4.1. Objective 1: To investigate the characteristics of biochars produced from different feedstocks and methodologies

4.1.1. Feedstock composition

Composition of feedstocks used for biochar production is listed in Table 4.1 and 4.2. Total C content was high (53.67%) in the mixed wood chips compared to tea pruning litter (48.09%). Whereas H, N, O, H/C and O/C ratio were lower in mixed wood chips than the tea pruning litter. Mixed wood chips recorded higher (165.55) C/N ratio than the tea pruning litter (125.00). Similarly, higher calorific value was recorded in the mixed wood chips as compared to tea pruning litter (14.79 J kg^{-1} and 11.23 J kg^{-1}, respectively). Nevertheless, tea pruning litter documented higher elemental content as well as heavy metals (K, P, Na, Ca, Mg, Mn, Fe, Zn, Pb, Cd, Co and Cu) compared to mixed wood chips.

4.1.2. Biochar yield, proximate and ultimate analysis

Production temperature, yield, proximate and ultimate analysis of the biochars are presented in Table 4.3. Regardless of the feedstock type, the conventional method of biochar production yielded highest followed by gasification and pyrolysis techniques (30-40%, 20-35% and 18-30%, respectively). Conventional biochars also recorded higher (TLC = 7.91%, WCC =7.74%) moisture content compared to gasification and pyrolysis biochars (TLG = 4.01%, TLP = 3.62%, WCG = 3.61%, WCP = 3.20%). Likewise, volatile matter and ash content were maximum (51.01% and 17.19%, respectively) in TLC biochar produced by conventional method and the lowest (29.71% and 10.93%, respectively) of the same was found in biochars produced through pyrolysis (WCP). Based on feedstocks, tea pruning litter biochars showed maximum moisture, volatile matter and ash content than mixed wood chips (Table 2). Whereas based on production methods, biochars obtained from pyrolysis process documented lower H/C ratio (WCP=0.42, TLP = 0.43) followed by gasification technique (WCG = 0.44, TLG = 0.45) and the highest H/C ratio was noted in biochars obtained from conventional method (TLC = 0.56, WCC = 0.49). Similarly, lowest O/C ratio was found in WCP (0.15) followed by WCG (0.20) and TLP (0.22) biochars while, TLC (0.71) biochar was recorded highest for the same.

4.1.3. Elemental composition

Higher elemental composition was documented in conventionally made (TLC, WCC) biochars (Table 4.2). However, no significant difference for elemental composition was noted in the biochars produced through pyrolysis and gasification methods. Between the feedstocks, tea pruning litter found superior on the basis of studied elemental content.

4.1.4. pH, electrical conductivity (EC mS cm^{-1}), and cation exchange capacity (CEC cmol$_{+}$kg^{-1})

Recorded pH and EC of the biochars are summarized in Table 4.3. Produced biochars were basic in nature with pH between 8.6–9.3. Compared to conventional method of biochar production, biochar from pyrolysis and gasification method noted higher pH and EC values. Highest (989 mS cm^{-1}) EC was documented in TLP biochar and the lowest (792 mS cm^{-1}) of the same was found in WCC biochar. Both pH and EC showed highest value when tea pruning litter was used as feedstock. Highest CEC (19.53 cmol$_{+}$kg^{-1}) was noted in TLP biochar followed by TLG (18.76 cmol$_{+}$kg^{-1}) and WCP (17.21 cmol$_{+}$kg^{-1}). The lowest (12.25 cmol$_{+}$kg^{-1}) of the same was recorded in TLC biochar.

4.1.5. Surface acidity (mmolg^{-1}) and basicity (mmolg^{-1})

Surface acidity and basicity of the produced biochars were listed in Table 4.3. Better alkaline functionalities were observed in the studied biochars than acidic functionalities. Biochars produced from tea pruning litter recorded higher surface basicity while mixed wood chips tend towards lower pH value. Comparing the production methodologies, biochar made by pyrolysis method (TLP) documented highest (2.86 mmolg^{-1}) alkalinity whereas, higher (0.092 mmolg^{-1}) surface acidity was reported in conventionally produced biochar (WCC).

