surface areas and cation exchange capacity, and due to their reversible adsorption of nutrients, they can be used for metal adsorption/immobilization and fertility improvement (Mishra et al. 2018; Wang et al. 2021).

In large areas, especially in arid and semi-arid climates, it is not economically possible to improve soil and vegetation using man-made biochar. In fact, it is very expensive for the local community in arid/semi-arid environments with low income to prepare and transport biochar to the target lands. Therefore, available MB is a suitable solution for improving agriculture products along with sustainable use and management of soil resources (Wang et al. 2020; Xu et al. 2021). However, there is no detailed information about the MB efficiency on soil and plant improvements. Therefore, the main objectives of this research were 1; study the effect of MB levels on the performance of bush *Fortuynia bungei*, shrub Calligonum comosum and tree Ziziphus spina-christi, 2; study the effect of three different methods of biochar application{including; mixed with the 25 cm topsoil (MTS), mixed with the 25cm subsoil (MSS), and mixed with the whole soil (MWS) of the hole (50*50 cm)} on plant performance, and 3; study the effect of MB application on the soil chemical and biological characteristics under plant cultivation in arid areas.

2 Materials And Methods

2.1 Site description

This study was carried out in the nursery of the Department of Natural Resources and Watershed Management of Jiroft and Kohnuj (south of Kerman province, Iran). This site located at an elevation of 1760.0 meters above sea level, with long-term mean precipitation of 86 mm and the mean annual temperature of 16.5ºC.

2.2 Study species

In arid/semi-arid lands, vegetation consist of different forms such as bush, shrub, and tree, where selection of suitable species/life form with suitable treatments that can tolerate the climatic and soil factors with high performance under stressful conditions should be given attention and priority

(Yazdanshenas et al. 2019). Here, the studied species included the bush *F. bungei*, the shrub *C. comosum* and the tree *Z. spina-christi*. Tree *Z. spina-christi* is an evergreen species with medicinal, edible and industrial uses. *C. comosum* is a shrub species with 2 to 3 meters high, and is suitable for the landscaping of roadsides and around the highways (Alihouri 2018), which is useful in feeding livestock during droughts and lack of fodder. This plant has good palatability, especially for camels (Danaie et al. 2017). *F. bungei* is a perennial plant, with a woody base, with a wide distribution in desert areas, which due to its strong adaptation to dry and desert areas and has fodder, protection and tourism values, can be used for in de-desertification programs (Mohebby et al. 2018).

2.3 Experimental design

The experiment was conducted based on a completely randomized factorial design at four levels of MB in three different application methods with four replications for two consecutive years (2020-21).

The seeds of *F. bungei*, *C. comosum* and *Z. spina-christi* species (Pure live seeds = 0.98) were obtained from the gene bank of Forestry and Rangeland Research Institute and were analyzed for the germination test in the laboratory using the standard test method. 5 seeds of each species were planted in pots. The pots were watered once every three days, and after the seedlings grew and became two-leafed, one seedling was selected and planted in prepared holes in the nursery.

Table 1 Physiochemical properties of soil and mineral biochar used in this study

Table 1
Physiochemical properties of soil and mineral biochar used in this study

Factor	Biochar	Soil
pH	6.73 ± 0.10	7.4 ± 0.40
EC (ds/cm)	7.19 ± 0.20	4.22 ± 0.80
OC (%)	10.71 ± 0.01	0.7 ± 0.20
OM (%)	18.39 ± 0.03	1.3 ± 0.40
K (ppm)	320 ± 4.20	88.5 ± 11
P (ppm),	28.36 ± 0.24	13.7 ± 5.50
N (%)	0.87 ± 0.01	0.39 ± 0.04
Silt (%)	-	40 ± 5.40
Clay (%)	-	16 ± 4.60
Sand (%)	-	44 ± 7.20
Moisture content (%)	5.8 ± 0.03	5.3 ± 1.30
Bulk density (g/cm^3)	-	1.43 ± 0.02

2.4 Biochar application and agricultural practices

Holes were prepared for seedling cultivation in the nursery. The size of the holes in the nursery was 50*50*50cm. Soil texture in the holes were uniformed by adding sand to create a loam soil (Prakash et al. 2010). Soil characteristic of the nursery is shown in Table 1.

The clay- based MB was prepared from a natural biochar mine located in the Kuhbanan city of Kerman province, Iran (31°24'37"N, 56°16'57"E). The MB characteristics are shown in Table 1. The MB was used in holes before 10 days of the planting. The amount of biochar was used based on volume percentage of the culture environment (prepared holes volume). Biochar treatment was considered as 0, 5, 10, 15, 20 and 25% by volume. Also, MB was used in three different methods, including 1) mixed with the 25 cm topsoil (MTS) of the hole, mixed with the 25cm subsoil (MSS) of the hole, and mixed with the whole soil (MWS).

Seedlings of each specie were planted in holes and irrigation was applied based on field capacity (FC) (SSSA 2001). For this purpose, a hole was irrigated, and a soil sample was taken to measure the amount of water content two days after irrigation. The amount of water was given to hole, according to the difference in the percentage of soil moisture based on FC. Therefore, irrigation was considered for holes at 100% FC values. During the growth seasons, solar radiation, maximum air temperature, minimum air temperature, wind speed, mean relatively humidity were, 18.6 MJ/day, 30°C, 28.2°C, 0.51 m/s, and 34%, respectively.

