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Biochar Integration with Legume Crops in Summer Gape Synergizes Nitrogen Use Efficiency and Enhance Maize Yield

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Abstract: Besides carbon (C) sequestration, biochar (BC) is recently believed to deliver multiple eco-friendly benefits to the soil for enhancing crop productivity. Use of mineral fertilizers coupled with BC been suggested a promising sustainable strategy for increasing crops yield. However, imperative study is needed to investigate (1) BC integration with multiple legumes crop adjusted in summer gape for pooling more organic carbon and nitrogen, and (2) subsequently looking into its synergism with mineral N in the following crop. Therefore, two years' field experiments were conducted on maize under cereal based cropping pattern with the adjustment of legumes (i.e., mungbean, cowpea, and Sesbania) with a fallow in summer. In legumes, treatments consist of (0 and 50 t ha^{-1}) BC application. However, N rates of 0, 90, 120, 150 kg ha^{-1} were added to the subsequent maize crop. Preceding legumes plots with the use of 50 t ha^{-1} biochar enhanced maize grain yield, above ground biomass, stover N, grain N, soil C, and N content after maize harvest and N use efficiency as compared to non-legumes with BC and legumes without BC plots. N application increased grain yield, above-ground biomass, stover N, grain N, and soil N but reduced N use efficiency with higher rates. Conclusively, the integration of biochar and legumes is a promising option for increasing the entire farm production of cereal-based cropping systems. This increment in yield was associated with supplying a viable input of N and C to soil and increased yields from this supplementary 'summer gap' crop.

Keywords: chemical fertilizer; soil carbon; soil nitrogen; grain yield; cereal based cropping pattern

1. Introduction

Recently, to overcome the food demand of the world's growing population, the use of nitrogen (N) fertilizer cannot be ignored [1]. While its overuse can pollute the environment by nutrients leaching, runoff, and volatilization (greenhouse gas emission) [2]. Therefore, the use of biochar in a low fertile soil is a useful technique to improve soil carbon, soil health [3], and its crop productivity [4]. Biochar is a carbonaceous compound with is produced from the thermal decomposition of plants residues and organic wastes [5]. Biochar solicitation has attained an increasingly interest to reclaim nutrients poor soils [5]. Use of biochar can improve plants growth by enhancing nutrients availability, enhance microbial activity, water nutrient holding capacity, and increased bulk density [5–7]. The application and management of biochar and climatic factors greatly influence soil physiochemical properties due to slow decomposition rates and prolongs soils fertility [8]. In addition, biochar is highly recalcitrant to microbial decomposition and ensures a long term benefit for soil fertility [8]. Integration of biochar with synthetic fertilizers can improve yield of the crops in the highly weathered or degraded soils [8–10]. Since accumulation of biochar to soil implicates several N pools, further studies are required to explain the gross N restriction and release rates [11]. Biochar obtained from maize crop under 350 °C or 550 °C with a C: N ratio of 43 and 49 was used at the rate of 10 g kg^{-1} to sandy loam soil. This promoted mineralization of the most undecomposed fractions probably due to the priming effects of biochar [12,13]. Biochar produced through low temperature ultimately increased soil pH and also augmented soil turnover of soil microbes. This coincides with the results of Schomberg at al. [14,15].

Soil fertility as well as crop productivity significantly improved with the application of synthetic N fertilizers [16]. Maize grain and biological yield was enhanced by 43–68% and 25–42% respectively [17]. Soil residual N was also improved by 18–34% [18]. Residue alone or mixed with N fertilizer have synergistic effects on plant development and productivity as well as soil bulk density, pH, and water-nutrient holding capacity [19]. Higher total N in soil could be achieved by the synergistic effects of N with crop residues or farm yard manures. N is one of the essential plant nutrients and its adequate quantity in plants' tissues is necessary for healthy plant growth and development [20]. The structure and function of the agro-ecosystem is largely stimulated by legumes. [21]. Legumes, as a preceding crop, can enhance the quality and quantity of many crops in the current cropping system [22]. Legumes are the major source of mineral, vitamins, and proteins for human and livestock as well as improves by converting atmospheric N into plant available form through symbiosis. Addition of legumes in cropping system is a possible solution for reducing reliance on synthetic N. Use of legumes can shrink the dependence on chemical N fertilizers and to adopt the use of restorative crops for the sufficient supply for N to the crops. For sustainable agriculture, legumes in cropping pattern are more appropriate than exhaustive and chemical-based system. Less work has been done to compare the significance of biochar and legumes in summer gap for enhancing the N use efficiency, productivity, and profitability in cereals based cropping system. Hence, a comprehensive study was undertaken to investigate the effects of biochar with legumes crops in summer gap synergizing N use efficiency maize yield grown under a cereal-based cropping system.

2. Materials and Methods

2.1. Location and Cropping History of Experimental Area

The experiments were conducted at research farm at the University of Agriculture Peshawar, Khyber Pakhtunkhwa Pakistan during 2011–2013. The agriculture experimental farm is located at 34.01° N latitude, 71.35° E longitude, at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km North of the Indian Ocean and has continental type of climate. The research farm is irrigated by Warsak canal from river Kabul. Soil is clay loam, low in organic matter (0.87%), phosphorus (6.57 mg kg^{-1}), potassium (121 mg kg^{-1}); alkaline (pH 8.2); and with calcareous nature [19]. The air temperature and precipitation data is collected from meteorological station and is presented in Figure 1. Before maize crop summer legume crops were grown in the gap after wheat harvest till sowing of maize for fodder, green manure, and seed purposes.

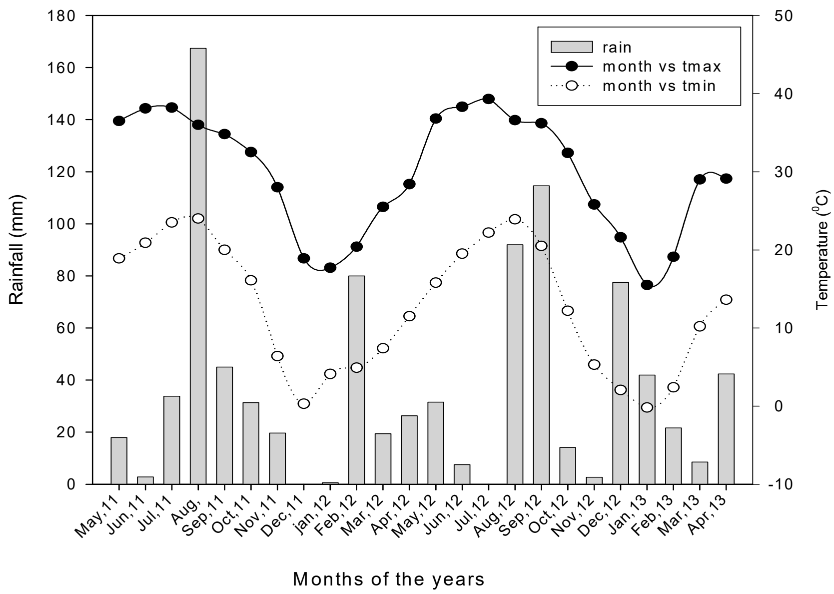

Figure 1. Mean monthly precipitation and air temperature during May 2011 to April 2013.

