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Different carbon sources optimizes soil temperature and improves soil water content in field grown spring wheat.

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Abstract: Water and nutrients shortage threatens agricultural sustainability in many arid and semiarid areas of the world. It is unknown whether improved water and nutrient conservation practices can be developed to alleviate this issue while increasing crop productivity. In this study, experimental work included the application of straw, biochar and N fertilizer. The straw and biochar were applied alone or combined with N fertilizer (0 and 100 kg N ha^{-1}). Application of biochar and straw in combination with N fertilizer caused a reduction in mean soil temperature by an average of 20.05% and 18.10% relative to soils without carbon. Biochar and straw– amended soils significantly ($P < 0.05$) increased soil moisture content by 11.04% and 13.68% compared to no carbon treatments. Statistically comparable temperatures and moisture were recorded for both straw and biochar treated plots. Both biochar and straw treated soils produced the lowest bulk density (0–5 cm) at 1.15 g cm^{-3}, and no carbon soils the highest at 1.20 g cm^{-3}. The improved soil quality translated into higher biomass in the biochar (1906 kg ha^{-1}) and biomass (1643 kg ha^{-1}) and soils without carbon the lowest at 1553 kg ha^{-1}. The improvement of soil moisture and the optimization of soil temperature for the two residue treated soils allow us to conclude that combined application of biochar and straw at the rate used in this study can be used as an effective farming model in alleviating water and nutrient shortage in semiarid environments.

Keywords: biochar; dryland; residue; nitrogen fertilizer; straw; wheat productivity

1. Introduction

Inadequate water and nutrient supplies limit crop yields in the western Loess Plateau of China. Rainfall availability and soil fertility depletion are the main factors influencing successful crop establishment and yield in the northwestern province of China [1, 2]. Cropping in the Loess Plateau is dependent on availability of rainfall, but this can be erratic and with high inter–annual variation [1]. Spring wheat is one of the dominant crops in this region, but its growth is restricted by the limited and erratic rainfall [3].Thus, yield of spring wheat in this region is far less than potential yield, ranging from 1500 to 3000 kg ha^{-1} [1]. The region is primarily used for crop production, but it is also severely affected by soil erosion and high evaporative losses, which therefore restrict productivity [4]. These effects have reduced soil resilience and therefore can have long–term implications for food security to the rural communities [5]. Farmers needs to manage water and nutrient resources wisely to ensure long-term agricultural sustainability and local food security. Optimizing soil temperature and increasing soil water content is a major goal for achieving sustainable spring wheat production, which will have a great impact at local and regional scale.

Responses to the harsh conditions include adequate fertilization programs and effective soil and water conservation techniques for semiarid environments. Some of these practices are being implemented in the NW of China [6] with satisfactory results in terms of improved rainfall–use efficiency. The adoption of sound soil management strategies such as, crop residues practices, biochar application and efficient N fertilization has been suggested to improve soil water and nutrients [9,10]. These strategies can be achieved by increased input of crop residues while minimizing C loses by erosion, decomposition and carbon emission. The incorporation of biochar into soil varies soil structure, porosity and bulk density [10]. According to [10] this may in turn have consequences for important soil functions such as soil water and nutrient retention and plant growth. Nitrogen fertilization impact on soil temperature and moisture by enhancing crop biomass production and stabilize microclimate in soil and thus impact soil productivity [11]. Soil application of organic materials couple with appropriate N fertilization could significantly improve soil microenvironments, thus increasing crop yields and resource use efficiency.

Based on many years of experimentation on the regulation mechanisms for soil temperature and moisture, we propose application of biochar and straw alone or integrated together with nitrogen fertilization in the spring wheat cropping system. This study hypothesized that increased C inputs alone or in combination with nitrogen fertilizer would raise the soils potential to optimize soil temperature, increase soil moisture content whiles increasing straw yield. In testing the hypothesis, we determined (ii) the change of soil temperature and soil moisture during key plant growth stages under the continuous spring wheat systems.