2.5 Plant measurements

The changes in vegetation characteristics of the seedlings (i.e. height, canopy cover) were monitored and recorded during two consecutive years. Vegetation characteristics were measured twice late growing season 2020 (LGS) and late growing season 2021. At the end of the experimental period, the height and canopy diameter of seedlings was recorded and plants were removed from the holes, were dried in the shade for one week. Biomass was measured late growing season 2021 (LGS2021). The roots were separated from the aerial parts and washed and dried. After drying, the aboveground biomass, belowground biomass (root) and the total biomass of each plant were recorded.

The relative water content was measured for both aboveground and belowground biomass as follows:

$$RWC = \left(\frac{FW - DW}{FW}\right) * 100$$

Where, RWC is relative water content, FW is fresh weights, DW is dry weights (Bhardwaj and Yadav 2012).

2.6 Soil measurements

Soil characteristics were measured twice early growing season 2020 (EGS2020) and late growing season 2021 (LGS2021). The holes in which biochar has been mixed with the entire soil were selected and soil samples were taken and analyzed. Soil properties including organic matter, nitrogen, phosphorus, potassium, acidity and electrical conductivity were measured for samples in the lab. Briefly, the electrical conductivity of each saturated soil sample was obtained using extraction filter paper and using a conductometer device (EC meter). Soil acidity was measured by saturated mud method using pH meter (Corning 120 pH meter). To determine the percentage of organic matter, 10 milliliters of potassium bichromate and 20 milliliters of concentrated sulfuric acid were added to each 1 gram soil sample and placed in a fixed place for 30 minutes, then 200 milliliters of distilled water were added. And about 10 drops of orthophenatroline-ferro indicator were added to each sample and the titration of the samples was done with sulfate transfer and the amount of sulfate used for each sample was recorded. The amount of organic matter of each soil sample was calculated using the relevant formula. Also, the amount of nitrogen was measured by Kjeldahl's method (1883), phosphorus by Elson's method (1962) and potassium by ammonium acetate method.

Also, biological characteristics were measured four times including early growing season 2020 (EGS2020), late growing season 2020 (LGS2020), early growing season 2021 (EGS2021), and late growing season 2021 (LGS2021). soil respiration (SR) was determined according to the CO_2 evolved from moist soil, adjusted to 55 percent water holding capacity, and pre-incubated for 7 days at 20 C in the dark (Dinesh et al. 2013). Soil enzyme activities were measured for samples. For this purposes, urease (UR), -

glucosidase (G), dehydrogenase (DH), and acid phosphatase (AcP) activities in the soil were determined using standard method (Bottomley et al. 2020).

2.7 Data analysis

Data were checked for normality, then, two-way analysis of variance and combined analysis were performed to compare the results of the treatments. Data grouping was done with Duncan's multiple range test (MRT) in SPSS v.17.01 software. Data were also submitted to a PCA analysis to indicate the ecological relationships between soil and plant characteristics (for MWS treatments) at the end of the experiment using the PC-ORD.

3 Results

3.1 Plant performance under MB application

The evaluation of the height of the plant (HP), canopy diameter (CD), aboveground biomass (AB) and belowground biomass (BB) under the influence of different levels of biochar and its application method was obtained differently for different species (Table 2). In general, the height of the species was shown different under the influence of the plant species. Also, the combined effects of species-treatment on the height of the plant during this period showed a significant effect at the level of 5% error. Ignoring the type of plant species, the level of biochar used and its application method, the growth rate of different species was obtained. The highest growth rate was related to the 20–25% biochar used and also related to the mixture of biochar with the whole soil profile in the holes.

Table 2
statistical analyses (Mean square) of the effects of species, biochar level and its application method on the plant characteristics.

Sources	HP	AB	BB	TB	CD	AM	BM
Sp	1255.4**	7625.7**	6857.8**	8853.2**	850.4*	62.2ns	53.4ns
BAM	688.4 **	885.4 **	745.6 **	746.2 **	985.7 **	55.4ns	45.7ns
BL	655.2 **	8654.6 **	754.4 **	7764.2 **	185.2 **	158.3*	134.6*
BAM*Sp	258.4 **	698.42 **	658.5 **	1058.4 **	110.4ns	35.6ns	32.2ns
Sp*BL	152.3*	358.6**	285.7**	745.4**	222. 5*	24. 3ns	30.4ns
BAM*BL	154.5 *	175.5 *	154.5 *	425.5 *	228.4*	21.5ns	18.7ns
BAM*BL*Sp	45.3 ns	149.4 *	115.7 *	175.5 *	156.8 *	11.4ns	13.8ns

HP = Height of plant, Sp = Species, BAM = Biochar application method, B = Biochar level, AB = Aboveground biomass, BB = Belowground biomass. TB = Total biomass, CD = Canopy diameter, AM = Aboveground moisture, BM = Belowground moisture, *: Significant difference at 5% error, **: Significant difference at 1% error, ns: No significant difference.

Table 2 statistical analyses (Mean square) of the effects of species, biochar level and its application method on the plant characteristics.

Figure 1A-C shows the height of the plants for different species, MB level and biochar application method. Based on the results, *C. comosum* had the highest growth height (equivalent to 50 cm) compared to the other two species, and the lowest height of 39 cm was related to *F. bungei* species. For each plant species, the higher amount of growth was related to the use of biochar mixed with the entire soil profile (Fig. 1B). Also, according to the results, with the increase in the level of biochar used, the height of each plant has shown higher values. However, there was not significant between 20 and 25%MB (Fig. 1C).

Canopy cover, like the height of cultivated species, is affected by different levels of biochar and the way biochar is used (Fig. 1D-F). The highest amount of canopy cover equal to 56 cm was related to the *C. comosum* specie. Also, the amount of canopy cover under MTS (44 cm) and MWS (54 cm) treatment was the highest and the lowest, respectively (Fig. 1E).