2.2. General Experimental Details

Cropping pattern of wheat followed by legumes and then maize was implemented for the current experiment. The seedbed is prepared by ploughing the field with cultivator followed by rotavator at field capacity and leveled for each crop. The legume crops were sown in the mid gap between wheat and maize. Legumes likewise cowpea was used for fodder purpose; mungbean for grains and Sesbania was sown for green manure purpose. A fallow plot was included in the experiment as control. Biochar at the rate of 0 and 50 t ha^{-1} were used in the experiment. Maize crop was fertilized with four N levels (0, 90, 120, and 150 kg ha^{-1}. After harvesting wheat crop, legumes with 0 and 50 t ha^{-1} of biochar were sown manually by hand in the first week of May. All the agronomic practices—i.e., hoeing, weeding, pesticide application, etc.—were kept constant for all legumes. The seeds of all legumes were properly inoculated with appropriate inoculum in order to maximize nodule formation. Prior to maize plantation, the biomass of Sesbania was properly incorporated into the soil.

2.3. Experimental Design and Agronomic Practices

Randomized complete block design having three replications and plot size of 5 × 16 m was used for legumes. Similarly, the plots of previous legume experiment were split into four sub plots to adjust four rates of N for maize experiment. The sub plot size for maize was 5 × 4 m^2. The soil was prepared for maize by disc plough followed by rotavator for making fine seed bed without disturbing the demarcation of legumes experimental plots. Maize was sown by drill in the mid July with four levels of N. The same experiments were repeated on the same plots without disturbing the demarcation of each sub plot for two years (2011–2012 and 2012–2013). At first irrigation cypermethrin was added along with irrigation water to make the seedsafe from soil insects and pests. For weed control chemical herbicide atrazine was applied after 30 days of sowing. The crop was harvested when the husk leaves become yellow in color and the grain moisture content is less than 20%.

2.4. Characteristics and Method of Biochar Preparation

In this experiment biochar was produced using traditional on-farm method that is common for small scale formation of charcoal in Pakistan. Wood of Acacia spp. For 3–4 h at 300–500 °C was burnt in low supply of oxygen and grinds to a form a course powder. The pH (6.84 ± 0.02) and EC (3040 ± 101 µS cm^{-1}) were determined in 1:1 w/v biochar-to-distilled water samples with standard electrodes. Similarly, it had 40% C, 2.25% N, 0.14% P, 2052 mg kg^{-1} K, 450 mg kg^{-1} Na, 2.24% Ca, and 0.92% Mg.

2.5. Determination of N and C Content in Soil and Plant Samples

Soil, grain, and stover samples of maize crop were analyzed for N content following by Kjeldahl method of Bremner et al. [23]. For determination of organic C Soil samples were collected at the depth of 0–15 cm from each treatment Walkley and Black [24]. N uptake by crops and N use efficiency were determined by the method described by Sharma and Behera 2009 [25].

$$N\ Use\ Efficiency = Grain\ yield \div N\ uptake \times N\ supplied$$

2.6. Dry Matter and Grain Yield of Maize

Data regarding dry matter and grain yield of maize was recorded by harvesting three central rows in each sub plot. Sun-dried samples were threshed and weight with balance and then converted into kg ha^{-1} for the determination of above ground biomass and grain yield of maize.

2.7. Statistical Analysis

Analysis of variance (ANOVA) was used to analyze the data by using RCBD with split plot arrangement for maize and wheat experiments using SPSS software (SPSS, Inc., Chicago, IL, USA). The treatment means were compared at $p < 0.05$ level of probability using LSD test [26]. The figures were plotted by origin pro software.

3. Results

3.1. Soil Properties

3.1.1. Soil C after Maize Harvest (g kg^{-1})

Data regarding soil C after maize harvest are presented in Table 1. Biochar application significantly affected soil C after maize harvest (Figure 2). However, the effect of legumes and N rates and years (1&2) as source of variation were not significant. All the interactions were significantly affected soil C after maize harvest except BC × N. The application of biochar improved soil C after maize harvest. Biochar application at the rate of 50 t ha^{-1} resulted in 1.44 g kg^{-1} higher soil C as compared to no biochar plots. The use of N at 90 kg N kg^{-1} resulted in greater 0.83 g kg^{-1} soil organic carbon (SOC) compared with 150 kg N ha^{-1}. Plots grown with Sesbania had higher (1.13 g kg^{-1}) SOC content compared with cowpea grown plots. Furthermore, the year 2012–2013 produced 0.14 g kg^{-1} of SOC than that of 2011–2012, respectively. During 2011–2012 and 2012–2013, the BC × L interaction indicated that the plots previously sown with Sesbania mixed in combination with biochar showed more 9.45 and 7.94 g kg^{-1} soil C. L × N interaction revealed that 9.4 and 8.74 g kg^{-1} higher soil C was noted in plots aggregated with Sesbania and 90 kg N ha^{-1}. While, during 2011–2012, and 2012–2013, the B × N interaction showed 7.53 and 6.89 g kg^{-1} of higher soil C in plots fertilized with 120 kg N ha^{-1} integrated with biochar.

Table 1. Effect of biochar, legumes, and nitrogen rates on soil organic carbon carbon (g·kg^{-1}) after maize harvest.