4.1.6. Biochar surface morphology

The scanning electron micrograph of biochar surfaces revealed its irregular geometry and porous nature. Substantial destruction of pore structures was noted in conventionally produced biochars in contrast to biochars made by pyrolysis and gasification method (Image 4.1). Conventionally made biochars documented lesser specific surface area than those obtained from gasification and pyrolysis methods (Table 4.3). Maximum specific surface area of 178.3 m^2g^{-1} was observed in biochars produced from pyrolysis technique (WCP) followed by gasification (WCG 174.7 m^2g^{-1}). Whereas, TLC (85.61 m^2g^{-1}) comes in the bottom of the list. Irrespective of the production method, biochars obtained from tea pruning litter gives lower specific surface area compared to biochars obtained from mixed wood chips.

4.1.7. Poly Aromatic Hydrocarbons (PAHs)

Naphthalene, Benzo (b) fluranthene, Benzo (g, h, i) perylene, Benzo (k) fluoranthene were found in all the biochars obtained from tea pruning litter. Whereas, only naphthalene was detected in the biochars obtained from mixed wood chips (Table 4.4)

4.1.8. Water holding capacity

Water holding capacity (WHC) of the studied biochars varied based on pyrolysis temperature and the feedstocks. The uppermost value (96.8% in WCP) for water holding capacity was noted when biochars were produced at 650˚C. Whereas, conventionally made TLC biochar at temperature 350˚C noted the lowest WHC (91.29% in TLC) (Table 4.3).

4.1.9. Adsorption capacity

Table 4.3 shows the adsorption capacity of the produced biochars. It has been observed that irrespective of the feedstock, the gasification made biochars are better absorber (332.28 mg g^{-1} and 321.15 mg g^{-1} for TLG and WCG, respectively) than pyrolyzed biochars (284.67 mg g^{-1} and 279.26 mg g^{-1} for TLP and WCP, respectively). Conventionally made biochars documented least adsorption capacity (225.40 mg g^{-1} and 185.75 mg g^{-1} for TLC and WCC respectfully). Results also documented better adsorption capacity of tea pruning litter biochars compared to mixed wood chips.

4.1.10. Functional groups in the produced biochars

Figure 4.1 represents the IR spectra of the studied biochars. Production method has no significant influence on surface functional groups of the studied biochars. Biochars obtained from tea pruning litters (TLC, TLG and TLP) showed presence of C—H, C=O, aromatic C=C, CH_2, C—O—C, C—N and O—H functional groups on their surfaces. Whereas surfaces of mixed wood chips biochars (WCC, WCG and WCP) revealed existence of CH_2, C—O—C, C—N and O—H. Observed peaks at 3421-3447 cm^{-1} indicates presence of O—H [1]. Whereas, 2922 cm^{-1} are the sign of C—H groups [2]. Peaks at 1600-1643 cm^{-1} determines the presence of C=O, aromatic C=C and lactone groups [3] and peaks at 1417 cm^{-1} corresponds to CH_2 groups [4]. Occurrence of peak at 1000-1100 cm^{-1} represents C—O—C pyranose ring skeletal vibration or C—N stretch of an aliphatic primary amine [4]. Furthermore, peaks between 803 and 875 cm^{-1} relate to carbonates and C—H [5].

4.1.11. Calorific value (CV) or heating capacity

Calorific value of the biochars is reported in Table 4.3. The recorded CV was 17.4 to 27.5 MJ kg^{-1}. Compared to tea pruning litter biochars, mixed wood chips showed greater heating ability. Highest CV value was displayed by WCP and TLC exhibited the least.

4.1.12. Recalcitrance potential (RP) and carbon sequestration potential (CSP)

All the tested biochars fall into most recalcitrant category (WCP >WCG >TLP >WCC >TLG) (Figure 4.2). However, TLC (R50 = 0.60) biochar falls into minimal degradation category. Additionally, carbon sequestration potential (CSP) was maximum in TLP (39.49%) followed by WCC (36.52%) and the least of the same was documented in TLC (24.35%).

4.1.13. Correlation analysis of biochar properties

Correlations amongst the biochar properties are displayed in the Image 4.2. Strong negative correlations were observed among biochar pH, EC, SA, CV, WHC, adsorption potential, and MBC with MC, VM, and ash content, H/C and O/C ratio of the same at both $p<0.05$ and $p<0.01$ significance level. Whereas, strong positive correlations of carbon content in the biochars were noted with CEC, SA, CV, WHC and R50 values of the biochars at $p<0.05$ level.