Figure 1 Plant height and canopy diameter for different species, biochar levels and biochar application methods.

The aboveground and belowground biomass of different plant life forms significantly changed under the influence of plant species, life form types and application method*plant species at the 1% error level. Also, there was a different under the influence of the combined effects of treatment*plant species at the 5 percent error level (Fig. 2A-F). *C. comosum* had the highest biomass production (2.16 and 0.92 kg, for aboveground and belowground biomass, respectively). Biochar application method also had a significant effect on plant biomass so that the highest values (2.4 kg) were shown under the factor of biochar mixture with the whole soil profile, and the lowest value was observed for biochar mixture with subsoil (1.4 kg). Also, the levels of biochar used have a positive effect on the biomass of cultivated plants, so that the use of biochar with a ratio of 15–20% showed the highest production (Fig. 2C, F).

Figure 2 Aboveground and belowground biomass for the different species, biochar levels and biochar application methods.

The evaluation of the areal (aboveground) and root (belowground) moisture content showed that there is a significant difference between under different levels of MB. Overall, the most difference was related between MB 0 and MB 10%. The most moisture content of the roots (28.0%) and aerial parts (26.0%) was observed under 10%MB application.

On the other hand, with the increase in the amount of biochar, the amount moisture of the root and aerial parts will not increase (Fig. 3).

Figure 3 Moisture content in root and aerial parts of plant under different levels of biochar and

3.2 Soil characteristics under MB application

Evaluation of soil properties showed that MB application significantly influenced some soil properties ($P < 0.05$). Table 3 shows the comparison of changes in soil characteristics under the influence of different biochar levels and plant species. Based on the results, nitrogen, OM and EC were significantly changed at the level of 1% error under the influence of the biochar levels. Moreover, Soil respiration, b-glucosidase, acid phosphatase, urease were influenced by MB levels. Furthermore, dehydrogenase was influenced by both species and MB levels (Table 3).

Table 3
Statistical analysis of the effects of species, biochar levels on soil chemical and biological properties.

	Factor	Species	Biochar level	Species* Biochar level
Chemical properties	N (%)	0.002^{ns}	2.23^{*}	2.143^{ns}
	OM (%)	0.163^{ns}	21.67^{**}	3.581^{*}
	P(ppm)	11.13^{ns}	12.45^{ns}	63.24^{ns}
	K(ppm)	1342.42	1345.35^{ns}	652.42^{ns}
	EC (ds/cm)	0.315^{*}	0.737^{**}	0.142^{*}
	pH	0.019^{ns}	0.230^{ns}	0.210^{ns}
	$Caco_3$	23.451^{*}	15.123^{ns}	9.457^{ns}
Biological properties	Soil respiration (SR)	16.151^{ns}	95.80^{**}	74.111^{*}
	-glucosidase (G)	0.254	0.754^{**}	0.614^{*}
	Acid phosphatase (AcP)	5.231^{ns}	19.471^{**}	3.654^{ns}
	Urease (UR)	0.564^{ns}	0.958^{*}	0.342^{ns}
	Dehydrogenase (DH)	1123.475^{*}	1457.124^{**}	1004.475^{*}

*: Significant difference at 5% error, **: Significant difference at 1% error, ns: No significant difference.

Table 3 Statistical analysis of the effects of species, biochar levels on soil chemical and biological properties.

Based on the results, with the increase in the amount of biochar in the soil, b-glucosidase and dehydrogenase have shown the most changes, so that with the increase in the amount of biochar from the level of 0 to the level of 25%, the value of this characteristic has reached the value of 4.7 to 2.4 for G and of 46 to 78 for DH, respectively (Fig. 4B). Similarly, changes have occurred in other enzymes. Some characteristics, such as OM, have shown a relative increase with increasing the amount of biochar to higher levels such as 20 to 25% (Fig. 4G). In general, by adding 5% MB to the soil, significant changes have been observed compared to the 0 MB level. But by adding 10 to 15% biochar to soil, it has caused significant changes in the biological and chemical properties of the soil (Fig. 4).

Figure 4 Soil respiration (A), urease (B), -glucosidase (C), dehydrogenase (D), and acid phosphatase (E) Soil organic matter(G), and electrical conductivity (H) under change under different levels of biochar.

3.3 Soil-plant ecological relationships under MB application

The PCA analysis showed the relationships between soil/vegetation characteristics (Table 4, Fig. 5). Based on the result, the cumulative variance (%) is 66.73, 81.82 and 89.32 for axis1, axis2 and axis3, respectively. According to the gradient values of the ecological relationships, factors of soil respiration (SR), b-glucosidase (G), urease (UR), dehydrogenase (DH), aboveground biomass (AB), belowground biomass (BB), total biomass (TB), canopy diameter (CD), EC, N, P, soil moisture (SM) and $CaSO_4$ (eigenvector = 0.325, 0.318, 0.311, 0.318, 0.332, 0.341, 0.342, 0.371, 0.417, 0.420, 0.432 and 0.358, respectively) showed the greatest length through the axis 1. Also, plant aboveground moisture (AM), plant belowground moisture (BM), pH and K (eigenvector = 0.642, 0.626, 0.599 and 0.410, respectively) showed the greatest length through the PCA axis 2 (Table 4).