Biochar (BC) (ton ha^{-1})	**Legumes (L)**	**Nitrogen (N) (kg ha^{-1})**				
		0	**90**	**120**	**150**	**Mean**
0	Cowpea	8.61	7.18	8.22	7.81	7.96
0	Mungbean	7.75	8.57	7.55	7.03	7.73
0	Sesbania	5.34	9.91	7.99	6.85	7.52
0	Fallow	7.13	9.56	7.68	7.15	7.38
50	Cowpea	9.24	6.44	7.99	7.73	7.85
50	Mungbean	8.52	8.98	8.72	8.05	8.59
50	Sesbania	10.04	9.81	11.63	10.68	10.54
50	Fallow	8.99	10.06	10.08	8.49	9.41
			BC × N			Mean
0		7.21	8.80	7.36	7.21	7.65 b
50		9.20	8.82	9.61	8.74	9.09 a
			L × N			Mean
	Cowpea	8.93	7.81	8.11	7.77	7.90
	Mungbean	8.13	8.77	8.14	7.54	8.15
	Sesbania	7.69	9.86	9.81	8.77	9.03
	Fallow	8.06	8.81	7.88	7.82	8.39
		8.20	8.81	8.48	7.98	
	Year	Year 1	Year 2			
		8.95	9.09			
Main effects		$LSD_{(0.05)}$		Interactions	Significance level	
Year		ns		BC × L	*	
Biochar (BC)		*		L × N	*	
Legumes (L)		ns		BC × N	ns	
Nitrogen (N)		ns		BC × L × N	*	

Means of the same category followed by different letters are significantly different from each other at 5% level of probability. * = Significant at 5% level of probability. ns = Non-significant. LSD, Least Significance difference.

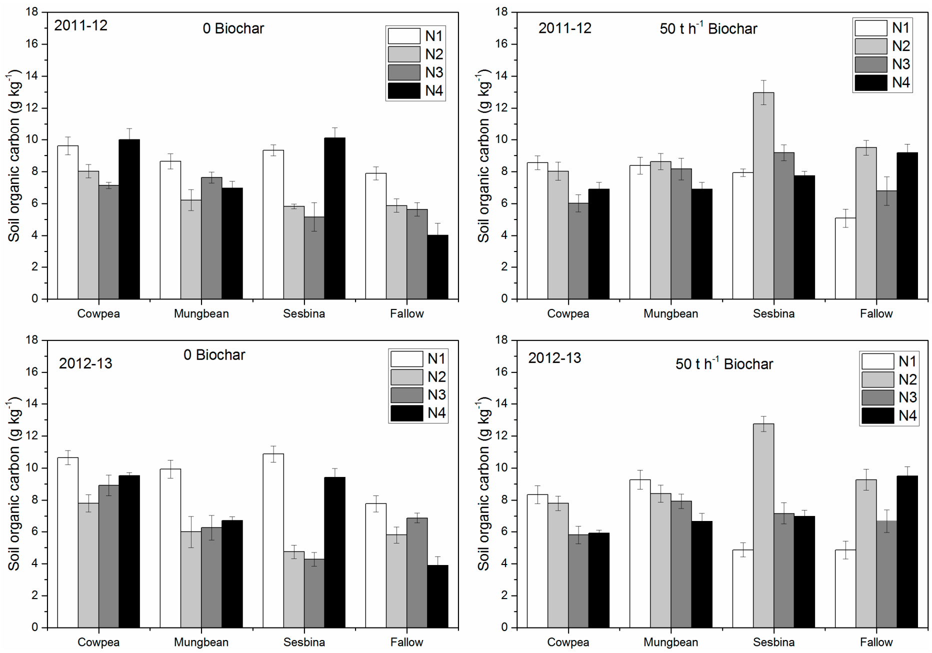

Figure 2. Changes in soil organic carbon (SOC) (g kg^{-1}) under different nitrogen (N) fertilizer, biochar and legumes after maize harvest during 2011–2012, and 2012–2013.

3.1.2. Soil N after Maize Harvest (g kg^{-1})

Data concerning soil N after maize harvest are presented in Table 2. Analysis of data showed that legumes and biochar significantly affected soil N after maize harvest (Figure 3). Likewise, nitrogen rates and year as source of variation showed significant difference for soil N (Figure 3). All interactions significantly affected soil N after maize harvest. Legumes as a preceding crop increased soil N by 15.3% over fallow as control. The plots previously sown with mungbean increased soil N by 0.15 g kg^{-1} followed by cowpea 0.10 g kg^{-1} or Sesbania 0.10 g kg^{-1} compared with that of fallow. The application of biochar enhanced 8.33% of soil N content after maize harvest. Application of 50 t biochar ha^{-1} resulted 0.08 g kg^{-1} higher soil N compared to no biochar plot. The application of N at150 kg N ha^{-1} had higher (0.07 gkg^{-1}) soil N followed by 120 (0.04 g kg^{-1}) and 90 kg N ha^{-1} (0.04 g kg^{-1}) compared with that of soil N in control plots. During 2011–2012 and 2012–2013, the BC × L interaction showed that cultivation of cowpea mixed with biochar showed 1.06 and 1.25 g kg^{-1} maximum soil N. Over 2011–2012 and 2012–2013, L × N interaction showed 1.0 and 1.1 g kg^{-1} higher soil N in plots aggregated with Sesbania and 150 kg N ha^{-1}. Soil N in biochar and their interaction with mineral N was higher than in control treatments indicating that remaining legumes and biochar maintained the N levels of the soil, [27] reported a considerable enhancement in the nutrient content of the soil after the harvest of sorghum due to the application of 50 t ha^{-1} of biochar. The interaction of BC × N showed maximum soil N in control plots integrated with biochar. The BC × L × N interaction showed higher soil N in control plots incorporated with cowpea and biochar.

Table 2. Effect of biochar, legumes, and N rates on soil N (g kg^{-1}) after maize harvest

Biochar (BC) (ton ha^{-1})	**Legumes (L)**	**Nitrogen (N) (kg ha^{-1})**				
		0	**90**	**120**	**150**	**Mean**
0	Cowpea	0.41	0.97	0.84	0.92	0.79
0	Mungbean	0.88	0.92	1.14	1.32	1.06
0	Sesbania	1.13	0.71	0.77	0.91	0.88
0	Fallow	0.63	0.98	0.84	0.68	0.78
50	Cowpea	1.35	0.79	1.16	1.01	1.08
50	Mungbean	0.95	1.14	0.80	0.67	0.89
50	Sesbania	0.77	0.97	1.00	1.18	0.98
50	Fallow	0.91	0.86	0.79	0.93	0.87
			BC × N			Mean
0		0.76	0.90	0.90	0.96	0.88 b
50		1.00	0.94	0.94	0.95	0.96 a
			L × N			Mean
	Cowpea	0.88	0.88	1.00	0.96	0.93 a
	Mungbean	0.91	1.03	0.97	1.00	0.98 a
	Sesbania	0.95	0.84	0.88	1.05	0.93 ab
	Fallow	0.77	0.92	0.82	0.80	0.83 b
		0.88 b	0.92 ab	0.92 ab	0.95 a	
	Year	Year 1	Year 2			
		0.86 b	0.97 a			
Main effects		LSD$_{(0.05)}$		Interactions	Significance level	
Year		*		BC × L	*	
Biochar (BC)		*		L × N	*	
Legumes (L)		0.074		BC × N	*	
Nitrogen (N)		0.053		BC × L × N	*	

Means of the same category followed by different letters are significantly different from each other at 5% level of probability. * = significant at 5% level of probability. ns = non-significant.