2. Materials and Methods

2.1 Experimental site

The study was conducted at the Dingxi Experimental Station (35°28′N, 104°44′E, elevation 1971–m above–sea–level) of the Gansu Agricultural University in Northwestern China. The research station is located in the semiarid Western Loess Plateau, which is characterized by step hills and deeply eroded gullies. This area has Aeolian soils of sandy–loam with low fertility, locally known as Huangmian soils [12]. This soil type has a sandy-loam texture and relatively low fertility with pH of ≈8.3, soil bulk density of 1.19g cm^{-3}, soil organic carbon (SOC) of 8.13 g kg^{-1} from 0-30 cm soil depth, and Olsen-P ≤13 mg kg^{-1}. Long–term (annual) rainfall records for Dingxi station show an average of 390.9 mm per year; annual evaporation was 1531 mm; aridity was 2.53. Annual cumulative temperatures >10°C are 2239.1°C and annual radiation was 5929 MJ m^{-2}, with 2476.6 h of sunshine. The climate is warm, sunny and moist during summer. In–crop season rainfall recorded at the site during the course of the experiment was 174.6, 252.5 and 239.4 mm in 2014, 2015 and 2016 respectively. Daily rainfall recorded during the course of the study is presented in Figure 1.
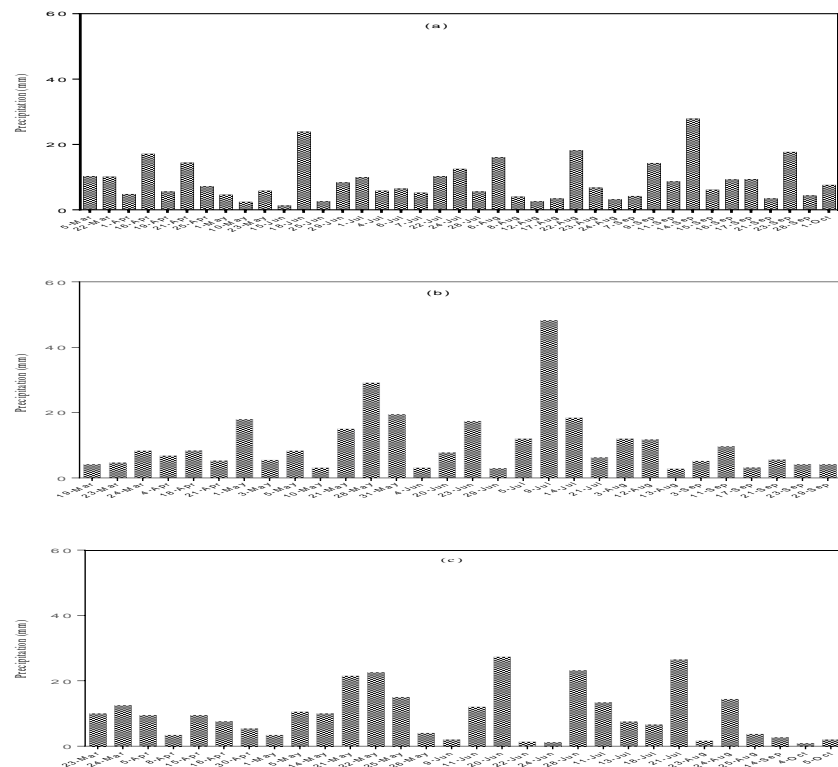
Figure 1: Daily rainfall records for the 2014 (a), 2015 (b) and 2016 (c) season

2.2 Experimental design and treatment description

The experiment involved addition of different carbon (C) sources; namely: biochar and straw, and N fertilizer in the form of urea (46% N) arranged in a randomized block design with 6 treatments and 3 replications. The treatments were: CN_0 – control (zero-amendment), CN_{100} – 100 kg ha^{-1} N applied each year, BN_0 – 15 t ha^{-1} biochar applied in a single dressing in 2014, BN_{100} – 15 t ha^{-1} biochar (single dressing in 2014) + 100 kg ha^{-1} N applied each year, SN_0 – 4.5 t ha^{-1} straw applied in 2014 and $SN100$ – 4.5 t ha^{-1} straw in 2014 + 100 kg ha^{-1} N applied each year. Biochar and straw were applied at the same quantity based on the straw returned to the soil. Biochar was incorporated into the soil using a rotary tillage implement to a depth of ≈10 cm. The biochar used in the experiment is a commercial milled charcoal sourced from a local supplier (Golden Future Agriculture Technology Co., Ltd, Liaoning, China). In straw–amended plots, the wheat straw from the previous crop was weighted and returned to the original plots immediately after threshing and spread evenly on the soil surface. The biochar and straw properties were, respectively, 0.43 and 0.38 g g^{-1} of total carbon, and 1.04 and 0.94 g kg^{-1} of total nitrogen. All the treatments received a blanket application of phosphorus (P) fertilizer, which was applied at 46 kg ha^{-1} P as ammonium dihydrogen phosphate (12% N, 52% P_2O_5) at sowing using a no–tillage seeder (depth: ≈20 cm). Spring wheat (*Triticum aestivum* L. cv. Dingxi 35) was sown continuously around the middle of March at a rate of 188 kg ha^{-1} seeds at 20-cm row spacing, and it was harvested each year between late July and early August. The plot's dimensions were 3–m by 6–m.