Table 4
Eigenvectors scaled to unit length as coordinates in a distance-based biplot

Factor	**PCA axis**			**Factor**	**PCA axis**		
	1	**2**	**3**		**1**	**2**	**3**
SR	-0.3256	0.0171	-0.1680	EC	-0.3717	0.0049	0.2151
G	-0.3181	-0.0923	-0.2620	pH	-0.2795	-0.5955	0.1025
AcP	-0.2424	-0.2398	0.5763	K	0.1690	-0.4102	-0.8189
UR	-0.3113	-0.1167	0.2308	N	-0.4170	0.0213	0.2466
DH	-0.3181	0.1831	-0.0009	P	-0.4329	-0.1048	0.0200
HP	-0.2440	0.0286	-0.6722	SM	-0.4302	-0.1372	0.1497
AB	-0.3328	0.1747	0.0939	CaSO4	0. 4078	-0.3589	0.3933
BB	-0.3412	0.0709	0.1317	OM	-0.5297	-0.2828	0.1852
TB	-0.3403	0.1027	0.1038	-	-	-	-
CD	-0.3241	-0.1854	-0.0977	-	-	-	-
AM	0.1201	0.6468	0.0397	-	-		-
BM	-0.1182	0.6220	0.1335	-	-	-	-
HP = height of plant, AB = aboveground biomass, BB = belowground biomass. TB = total biomass, CD = canopy diameter, AM = aboveground moisture, BM = belowground moisture, SR = soil respiration, UR = urease, G= -glucosidase, DH = dehydrogenase, AcP = acid phosphatase, SM = soil moisture, OM = organic matter, N = nitrogen, P = phosphorus, K = potassium, pH = acidity, EC = electrical conductivity.							

Table 4 Eigenvectors scaled to unit length as coordinates in a distance-based biplot

Figure 5 shows the distribution of the relationship between the physical properties and the biological properties of the soil in a two-dimensional space in the studied experiment on the effect of different levels of MB. According to the graph, many characteristics such as plant height, canopy cover, aerial biomass and underground biomass of plants are closely related to characteristics such as OM, nitrogen, P and soil moisture. The amount of soil lime as an independent factor shows a negative correlation with other evaluated characteristics (Fig. 5).

Figure 5 PCA diagram for the relationship between soil and vegetation characteristics

HP = height of plant, AB = aboveground biomass, BB = belowground biomass. TB = total biomass, CD = canopy diameter, AM = aboveground moisture, BM = belowground moisture, SR = soil respiration, UR = urease, G= -glucosidase, DH = dehydrogenase, AcP = acid phosphatase, SM = soil moisture, OM = organic matter, N = nitrogen, P = phosphorus, K = potassium, pH = acidity, EC = electrical conductivity.

The result of Pearson and Kendall correlations showed significant relationships between soil/plant variable and PC axes ($p < 0.01$). Biological characteristics of soil respiration ($R^2 = 0.849$), urease ($R^2 = 0.776$), -glucosidase ($R^2 = 0.810$) and dehydrogenase ($R^2 = 0.810$) showed a significant relationship with the first axis of PCA. Plant characteristics such as height ($R^2 = 0.477$), aboveground biomass ($R^2 = 0.887$), belowground biomass ($R^2 = 0.932$), total biomass ($R^2 = 0.814$), canopy diameter ($R^2 = 0.841$), plant aboveground moisture ($R^2 = 0.758$) and plant belowground moisture ($R^2 = 0.701$) significantly correlated with first/second axis. Also, among physiochemical properties of soil, Soil moisture content ($R^2 = 0.857$), organic matter ($R^2 = 0.591$), nitrogen ($R^2 = 0.806$), phosphorus ($R^2 = 0.868$), electrical conductivity ($R^2 = 0.640$) showed a significant relationship with the first axis (Table 5).

Table 5
Pearson-Kendall correlation between soil-plant characteristics and ordination axes

Factor	PCA axis			Factor	PCA axis		
	1	2	3		1	2	3
SR	0.849^{**}	0.001	0.025	EC	0.640^{**}	0.001	0.044
G	0.810^{**}	0.015	0.062	pH	0.362^{*}	0.453^{*}	0.010
AcP	0.471^{*}	0.104	0.299	K	0.132	0.215	0.631^{**}
UR	0.776^{**}	0.025	0.048	N	0.806^{**}	0.001	0.562^{**}
DH	0.810^{**}	0.061	0.001	P	0.868^{**}	0.014	0.001
HP	0.477^{*}	0.001	0.407	SM	0.857^{**}	0.024	0.021
AB	0.887^{**}	0.055	0.008	$CaSO_4$	0.597^{**}	0.212	0.146
BB	0.932^{**}	0.009	0.016	OM	0.591^{**}	0.358^{*}	0.032
TB	0.927^{**}	0.019	0.010	-	-	-	-
CD	0.841^{**}	0.062	0.009	-	-	-	-
AM	0.115	0.758^{**}	0.001	-	-		-
BM	0.112	0.701^{**}	0.016	-	-	-	-

**= significant at $p < 0.01$, *= significant at $p < 0.05$, HP = height of plant, AB = aboveground biomass, BB = belowground biomass. TB = total biomass, CD = canopy diameter, AM = aboveground moisture, BM = belowground moisture, SR = soil respiration, UR = urease, G= -glucosidase, DH = dehydrogenase, AcP = acid phosphatase, SM = soil moisture, OM = organic matter, N = nitrogen, P = phosphorus, K = potassium, pH = acidity, EC = electrical conductivity.

Table 5 Pearson-Kendall correlation between soil-plant characteristics and ordination axes

4 Discussion

According to the results, there was a difference between levels and application method of MB in the performance of bush *F. bungei*, shrub *C. comosum* and tree *Z. spina-christi*. In the first step, different levels of biochar significantly improved the physiological conditions and plant performance. In fact, just for a species (*C. comosum*), an increase in the level of biochar was directly associated with an increase in the height or biomass production. Similarly, Kul et al. (2021) showed that the maximum increase in the dry weight of aerial parts (74.8%) was obtained from the amendment of 10% biochar in the experimental conditions. In the other words, the effect of biochar levels was shown to be different based on plant species.