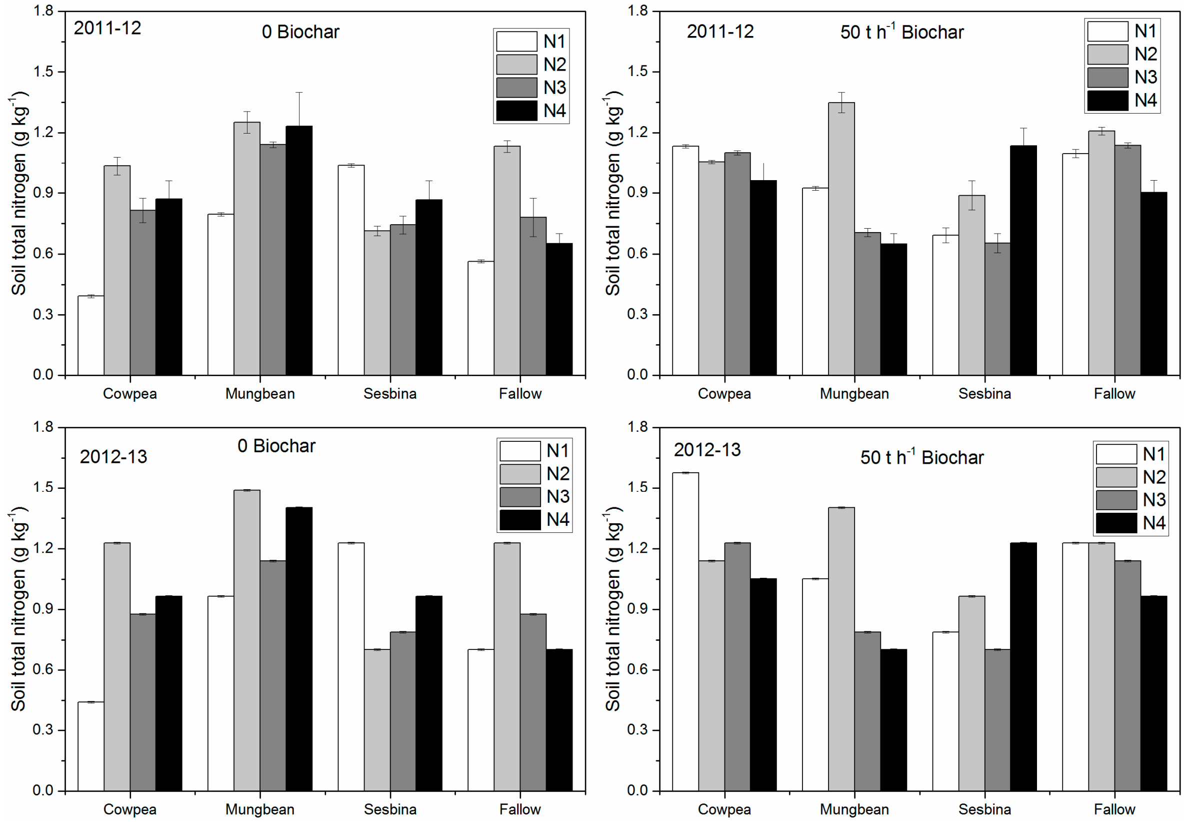

Figure 3. Soil total N content (g kg^{-1}) under different N fertilizer, biochar and legumes after maize harvest in 2011–2012 and 2012–2013.

3.2. Maize N Content

3.2.1. Stover N in Maize (g kg^{-1})

Legumes, biochar and nitrogen application significantly ($p < 0.05$) affected stover N in maize (Table 3 and Figure 4). However, year as source of variation did not significantly affect stover N. All interactions were found non-significant except BC × L. The plots previously sown with cowpea increased 32.4% stover N followed by Sesbania and mungbean (4.8%) as compared to fallow plots. The application of biochar also increased 20.7% stover N in maize and higher stover N 1.13 g kg^{-1} was recorded in plots applied with 50 tons biochar ha^{-1} compared to no biochar treated plots. Likewise, stover N in maize improved 23.6% with increasing level of nitrogen. N 1.32 g kg^{-1} of higher stover was recorded in plots when the crop was given fertilizer N at the rate of 150 kg ha^{-1} compared with the stover N in control plots. The BC × L interaction indicated that cultivation of cowpea mixed with biochar showed higher stover N. During 2011–2012 and 2012–2013, the L × N interaction showed 6.72 and 7.05 g kg^{-1} of higher stover N in plots aggregated with cowpea and 150 kg N ha^{-1}. While, The BC × N interaction revealed that 6.02 and 6.05 g kg^{-1} maximum stover N was measured in plots fertilized with 120 kg N ha^{-1} with biochar application. The BC × L × N interaction exhibited that maximum stover N was recorded in plots fertilized with 150 kg N ha^{-1} where cowpea was formerly mixed with biochar incorporation.