2.3 Determination of soil temperature

Soil temperature (Ts) at 5, 10, 15 cm were determined using a thermo–couple (JM624, Tianjin Jinming Instrument Co. Ltd., China) from each plot.

2.4 Determination of soil moisture

Soil moisture at the 0–5, 5–10 and 10–30 cm depth intervals was determined by taking a soil core of 5–cm in diameter, and subsequently drying the soil at 105°C for 24 h. Gravimetric water content at the three depth intervals was multiplied by soil bulk density (Blake and Harge, 1986) to obtain the volumetric water content, which is expressed in cm3 cm^{-3}. Soil samples for moisture were taken from inside the plots.

2.5 Determination of soil bulk density

Soil bulk density (BD) was determined by taking small cores, and by relating the oven–dried mass of soil to the volume of the core [13].

2.6 Carbon–to– nitrogen ratio

The carbon–to–nitrogen ratio (C/N) was calculated from the soil organic carbon (Table S1) and total nitrogen content (Table S2) determined.

2.7 Biomass yield

Plots were harvested by using hand sickles to a height of 5 cm aboveground and by discarding the outer edges (0.5-m) from each plot. Biomass yield was determined on a dry-weight basis by oven-drying the plant material at 105°C for 45 min and then to constant weight at 85°C.

2.8 Statistical analyses

Statistical analyses were undertaken with the Statistical Product Services Solution "22.0' (IBM Corporation, Chicago, IL, USA) with the treatment as the fixed effect and year as random effect. Differences between-treatments means were determined using Duncan's Multiple Range (Duncan, 1955). Significance was determined using a probability level of 5%

3. Results

3.1 Seasonal variations in soil temperature

Temperature changes for the upper 0–15 cm soil depth from the different treatments are given in Figure 2. Seasonal temperature increased with time after sowing, and produced a major peak on 21 June, 3 July and 20 July in 2014, 2015 and 2016 respectively. It declined after harvest in August of each year. Generally, higher soil temperatures were recorded during the cropping year 2014 (ranges between 12.74 to 25. 01°C, Figure 2a), followed by 2016 (ranges 11.80 to 24.30 ₒC, Figure 2c) and then 2015 (ranges 10.91 to 23.79°C, Figure 2b). Biochar and straw amended soils consistently had the lowest soil temperature in many instances during the sampling period, whereas no carbon treatment had the highest temperature during the measurement period in all depths. Significant differences ($P < 0.05$) were observed among treatments in some instances of measurement (Figure 2). During the sampling period, differences between straw and biochar treated plots were mostly not significant at $P < 0.05$. This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.
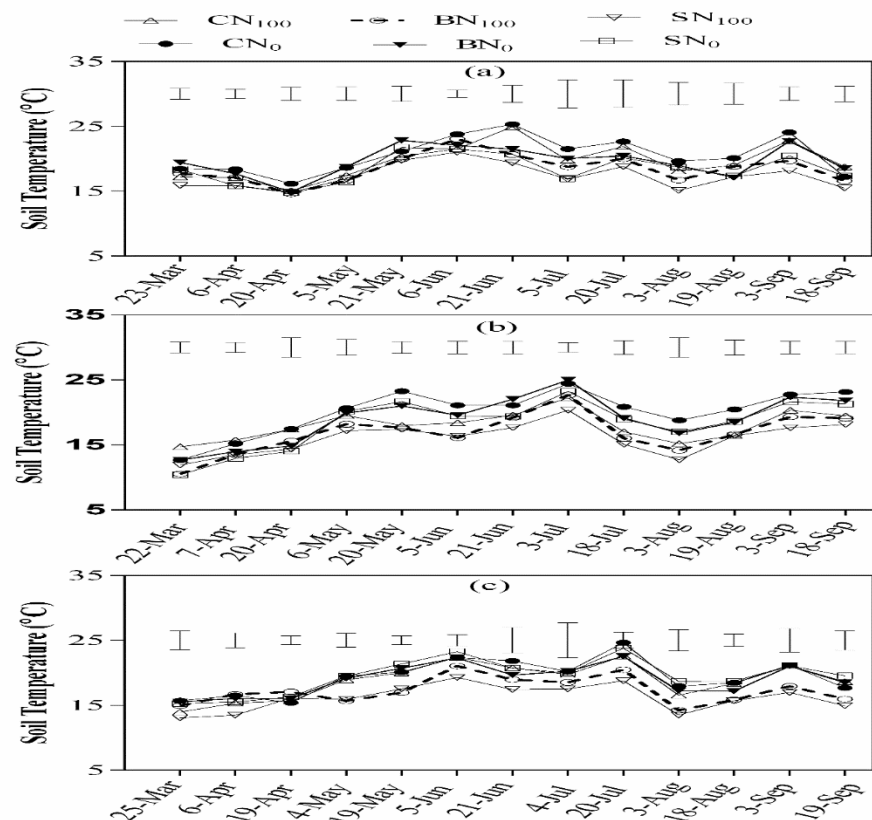
Figure 2:   Mean soil temperature at 5, 10, and 15 cm soil depth in 2014 (a), 2015 (b) and 2016 (c) as affected by carbon addition sources. The vertical bars represent the least significant difference (LSD) at P < 0.05 among treatments within a measurement date