Also, the application of different levels of MB significantly influenced some soil characteristics. Based on the results, the amount of biochar used significantly influenced soil properties. In general, with the increase the biochar in the soil, the amount of soil OM has also increased. With the increase/decrease of humidity or solutes under the influence of different MB levels in the soil, the amount of EC of the soil has also changed, so there were significant changes in relation to this factor under the cultivation of different species and under different levels of MB used.

Overall, the physical and chemical characteristics of biochar affect their effectiveness in soil (Hossain et al. 2020). And, under higher levels of MB (15–20%), plant and soil showed significant changes. Similarly, Moradi et al. (2019) investigated the effect of the type and level of biochar on some characteristics of calcareous soil, and results showed that with the increase in the amount of the biochar, soil OC, as well as the potassium, phosphorus and manganese increased significantly. Khadem (2017) also mentioned that as one of the best methods of soil management and improvement, biochar can sustainably increase soil OM and improve properties, i.e. physical, chemical and biological properties.

In the first step, the biochar application improves the alkaline-acidic conditions of the soil and as a result improves the biology of the soil and its nutritional properties (Hossain et al. 2020). Also, the application of biochar, by affecting the physical properties of the soil, improves the physical conditions of the soil, such as the apparent specific gravity and the available moisture, which strongly affects the biology of the soil and the improvement of plant performance (Biederman et al. 2017). Therefore, the application of MB, especially at the higher rate, significantly improved soil environment and plant performance (Wang et al. 2022b).

PCA analysis showed that many chemical and biological characteristics of the soil have increased with the increase of biochar level. It seems that there is a change in the microclimate of the soil, which causes a group improvement of the soil properties. In this research MB application significantly changed some properties of soil i.e. EC, pH and OM. Previous study of Masto et al. (2013) also showed an increase in pH (9%), EC (50%), OM (1.17%) under biochar application. Such changes have also been reported by improving growth conditions and increasing the biomass of rye plants under the influence of adding 50 g/kg of biochar to the soil in pots (Chirakkara et al. 2015). These changes also depend on the properties of used MB.

On the other hand, the lack of leaching of soil nutrients by using biochar is one of the important factors in improving the condition of the soil and cultivation conditions for plants, which has led to better growth if all the nutrients are present in the soil (Khalid Chaudhry et al. 2016). It seems that changes in soil properties are related to the biochar characteristics (Chrysargyris et al. 2020; Semida et al. 2019). In general, MB application improved some characteristics of soil and plant performance as well. The biochar production and its application in the soils of Iran, where the lack of OM is common, can be considered as one of the best and easiest methods compatible with the environment for improving their physical and chemical properties (Hossain et al. 2020; Khadem and *et al.* 2017). Also biochar application method should be noted in plant cultivation practices.

In arid areas, improving vegetation through suitable amendments plays the most important role in ecological-economical-social point of view (Sarli et al. 2019; Yazdanshenas et al. 2019), therefore, the application of MB may cause high ecological effects in the region at a low cost. The MBs can be economically justified due to their relatively low cost compared to man-made biochars. However, the underlying mechanisms related to the beneficial effects of biochar on soil are very complex, and more in-depth studies are needed to understand the interactions of biochar with soil organisms in extreme environments, which help to achieve the maximum benefits of biochar (Egamberdieva et al. 2022).

5 Conclusion

Depending the plant life form, and MB application method, the MB significantly influenced plant performance. With the increase in the level of biochar application, the improvement of soil conditions and functional characteristics of plants grown in loamy soil was observed. Mixing it with the entire soil (MWS), compared to the method of mixing biochar with surface (MTS) or deep soil (MSS), leads to higher plant production. Shrub *C. comosum* showed more biomass and height in relation to its control than bush *F. bungei* and tree *Z. spina-christi*. There was not significant difference between application of 20 to 25% biochar on most properties of soil and plant characteristics. Moreover, soil respiration, urease, b-glucosidase, dehydrogenase, and acid phosphatase significantly mprove by adding 205MB to soil. In general, by adding a minimum amount of MB to the soil, changes in chemical and biological properties and plant performance were observed, but the maximum improvement under the influence of 15 to 20% MB will be significant and economically viable.

Declarations

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Conflicts of interest. No potential conflicts of interest was reported by the authors.