Table 3. Effect of biochar, legumes, and N rates on stover N (g kg^{-1}) of maize

Biochar (BC) (ton ha^{-1})	**Legumes (L)**	**Nitrogen (N) (kg ha^{-1})**				
		0	**90**	**120**	**150**	**Mean**
0	Cowpea	4.45	5.02	3.56	5.51	4.63
0	Mungbean	3.66	3.83	4.72	5.45	4.42
0	Sesbania	3.40	4.53	5.66	5.77	4.84
0	Fallow	0.92	3.56	3.67	5.28	3.36
50	Cowpea	6.22	5.66	6.04	6.89	6.20
50	Mungbean	5.52	6.44	5.45	6.21	5.91
50	Sesbania	6.17	4.96	6.47	5.22	5.70
50	Fallow	3.72	3.12	4.67	4.29	3.95
			BC × N			Mean
0		3.10	4.23	4.40	5.50	4.31 b
50		5.41	5.04	5.66	5.65	5.44 a
			L × N			Mean
	Cowpea	5.33	5.34	4.80	6.20	5.42 a
	Mungbean	4.59	5.14	5.09	5.83	5.16 b
	Sesbania	4.78	4.74	6.07	5.50	5.27 ab
	Fallow	2.32	3.34	4.17	4.78	3.65 c
		4.26 d	4.64 c	5.03 b	5.58 a	
	Year	Year 1	Year 2			
		4.88	4.87			
Main effects		$LSD_{(0.05)}$		Interactions	Significance level	
Year		Ns		BC × L	*	
Biochar(BC)		*		L × N	ns	
Legumes(L)		0.18		BC × N	ns	
Nitrogen (N)		0.14		BC × L × N	ns	

Means of the same category followed by different letters are significantly different from each other at 5% level of probability. * = significant at 5% level of probability. Ns: non-significant.

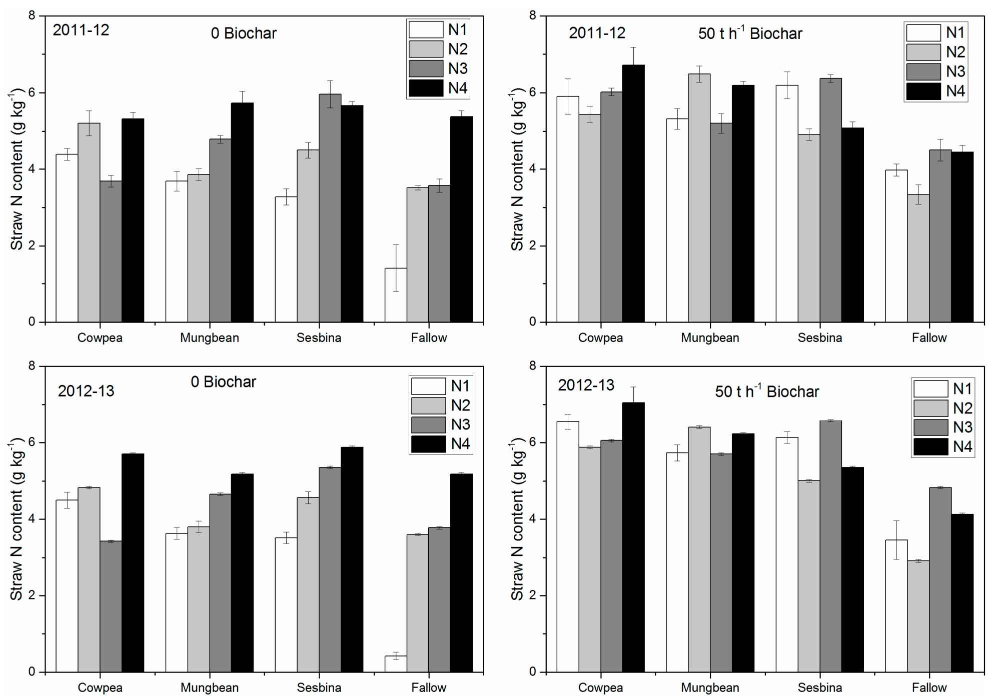

Figure 4. Effect on stover N content (g kg^{-1}) under different N fertilizer, biochar, and legumes after maize harvest during 2011–2012 and 2012–2013.

3.2.2. Grain N in Maize (g kg^{-1})

Data relating to grain N in maize are given in Table 4. Statistical analysis of the data indicated that legumes and nitrogen rates significantly affected grain N in maize (Figure 5). Year as source of variation and biochar did not significantly affect grain N in maize. All interactions significantly affected grain N in maize except BC × N. The cultivation of legumes as preceding crop enhanced 16.8% of grain N in maize. The plots previously sown with cowpea increased (2.17 g kg^{-1}) of grain N as compared grain N in plots previously kept fallow. Similarly, grain N of maize continually increased (21.27%) with increasing level of N. Higher grain N (2.91 g kg^{-1}) was under 150 kg N ha^{-1} compared to control plots. The L × N interaction showed that 14.3 and 14.4 g kg^{-1} higher grain N was noted in plots integrated with cowpea and 150 kg N ha^{-1} in 2011–2012, and 2012–2013. The BC × N interaction indicated that 14.0 and 14.2 g kg^{-1} higher grain N was recorded at 90 kg N ha^{-1} with biochar application during 2011–2012 and 2012–2013.

Table 4. Effect of biochar, legumes, and N rates on grain N (g kg^{-1}) of maize

Biochar (BC) (ton ha^{-1})	**Legumes (L)**	**Nitrogen (N) (kg ha^{-1})**				
		0	**90**	**120**	**150**	**Mean**
0	Cowpea	7.90	15.86	13.40	14.85	13.00
0	Mungbean	7.69	12.20	15.03	14.95	12.47
0	Sesbania	13.08	11.73	14.15	12.73	12.92
0	Fallow	11.87	10.33	11.20	9.65	10.76
50	Cowpea	11.79	14.70	10.85	14.01	12.84
50	Mungbean	11.95	16.56	10.88	8.10	11.87
50	Sesbania	11.10	14.84	9.88	8.50	11.08
50	Fallow	20.81	10.73	10.83	10.62	13.25
			BC × N			Mean
0		10.13	12.53	13.44	13.04	12.29
50		13.91	14.21	10.61	10.31	12.26
			L × N			Mean
	Cowpea	9.84	14.28	12.13	15.43	12.92 a
	Mungbean	9.82	11.38	12.95	14.53	12.17 b
	Sesbania	12.09	10.28	12.01	13.61	12.00 c
	Fallow	11.34	10.53	11.01	10.13	10.75 d
		10.77 d	11.37 c	12.03 b	13.68 a	
	Year	Year 1	Year 2			
		12.27	12.28			
Main effects		$LSD_{(0.05)}$		Interactions	Significance level	
Year		ns		BC × L	*	
Biochar (BC)		ns		L × N	*	
Legumes (L)		0.13		BC × N	ns	
Nitrogen (N)		0.15		BC × L × N	*	

Means of the same category followed by different letters are significantly different from each other at 5% level of probability. * = significant at 5% level of probability. ns = non-significant.