3.2 Seasonal variations in soil moisture

The seasonal soil moisture trends over the study period are presented in Figure 3. Generally, the highest seasonal soil moisture values were recorded in straw and biochar treated plots. Lower seasonal soil moisture content was recorded in no carbon treated soils in each of the study year. On the whole, the highest seasonal soil moisture occurred on July 20 in 2014, July 18 in 2015 and June 21 in 2016.   The lowest seasonal soil moisture was recorded in March and April. Higher moisture contents were recorded during the cropping year 2015 (13.82–19.10 cm^3 cm^{-3}, Figure 3b), followed by 2016 (10.99–16.88 cm^3 cm^{-3}, Figure 3c) and then 2014 (7.28–13.51 cm3 cm^{-3}, Figure 3a). In 2014 and 2015, the soil moisture content peaked twice whiles a single peak was observed in 2016. The soil moisture differs significantly (P < 0.05) on certain occasions of measurements. During this period of measurement, straw and biochar treated soils mostly had higher soil moisture content whiles the lowest soil moisture content were recorded from the soils without carbon. Moreover, on many occasions the seasonal soil moisture did not differ (P < 0.05) between straw and biochar treated plots.
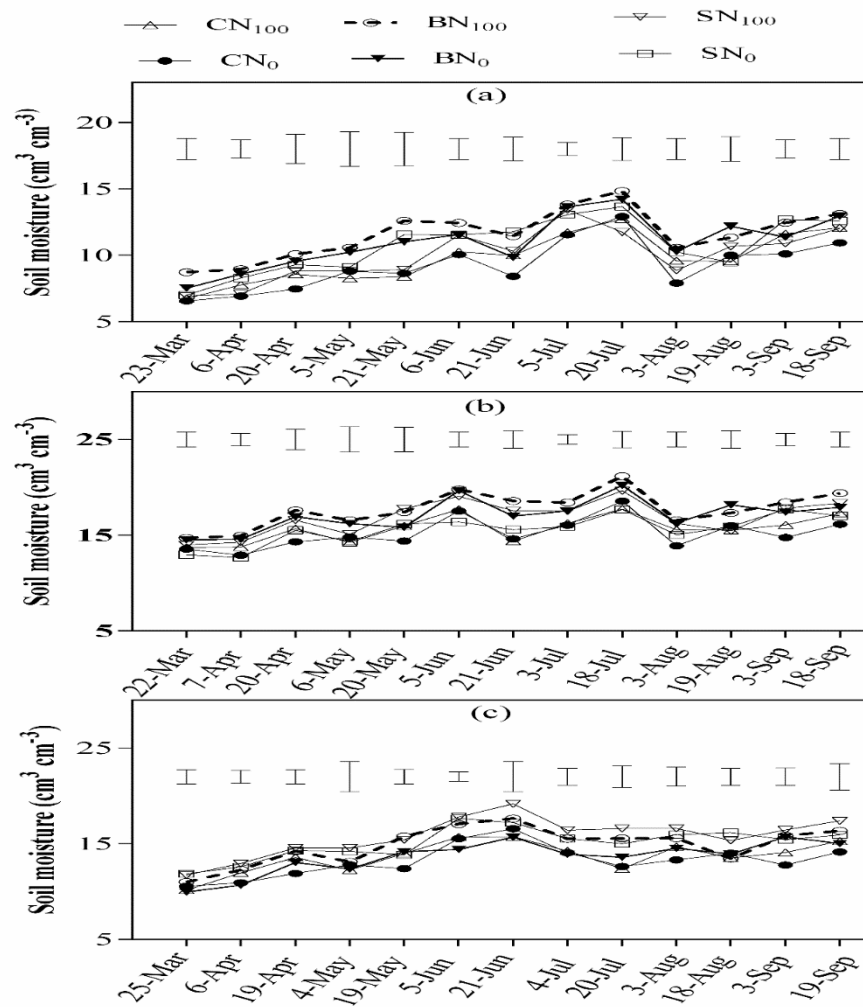
Figure 3:   Mean soil moisture content (cm cm– 3) at 0– 5, 5– 10, and 10– 30 cm soil depth in 2014 (a), 2015 (b) and 2016 (c) as affected by carbon addition sources. The vertical bars represent the least significant difference (LSD) at P < 0.05 among treatments within a measurement date.