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Figures

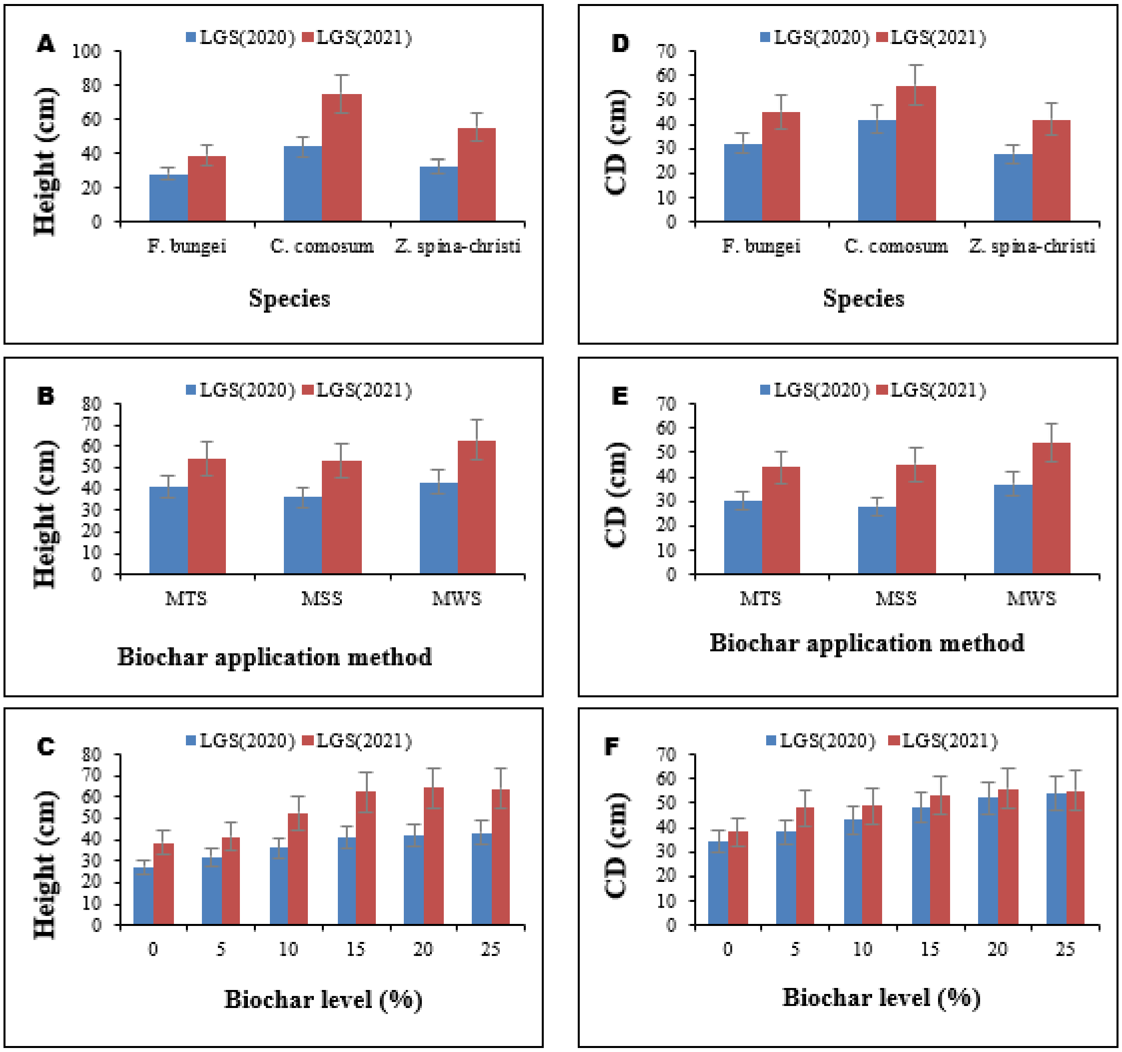

Figure 1

Plant height and canopy diameter for different species, biochar levels and biochar application methods. EGS=early growing season, LGS=late growing season.