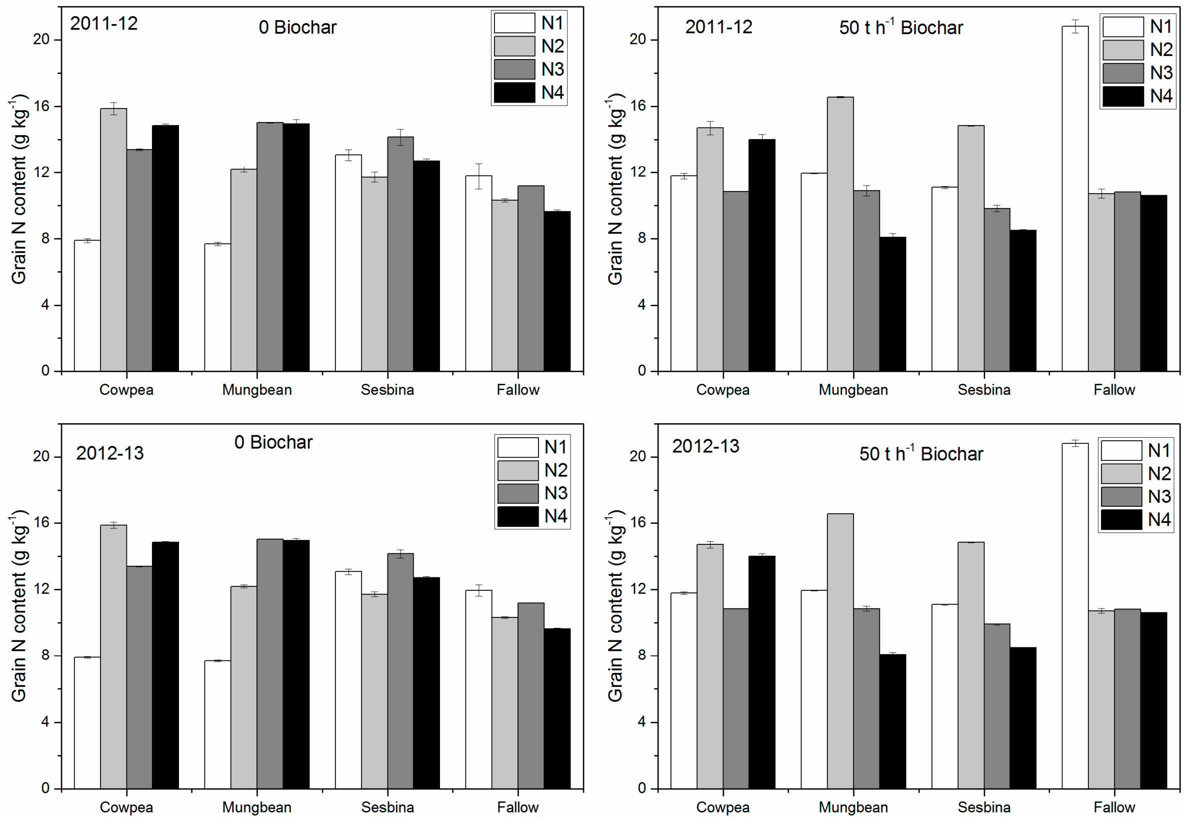

Figure 5. Effect of grain N content (g kg^{-1}) under different N fertilizer, biochar, and legumes after maize harvest during 2011–2012 and 2012–2013.

3.3. Nitrogen (N) Use Efficiency

Data concerning N use efficiency in maize are reported in Table 5. Statistical analysis of the data indicated not significant effect for years as source of variation and biochar application (Figure 6). However, legumes and nitrogen rates significantly affected N use efficiency. All interactions were significant for N use efficiency in maize. N use efficiency in maize did not increase with legumes. N use efficiency decreased 34.6% with the increase of N application. Higher N use efficiency of 47.26% was recorded in plots when the crop was given nitrogen fertilizer at the rate of 90 kg N ha^{-1} as compared to lower 30.87% in plots fertilized with 150 kg N ha^{-1}. The plots sown with mungbean showed minimum 26.26% of N use efficiency compared to fallow plots 38.90%. During 2011–2012, and 2012–2013, the interaction of L × N showed 68.3 and 70% higher N use efficiency in fallow plots fertilized with 90 kg N ha^{-1}. While BC × N interaction revealed that plots fertilized with 90 kg N ha^{-1} resulted in 51.5 and 58.1% of higher N use efficiency without biochar integration.

Table 5. Effect of biochar, legumes, and N rates on N use efficiency (%) of maize

Biochar (BC) (ton ha^{-1})	Legumes (L)	Nitrogen (N) (kg ha^{-1})				
		0	90	120	150	Mean
0	Cowpea	-	33.86	36.35	21.34	22.89
0	Mungbean	-	54.42	27.82	22.17	26.10
0	Sesbania	-	50.72	28.28	25.13	26.03
0	Fallow	-	70.09	49.90	41.33	40.33
50	Cowpea	-	33.21	40.84	20.68	23.68
50	Mungbean	-	29.97	38.22	37.48	26.41
50	Sesbania	-	37.60	44.16	41.96	30.93
50	Fallow	-	68.19	44.80	36.86	37.46

Table 5. *Cont.*

Biochar (BC) (ton ha^{-1})	Legumes (L)	Nitrogen (N) (kg ha^{-1})				
		0	**90**	**120**	**150**	**Mean**
			BC × N			Mean
0		-	52.27	35.59	27.49	28.84
50		-	42.24	42.00	34.24	29.62
			L × N			Mean
	Cowpea	-	33.53	38.59	21.01	23.28 d
	Mungbean	-	42.20	33.02	29.82	26.26 c
	Sesbania	-	44.16	36.22	33.54	28.48 b
	Fallow	-	69.14	47.35	39.10	38.90 a
		-	47.26 a	38.80 b	30.87 c	
	Year	Year 1	Year 2			
		28.47	29.99			
Main effects		LSD$_{(0.05)}$		Interactions	Significance level	
Year		*		BC × L	*	
Biochar (BC)		ns		BC × N	*	
Legumes (L)		2.29		L × N	*	
Nitrogen (N)		1.49		BC × L × N	*	

Means of the same category followed by different letters are significantly different from each other at 5% level of probability. * = significant at 5% level of probability. ns = non-significant.