3.3 Variations in mean soil temperature and moisture

Carbon, nitrogen and year had significant effect (P < 0.05) on mean soil temperature (Table 1) and significant interaction between carbon and year in affecting soil temperature in 0–5 and 5–10 cm was observed. Application of SN_{100} caused a reduction in mean soil temperature at the 0–5 cm soil depth compared to CN_0; an average increase of 21.03% was recorded (Table 2).   Statistically comparable temperatures were recorded for both straw and biochar treatments, whereas slightly increased temperatures (ranges from 6.65% to 8.12%) were recorded in the no carbon treatments. The lowest soil temperature recorded under the highest N fertilizer rates (N_{100}) was significant at P < 0.05 compared to their zero amended soil in most instances. The mean soil temperature had a decreasing trend with increasing in soil layer; this was consistent for all the years of this study.

Carbon and year independently had significant (P < 0.05) influence on soil moisture content in the layers reported here (Table 1), and their interactions were significant in affecting soil moisture content in all the layers studied. When compared to all treatments, the highest soil moisture contents were recorded in response to the biochar amended soils, followed by straw amended soils and the least soil moisture was noted in no carbon soils

(Table 3). The highest soil moisture content was observed in 5–10 cm under all treatments. Biochar and straw– amended soils significantly (P < 0.05) increased soil moisture content by 11.04% and 13.68% compared to no carbon treatments. Application of N_0 treatment had lower soil moisture contents in all treatments and depths.

Table 1: Analysis of variance for carbon and nitrogen fertilizer effects and their interaction

Source	Soil temperature (OC)			Soil moisture (cm3cm–3)		
	0–5	5–10	10–30	0–5	5–10	10–30
	……………………… (cm) ……………………………………………………					
Carbon (C)	21.22***	9.37***	8.69***	17.27***	15.45***	22.71***
Nitrogen (N)	35.31***	23.13***	14.85***	0.62 n.s.	14.47***	22.01***
Year (Y)	8.84***	77.68***	33.66***	43.93***	33.04***	15.40***
C x N	3.01*	0.62 n.s	0.68 n.s.	1.44 n.s.	0.77 n.s.	0.83 n.s.
C x Y	2.60*	2.69*	0.31 n.s.	6.89***	7.68***	4.90**
N x Y	0.57 n.s.	1.02 n.s.	0.54 n.s.	5.66**	2.50*	1.29 n.s.
Error	1.12	1.10	1.44	0.89	1.27	1.31

*, **, *** indicate significant difference at P < 0.05, P < 0.01, P < 0.001 respectively. n.s. indicate no significance difference at P < 0.05

Table 2: Soil temperature as affected by carbon addition sources

C source	Treatment Mineral N	Soil temperature (oC)											
		0–5				5–10				10–30			
		………………………………………… (cm)…………………………………..											
		2014	2015	2016	Mean	2014	2015	2016	Mean	2014	2015	2016	Mean
No carbon	N_0	23.98a	23.33ab	24.28a	23.86a	19.26a	16.68a	17.83a	17.93a	15.33ab	12.96a	14.78a	14.36a
	N_{100}	22.81abc	20.22abc	22.10bc	21.71abc	18.94a	15.69ab	15.53abc	16.72abc	14.54ab	11.40ab	14.07a	13.34ab
Biochar	N_0	21.61abc	22.91ab	22.54ab	22.35ab	17.79ab	15.41ab	15.66abc	16.29abc	15.13ab	12.03ab	13.53ab	13.56ab
	N_{100}	21.57abc	19.92abc	21.39bc	20.96abc	17.96ab	14.61ab	13.82c	15.46bc	13.50ab	10.70ab	12.86ab	12.35bc
Straw	N_0	22.92ab	21.95ab	20.59bc	21.82abc	18.78a	15.64ab	14.57bc	16.33abc	14.11ab	11.78ab	13.94a	13.28ab
	N_{100}	20.52bc	19.30bc	20.97bc	20.26bc	17.26ab	14.55ab	13.81c	15.20bc	12.89ab	10.19b	11.25b	11.44c