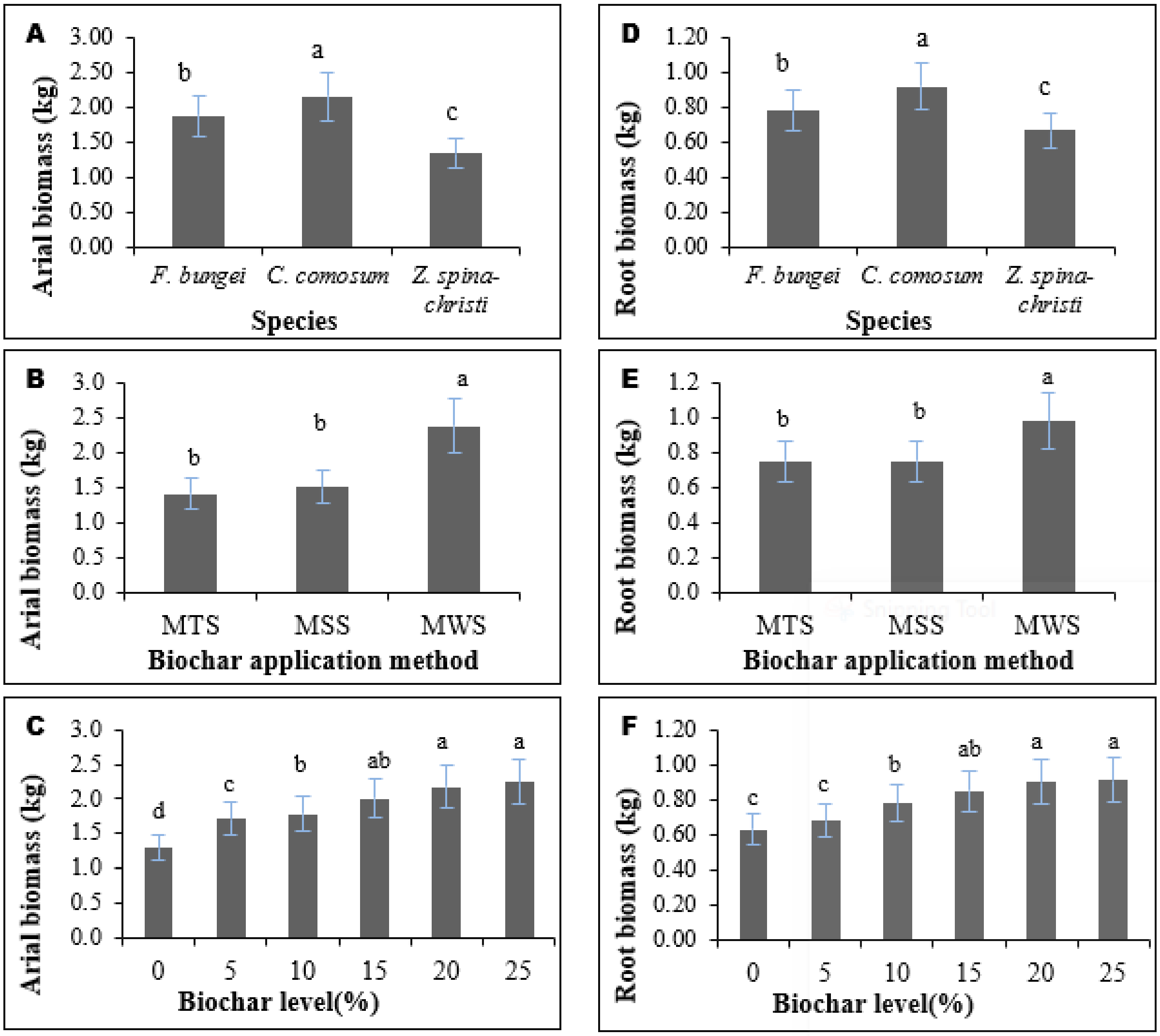

Figure 2

Aboveground and belowground biomass for the different species, biochar levels and biochar application methods.

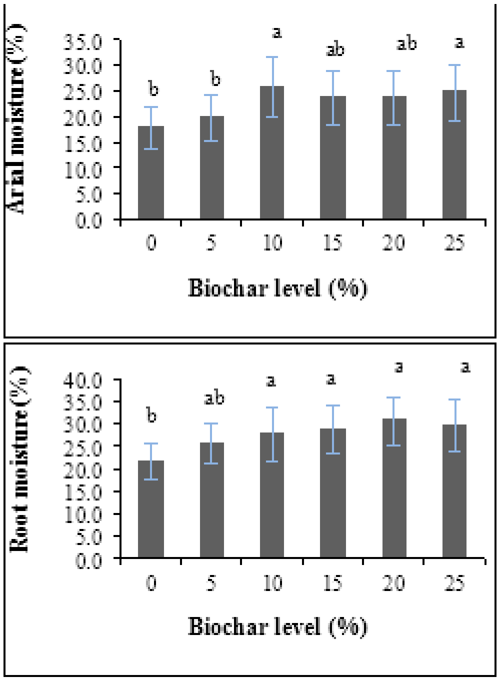

Figure 3

Moisture content in root and aerial parts of plant under different levels of biochar and