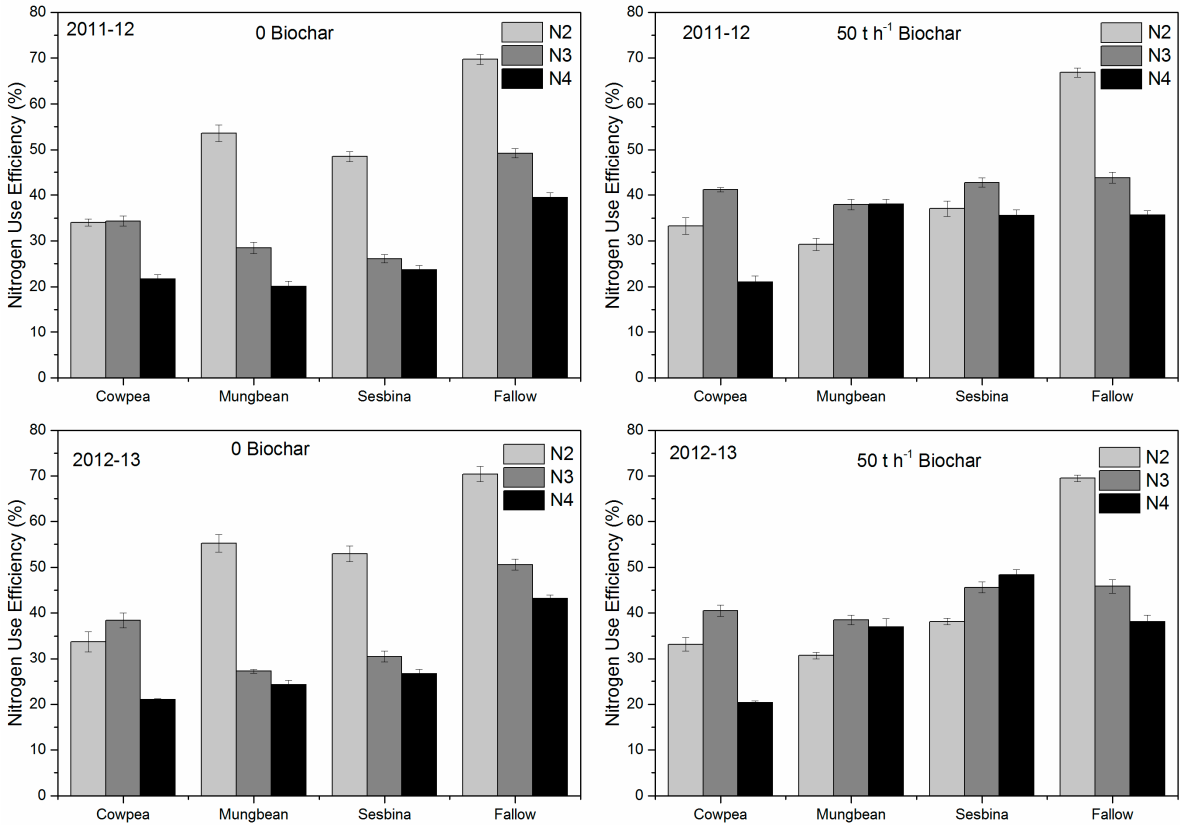

Figure 6. Changes in nitrogen use efficiency (%) under different N fertilizer, biochar, and legumes after maize harvest during 2011–2012 and 2012–2013.

3.4. Above Ground Biomass and Grain Yield of Maize

3.4.1. Above Ground Biomass (kg ha^{-1})

Year as a source of variation significantly ($p < 0.05$) affected on above ground biomass of maize (Table 6). The application of biochar did not significantly increase above ground biomass. However, legumes and N rates significantly affected above ground biomass. The BC × L and L × N interactions were significant, whereas rest of the interactions were found not significant. Legumes as preceding crop improved above ground biomass of maize. The plots previously sown with cowpea, sesbania, or mungbean produced 9.26% higher biological yield as compared to previously fallow plot. Likewise, biological yield was consistently improved by 21.5% with increasing nitrogen rates till 120 kg ha^{-1} but there was no significant increase with further increase in N level. Higher 31.6% above ground biomass was recorded at150 kg N ha^{-1} as compared to control plot.

Table 6. Effect of biochar, legumes, and nitrogen rates on above ground biomass (kg ha^{-1}) of maize

Biochar (BC) (ton ha^{-1})	Legumes (L)	Nitrogen (N) (kg ha^{-1})				
		0	90	120	150	Mean
0	Cowpea	5193	6134	7378	8127	6708
0	Mungbean	5080	6153	7766	7295	6574
0	Sesbania	5512	6399	8060	7767	6935
0	Fallow	4742	5457	6642	7294	6034
50	Cowpea	6453	7305	9344	10480	8396
50	Mungbean	5953	6610	8878	8644	7521
50	Sesbania	6204	6828	8192	8206	7358
50	Fallow	5045	5994	6470	6814	6081
			BC × N			Mean
0		5193	6134	7378	8127	6708 a
50		5080	6153	7766	7295	6574 b
			L × N			Mean
	Cowpea	5823	6720	8361	9303	7552 a
	Mungbean	5516	6382	8322	7969	7047 a
	Sesbania	5858	6614	8126	7987	7146 a
	Fallow	4893	5725	6556	7054	6057 b
		5523 c	6360 b	7841 a	8078 a	
	Year	Year 1	Year 2			
		6278 b	7623 a			
Main effects		$LSD_{(0.05)}$		Interactions	Significance level	
Year		*		BC × L	*	
Biochar(BC)		*		L × N	*	
Legumes(L)		600.17		BC × N	ns	
Nitrogen (N)		351.25		BC × L × N	ns	

Means of the same category followed by different letters are significantly different from each other at 5% level of probability. * = significant at 5% level of probability. ns = non-significant.

3.4.2. Grain Yield (kg ha^{-1})

Legumes, biochar and nitrogen rates significantly ($p < 0.05$) affected grain yield of maize (Table 7). Year as source of variation also had significant effect on grain yield of maize. All interactions were found non-significant except BC × L. Legumes as preceding crop improved grain yield of maize. The plots previously sown with cowpea, mungbean, or sesbania produced 12.5% higher grain yield as compared with that of fallow. The addition of 50 tons' ha^{-1} of biochar increased 7.2% grain yield in comparison with no biochar treatment. Likewise, nitrogen application constantly increased grain yield from 0 to 120 kg ha^{-1} but thereafter there was no significant increase in grain yield of maize. Higher 29.4% grain yield was recorded in 120 kg N ha^{-1} treated plots compared to that of control plots.