Values with different letters within a column are significantly different at P < 0.05

Table 3: Soil moisture content as affected by carbon addition sources

Treatment		Soil moisture (cm3cm–3)											
C source	Mineral N	0–5				5–10				10–30			
		-- (cm) ---											
		2014	2015	2016	Mean	2014	2015	2016	Mean	2014	2015	2016	Mean
No carbon	N_0	6.47b	8.97b	8.91c	8.11b	13.91b	14.11c	14.62c	14.21c	12.37b	13.21b	10.76b	12.11c
	N_{100}	7.29ab	11.41ab	11.07ab	9.93ab	13.89b	15.53bc	17.19ab	15.54abc	13.03ab	13.23b	13.33ab	13.19bc
Biochar	N_0	8.18ab	9.08b	8.92c	8.72ab	14.59ab	15.59bc	15.22c	15.13bc	12.73ab	13.52b	12.71ab	12.99bc
	N_{100}	8.91a	10.30ab	11.64a	10.28a	15.36ab	17.85ab	18.48a	17.23a	14.29ab	15.92ab	15.52a	15.24a
Straw	N_0	8.95a	8.81b	9.53bc	9.10ab	13.76b	16.55abc	17.23ab	15.84abc	14.34ab	14.48ab	13.68ab	14.17ab
	N_{100}	8.54a	9.19b	11.37ab	9.70ab	14.47ab	18.25ab	18.08a	16.94ab	13.59ab	16.29ab	16.29a	15.39a

Values with different letters within a column are significantly different at *P* < 0.05

3.4 Soil bulk density

Soil samples taken during the study period showed significant differences in the bulk density (BD) depending on the type of treatment and the depth of sampling (Table 4). Carbon, N fertilizer had significant effect on bulk density, although differences were not significant at P < 0.05 in some depths (Table 4). It was clear that the bulk density increased with soil depth in many cases irrespective of treatment over the experimental period. Significant differences between treatments were minor in the upper layer in 2014, but significant treatment effect was recorded in the 5–10 cm soil depth as the experimental period progressed from 2014 to 2016 (Table 5). The lowest averaged bulk density (1.14 g cm^{-3}) was found with biochar–amended soils, the highest with no carbon soils (1.21 g cm^{-3}) which represent a significant decrease of 6.14%. The results obtained with the straw–amended soil showed a similar trend, except that differences were not significant at P < 0.05 in most cases. Bulk densities of the straw–amended soil were not significantly different (P < 0.05) compared to biochar–amended soils.

Table 4: Analysis of variance for factors and their interaction

Source	Soil bulk density		C/N ratio		
	0–5	5–10	0–5	5–10	Stubble yield
Carbon (C)	11.10***	12.06***	9.30***	4.82*	83.80***
Nitrogen (N)	8.19**	0.77 n.s.	0.43 n.s.	0.19 n.s.	157.11***
Year (Y)	0.03 n.s.	5.43**	6.94**	3.19*	55.02***
C x N	0.98 n.s.	1.61 n.s.	0.40 n.s.	0.18 n.s.	3.12*
C x Y	0.10 n.s.	1.38 n.s.	1.90 n.s.	1.10 n.s.	0.37 n.s.
N x Y	0.70 n.s.	0.33 n.s.	0.49 n.s.	0.45 n.s.	2.53*
Error	0.003	0.005	1.302	1.785	28889.56

*, **, *** indicate significant difference at P < 0.05, P < 0.01, P < 0.001 respectively.
n.s. indicate no significance difference at P < 0.05.