Table 4.1. Characteristics of feedstocks

Feedstock	C (%)	H (%)	N (%)	O (%)	C/N	H/C	O/C	FC (%)	LC (%)	Ash (%)	VM (%)	CV MJ kg^{-1}
TL	48.09	6.4	0.45	41.46	125.0	1.6	0.64	18.91	19.90	8.61	72.53	11.23
MW	53.67	5.6	0.39	35.91	165.5	1.25	0.50	25.32	26.37	6.43	68.29	14.79

Where, TL = tea pruning litter, MW = mixed wood chips, FC = fixed carbon, LC = labile carbon, CV = calorific value, VM = volatile matter

Table 4.2. Elemental content of the feedstocks and biochars

	Na	Mg	Ca	K	P	Fe	Zn	Mn	Pb	Cd	Cu	Cr
						Feedstock's (mg kg^{-1})						
TL	245.0±0.7a	513.3±0.6a	254.9±0.4a	263.8±0.5a	479.4±0.6a	200.5±0.5a	562.9±0.7a	69.6±0.3a	22.3±0.6a	4.4±0.2a	8.5±0.1a	17.1±0.1a
MW	187.6±0.3b	467.8±0.3b	155.7±1.8b	229.06±0.2b	366.5±0.4b	137.3±0.4b	392.2±0.3b	63.9±0.4b	13.4±0.1b	2.6±0.1b	8.0±0.4b	16.7±0.2b
						Biochars (mg kg^{-1})						
TLC	372.7±0.8a	472.4±0.5a	286.9±1.0b	358.3±0.6a	696.4±0.4a	253.7±0.6a	684.1±0.5a	121.1±0.4a	23.3±0.2a	4.1±0.0a	9.0±0.1a	18.1±0.2a
TLG	365.2±0.3b	382.4±0.5b	267.7±0.3c	339.0±0.3c	575.4±0.6b	222.8±0.6abc	562.4±0.4c	97.9±0.6c	21.9±0.3b	3.4±0.4b	8.1±0.0bc	13.6±0.1b
TLP	322.0±0.4c	363±0.9c	291.4±0.2a	344.9±1.0b	611.6±0.2c	246.4±0.2ab	578.3±0.6b	104.3±0.7b	17.6±0.6c	4.5±0.2a	7.4±0.1cd	12.3±0.0c
WCC	256.5±0.6d	314.3±0.8d	165.9±0.4d	298.3±0.5d	433.5±2.1d	214±4.2bc	393.0±1.0d	77.6±0.7d	11.5±0.7d	1.3±0.0c	7.4±0.2cd	13.5±0.1b
WCG	232.4±0.3e	229.1±0.3f	156.6±0.3f	239±0.4e	424±1.4e	188.2±0.4d	257.3±0.5e	53.4±0.1f	9.4±0.1f	1.6±0.1c	7.7±0.1cd	11.7±0.1d
WCP	192.6±0.6f	236.2±0.5e	144.4±0.2e	245.9±0.4f	416.2±0.3f	204.3±0.4c	254.2±0.3f	62.9±0.4e	11.1±0.4e	1.2±0.0c	7.1±0.0d	13.5±0.2b

Where, TL= tea litters, MW = mixed wood, TLC = tea litter conventional, TLG = tea litter gasified, TLP = tea litter perolyzed, WCC = wood chips conventional, WCG = wood chips gasified, MCP = wood chips pyrolyzed. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different at $p<0.05$