Table 7. Effect of biochar, legumes, and N rates on grain yield (kg ha^{-1}) of maize

Biochar (BC) (ton ha^{-1})	**Legumes (L)**	**Nitrogen (N) kg ha^{-1}**				
		0	**90**	**120**	**150**	**Mean**
0	Cowpea	1904	2439	3135	3032	2628
0	Mungbean	2123	2511	3038	3173	2711
0	Sesbania	2054	2258	3041	2839	2548
0	Fallow	2000	2249	3147	3194	2647
50	Cowpea	2658	2397	3833	3663	3138
50	Mungbean	2710	2669	3159	3065	2901
50	Sesbania	2495	2708	3397	3073	2918
50	Fallow	1977	2400	2639	2650	2416
			BC × N			Mean
0		2021	2364	3090	3060	2634 b
50		2460	2544	3257	3113	2843 a
			L × N			Mean
	Cowpea	2281	2418	3484	3348	2883 a
	Mungbean	2417	2590	3099	3119	2806 a
	Sesbania	2275	2483	3219	2956	2733 a
	Fallow	1988	2324	2893	2922	2532 b
		2240 c	2454 b	3174 a	3086 a	
	Year	Year 1	Year 2			
		2375 b	3102 a			
Main effects		$LSD_{(0.05)}$		Interactions	Significance level	
Year		*		BC × L	*	
Biochar (BC)		*		L × N	ns	
Legumes (L)		191.17		BC × N	ns	
Nitrogen (N)		160.64		BC × L × N	ns	

Means of the same category followed by different letters are significantly different from each other at 5% level of probability. * = significant at 5% level of probability. ns = non-significant.

4. Discussion

4.1. Soil Properties

Biochar application significantly enhanced soil C after maize harvest. It may be due to the fact that breakdown the below parts (roots) of legumes and mineralization of nutrients is normally quite slow and may get a few months to several years depending on environmental factors. Moreover, biochar and residue incorporation enhance soil C and organic matter [27]. Additional application of N fertilizer caused unfavorable effects on post-harvest available nutrients. This may be ascribed to increased release of nutrients in the soil from native pools as well as their residual effects. Furthermore, the solubility of soil C may be increased due to the production of legumes and released of organic N during the decay of organic matter [22]. Furthermore, Savithri et al. reported the significant increase in soil C and available N of soil with the application of straw mulch and N fertilizer. Biochar, legumes, and nitrogen levels significantly affected soil nitrogen after maize harvest [28]. The cultivation of legumes as preceding crop increased soil N. Similarly, biochar application also enhanced soil N after maize harvest. N application also improved soil N and maximum soil N was recorded in plots fertilized with 150 kg N ha^{-1}. These results are in agreement with [29] who reported that the rank of available N in soil improved due to N fertilization. Similarly, soil N was increased in the treatment where N fertilizer was added with straw mulch to the previous wheat crop [30].

4.2. Maize N Content and NUE

Legumes, biochar and N application significantly increased straw N content in maize. Higher straw N was recorded in plots applied with fertilizer at the rate of 150 kg N ha^{-1}. While N recovery in biomass was significantly higher when the soil contained additional fertilizers [31,32]. Nitrogen fertilizer provides a nutrient source as well as power for microbial activities in order to mineralize the organic nitrogen and make it available to crop [22,33]. Legumes and N levels significantly improved grain N content in maize. The use of legumes as a preceding crop enhanced grain N in maize plants. Similarly, N fertilizer increase grain N by using 150 kg N ha^{-1}. The increase in grain N is due to legumes and fertilizer N application may be due to the outstanding organic carbon and available nitrogen build-up in the soil [34,35]. The current study showed that legumes and N application significantly affected N use efficiency in maize. Legumes cultivation decreased N use efficiency and was higher in fallow plots. Similarly, N use efficiency decreased with increasing level of N. Biochar application increased yields and nutrient use efficiency at a low fertility site [36]

4.3. Above Ground Biomass and Grain Yield of Maize

Grain yield is an imperative constituent for a crop. It usually depends upon various factors, such as crop management, water availability, soil fertility, and environmental factors [34,35]. The current study showed that biochar significantly improved grain yield but had no effect on above ground biomass. However, legumes and N levels significantly enhanced grain and above ground biomass of maize. Plots previously sown with legumes enhanced grain yield and above ground biomass of maize as compared to fallow treatment. The increase in growth and yield of cereal crop is related with the improvement of soil fertility by the improved organic matter [37,38]. Furthermore, the application of biochar helps in improving of soil physiochemical properties, which leads in the increase of grain yield [39–41] and sufficient amount of soil nitrogen availability lead to increase in plant growth and yield [42,43] and also the increase of 43–68% in grain yield is due to nitrogen application [17]. Moreover, the N application significantly enhance crop production in the course of additional nitrogen [43]. This may be due to previously sufficient available nutrients in soil resulting maximum above ground biomass. The adequate availability of nitrogen in soil made the crop prolific resulting in maximum biological yield [44]. In addition, growth parameters including biological yield increased with increasing N rates [45]. Furthermore, Akhtar et al. reported that N recovery in biomass was significantly higher when the soil contained additional fertilizers [42]. Pierce et al. and Danga et al. reported that grain legumes grown in turning round with annual cereal crops contribute to the total pool of nitrogen in the soil and improve the yield of cereals [21,46].

5. Conclusions

The addition of biochar significantly improved soil fertility by increasing soil C and N, and increased crop yield. Higher grain and biological yields of maize was noted with 120 kg N ha^{-1} in place of its recommended dose of 150 kg N ha^{-1} when sown after legumes. Similarly, plots previously sown with either cowpea or mungbean resulted in higher grain yield of maize. Furthermore, keeping in view the importance of biochar, for future perspectives, long–term experiments is needed to undertake on different soil types and to determine its impact on carbon sequestration and N dynamics for best N management practices.

Author Contributions: F.J. performed experiment; M.A. (Muhammad Arif) and K.A. helped in data analysis and making figures; A.K. and M.N. performed formal analysis and worked with the software; F.S. and S.Z. worked as investigators; F.J. and S.H. wrote the final full length draft; M.I. M.A.K. and M.A. (Muhammad Ali) contributed to design methodology, revising and editing English language; F.W., revised the article and provided funding. All authors have read and agreed to the published version of the manuscript.

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