Table 5: Soil bulk density as affected by carbon addition sources

Treatment		Soil BD (g cm^{-3})				
C source	Mineral N	0–5	5–10			
			………………………… (cm)………………………………………..			
		Mean	2014	2015	2016	Mean
No carbon	N_0	1.24a	1.32a	1.30ab	1.27a	1.29a
	N_{100}	1.20ab	1.20a	1.17cd	1.12c	1.16bc
Biochar	N_0	1.17bc	1.25a	1.25abc	1.24ab	1.25abc
	N_{100}	1.15bcd	1.21a	1.18bcd	1.17bc	1.19bc
Straw	N_0	1.21ab	1.22a	1.32a	1.23ab	1.25ab
	N_{100}	1.14cd	1.28a	1.18cd	1.16bc	1.21abc

Values with different letters within a column are significantly different at   P < 0.05

3.5 Carbon–to–nitrogen ratio

Table 4 shows the treatment effect and their interaction on carbon–to–nitrogen ratio (C/N) of the soil. Carbon and year had effect on C/N ratio thought not significant at P < 0.05 in 10–30 cm. The interaction between the treatment factors recorded no significant effect on C/N ratio in all layers studied here. Regardless of year, biochar treatment exhibited a higher C/N ratio than straw and no carbon soils (Table 6). These differences were not significant in most of the layers. Application of BN50 significantly increased C/N ratio at 0–5 cm by 12.48%, 13.47% and 12.53% compared to CN$_0$, CN$_{50}$ and CN$_{100}$ respectively (Table 6). Similar results were observed in 5–10 cm. The biochar treated soils showed higher C/N ratio compared to straw treated soils, but the difference were not always significant. Significant differences (P < 0.05) were not found between straw and no carbon treated soils in all layers studied.

Table 6: Carbon–to–nitrogen ratio of various carbon addition sources

Treatment		C/N ratio							
C source	Mineral N	0–5				5–10			
		-- (cm) --------------------------							
		2014	2015	2016	Mean	2014	2015	2016	Mean
No carbon	N_0	11.31a	11.21a	11.10b	11.21bc	11.22a	11.11a	10.65c	10.99a
	N_{100}	11.00a	11.59a	11.08b	11.22bc	10.70a	10.94a	11.16c	10.93a
Biochar	N_0	12.18a	11.17a	13.89a	12.41abc	12.02a	10.37a	12.72ab	11.70a
	N_{100}	11.63a	12.35a	13.09a	12.35abc	10.89a	12.28a	12.95ab	12.04a
Straw	N_0	11.46a	11.14a	11.53b	11.37abc	11.12a	10.35a	11.75bc	11.09a
	N_{100}	11.48a	11.03a	13.32a	10.97abc	11.47a	10.77a	11.41abc	11.42a

Values with different letters within a column are significantly different at P < 0.05

3.6 Stubble yield

There was significant interaction between carbon and nitrogen, and nitrogen and year affecting stubble yield at P < 0.05 (Table 4). In addition, carbon, nitrogen and year individually had significant effect on stubble yield. Application of N_{100} treatments on biochar treated soils (BN_{100}) consistently increased stubble yield by 38.76% in 2014, 37.16% in 2015 and 29.96% in 2016 on average compared to soils without carbon (Table 7). Similarly, BN100 significantly increased stubble yield in 2014 (by 35.36% and 26.09%), 2015 (by 39.76% and 22.97%) and 2016 (by 21.49% and 12.57%) compared to SN0 and SN_{50} respectively (Table 7). At a lesser magnitude, the use of N fertilizer at a rate of 100 kg ha–1 on soils without carbon boosted stubble yield by 22.44%, 23.40% and 33.08% in 2014, 2015 and 2016 relative to soils without N fertilizer. Application of SN100 also caused significant increases in stubble yield compared to no carbon soils, an average increase of 32.00%, 28.72% and 32.01% were recorded in 2014, 2015 and 2016 respectively (Table 8). On average, biochar amended soils produced the greatest stubble yield, followed by straw treated soils and the least in no carbon soils.

| Treatment | | Stubble yield (kg ha–1) | | | |
| C source | Mineral N | | | | |
		2014	2015	2016	Mean
No carbon	N_0	2776d	3030d	2455d	2754c
	N_{100}	3399bc	3739b	3267bc	3468b
Biochar	N_0	3295bc	3530bc	3147bc	3324b
	N_{100}	4291a	4630a	3788a	4236a
Straw	N_0	3170bc	3312cd	3118bc	3200bc
	N_{100}	4082a	4345a	3633a	4020b

4. Discussion

Discussion

According to [16] soil temperature and moisture content, particularly in the 0–30 cm depth interval is important for crop production in dry areas. In the present study, the use of biochar and straw combined with N–fertilizer was shown to increase soil moisture and reduce soil temperature, particularly in the topsoil (0–30 cm depth range). But biochar combined with N–fertilizer had the greatest effect. Application of biochar has been reported to increase volumetric water content in soil, improve soil water retention and increase water infiltration [10, 17]. Application of biochar could therefore be used to store more rainfall in soil and increase rainfall use efficiency in dryland areas. Increased soil water holding capacity that follows biochar addition is explained by increased total porosity in soil and specific surface area [18]. Soil moisture under biochar and straw combined with N–fertilizer was lost slowly and the available water was maintained for a longer period of time that is available for crop plants. The increased soil moisture with biochar and straw covering can partly offset the water deficit in intensified cropping systems and this can be an ideal practice for empowering the capacity of soil water conservation in this extremely semi-arid environment.