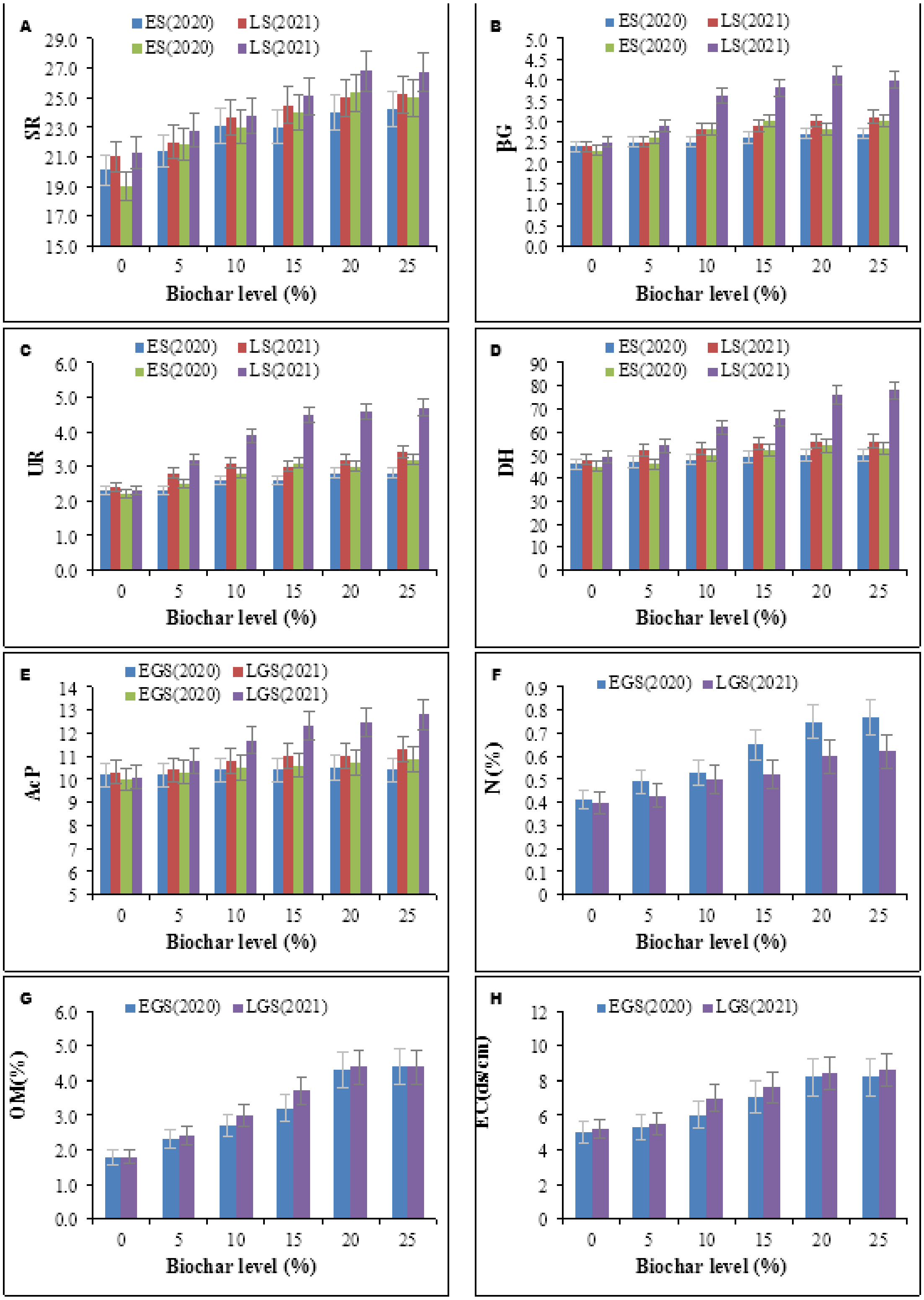

Figure 4

Soil respiration (A), urease (B), -glucosidase (C), dehydrogenase (D), and acid phosphatase (E) Soil organic matter(G), and electrical conductivity (H) under change under different levels of biochar in early spring (ES) and late spring (LS). EGS=early growing season, LGS=late growing season.

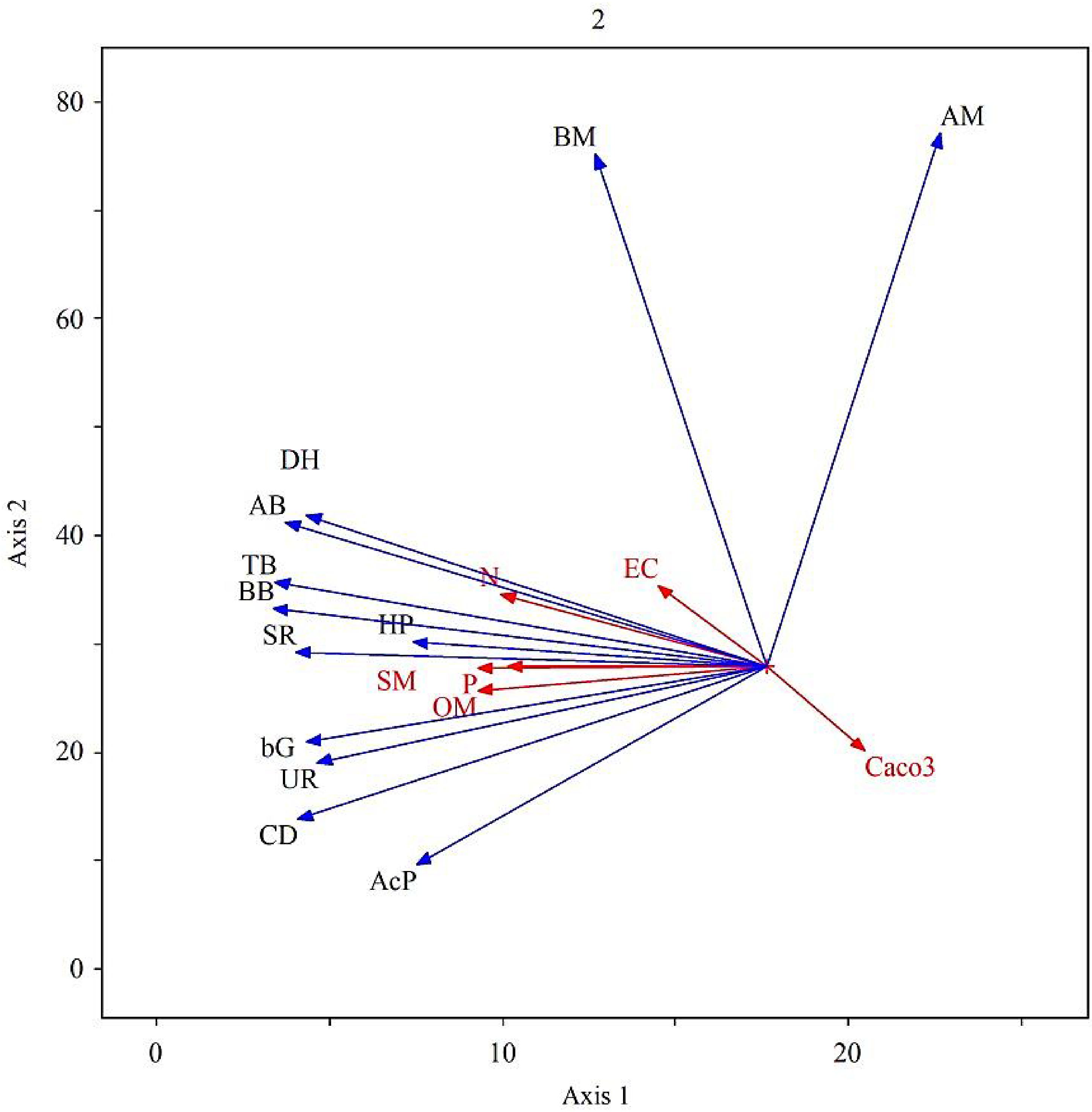

Figure 5

PCA diagram for the relationship between soil and vegetation characteristics
HP= height of plant, AB= aboveground biomass, BB=belowground biomass. TB= total biomass, CD=canopy diameter, AM= aboveground moisture, BM=belowground moisture, SR=soil respiration, UR= urease, G= -glucosidase, DH= dehydrogenase, AcP= acid phosphatase, SM= soil moisture, OM=organic matter, N=nitrogen, P=phosphorus, K=potassium, pH=acidity, EC=electrical conductivity.