Studies have shown that there is a close relationship between soil temperature and soil moisture, because soil moisture can directly affect the transmission of heat on the soil surface. In turn, soil temperature can affect soil evaporation (E) and evapotranspiration (ET). Among the water conservation approaches evaluated in this study, biochar and straw combined with N–fertilizer was most effective in reducing soil temperature, which may be related to the increased soil water content under different treatments that affected the soil thermal conductivity. Previous studies have demonstrated that each individual farming practice has its own effect on crop productivity, but integrated application of proven farming practices can enable the increase of crop yields and optimize resource use efficiency [19]. Crop residues on the soil surface typically form a barrier against evaporation, thus, maintaining the water storage in the plant root zone [20]. The findings of the present study clearly demonstrate that biochar and straw combined with N–fertilizer can significantly decrease evaporation and evapotranspiration during the entire growing season compared to soils without carbon treatment. It suggests that the biochar and straw combined with N fertilization can be used to harvest more rainwater in rainfed areas or reduce the amount of irrigation in irrigation areas.

Treatment effects on soil bulk density, although small, suggested that there is potential for greater long–term impacts. The reduction effect of the treatments on soil bulk density was greater on biochar treated soils than the other treatments. The organic matter addition could cause increases in the total soil volume and decreases in the values of soil bulk density. In support, the current study showed significant increase in crop biomass when biochar was applied. [21] found that application of biochar combined with inorganic fertilizer significantly decreased bulk density. The decrease of bulk density with the addition of biochar and to a lesser extent on straw amended soils may be associated with the increase of soil aggregation and macro porosity. This study did not evaluate soil aggregate; however the data of soil bulk density allows us to draw such conclusion.

The greatest spring wheat biomass productivity was recorded on biochar treated soils and the lowest on soils without carbon treatment. Improved biomass yield in the current study could be attributed to increased nutrient availability through enhanced soil quality. Biochar amendments have previously been shown to increase crop productivity by improving soil quality [22]. Nitrogen fertilizer and biochar applied together increased wheat biomass and grain yield [23], reflecting the potential of biochar to improve the efficiency with which plants use N–fertilizer. The higher biomass yield obtained on the straw amended soils compared to the soils without carbon in this study is attributed to the fact that in drier soils surface crop residues provided a better soil environment by reducing the temperature, conserving water, and improving soil quality resulting in better growth and hence yield [24]. The lowest yield recorded on the no carbon soils throughout this study may be related to the removal of all the aboveground biomass at the end of the cropping season. [25] showed that field practices with low carbon inputs deplete soil organic carbon and reduces crop productivity. Furthermore, the relative lower biomass found in the no carbon treated soils could be attributed to the effect of the C/N ratio in driving down the soluble N pool.

The C/N ratios within this study vary between 10.24 (no carbon) and 14.01 (biochar soils). Similar to other studies [25], the highest C/N ratios were found in biochar treated soils, followed by straw treated soils. This increase in C/N ratio could be explained by the increased availability of C and N in the soil (26) and the slower rate of decomposition [26] and thus low carbon loss. This result demonstrate that the incorporation of biochar combined with N fertilizer in calcerous soils could result in slower rate of decomposition as C/N ratio influences microbial population and activity and consequently increase reduce carbon emission in semi–arid rainfed areas.

5. Conclusions

This study demonstrates that application of biochar improved soil conditions; decreased soil bulk density and temperature and increased soil moisture to significantly

greater extent than the other treatments tested. Improved soil quality in biochar amended soils translated into higher biomass production in that treatment. The results of this study show the positive effects of organic matter addition to improve soil quality. The results of this study emphasize the promising potential of biochar application in rainfed spring wheat farming to improved soil quality and increased crop productivity in the semiarid Loess Plateau of China.

Conflicts of Interest: "The authors declare no conflict of interest." "The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results".

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