Table 4.3. Characteristics of biochars

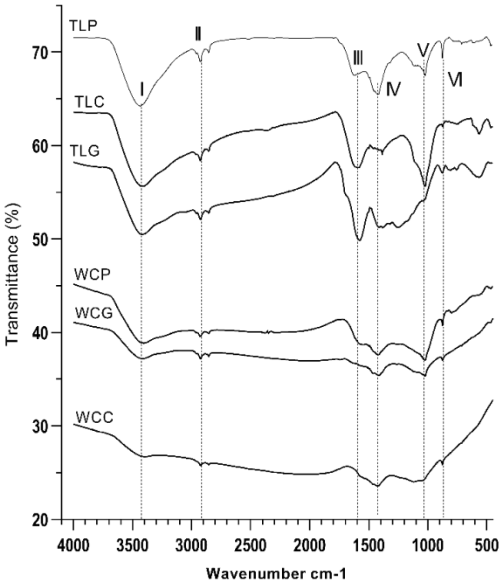
Biochars	TLC	TLG	TLP	WCC	WCG	WCP
PT (˚C)	350	650	650	350	650	650
Yield (%)	30-35	20-30	18-25	30-40	20-35	18-30
MC (%)	7.91	4.01	3.62	7.74	3.61	3.2
VM (%)	51.01	34.23	30.93	42.03	31.87	29.71
Ash (%)	10.93	12.26	15.74	11.74	13.43	17.19
FC (%)	32.4	54.52	58.64	44.6	57.23	61.84
LC (%)	16.44	13.3	14.05	22.61	17.64	17.09
C (%)	48.84	67.92	72.64	67.2	74.87	78.93
H (%)	2.3	2.59	2.64	2.76	2.8	2.82
N (%)	0.95	0.7	0.96	0.58	0.24	0.38
O	46.72	27.36	22.02	28.43	20.22	15.94
C/N	60.74	113.20	88.97	136.58	366.47	243.33
O/C	0.71	0.30	0.22	0.31	0.20	0.15
H/C	0.56	0.45	0.43	0.49	0.44	0.42
pH	8.9	9.2	9.3	8.8	9.3	9.3
EC (mS cm^{-1})	825	897	989	792	838	972
CEC ($cmol_+kg^{-1}$)	12.25	18.76	19.53	15.67	16.98	17.21
Aci ($mmolg^{-1}$)	0.089	0.057	0.041	0.092	0.065	0.043
Alk ($mmolg^{-1)}$	1.82	2.25	2.86	1.47	2.14	2.38
SA (m^2g^{-1})	85.61	141.94	174.84	99.64	174.7	178.33
WHC (%)	91.29	92.3	92.85	93.4	95.14	96.83
AC (mg g^{-1})	225.4	332.28	284.67	185.75	321.15	279.26
CV MJ kg^{-1}	17.48	20.46	22.37	19.62	21.82	27.5
RP50	0.6	0.76	1.09	0.9	1.11	1.12
CSP (%)	24.35	28.6	39.49	36.52	33.46	32.03

Where, TLC = tea litter conventional, TLG = tea litter gasified, TLP = tea litter perolyzed, WCC = wood chips conventional, WCG = wood chips gasified, WCP = wood chips pyrolyzed, PT = production temperature, MC = moisture content, VM = volatile matter content, FC = fixed carbon, EC = electrical conductivity, CEC = cation exchange capacity, Aci = acidity, Alk = alkalinity, SA = specific surface area, WHC = water holding capacity, AC = adsorption capacity, CV= calorific value, RP50= recalcitrance potential, CSP = carbon sequestration potential

Table 4.4. Existing EPA PAHs in the produced biochars

Biochar	Tea pruning liter based biochars (TLC, TLG, TLP)	Mixed wood chips based biochars (WCC, WCG, WCP)
PAHs	Naphthalene Benzo (b) fluranthene Benzo (g,h,i) perylene Benzo (k) fluoranthene	Naphthalene

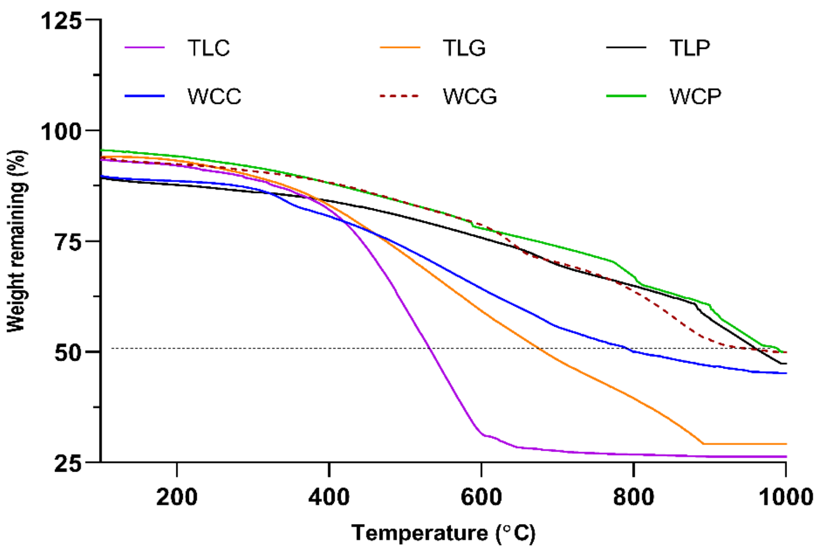
Figure 4.1. Fourier transform infrared spectrum of the biochars



	Wavenumber cm^{-1}	Functional groups
I	3421-3447	O-H
II	2922-2940	C-H
III	1600-1643	C=C, C=O
IV	1417	H-C-H
V	1000-1100	C-O-C, C-N
VI	803-875	C-H

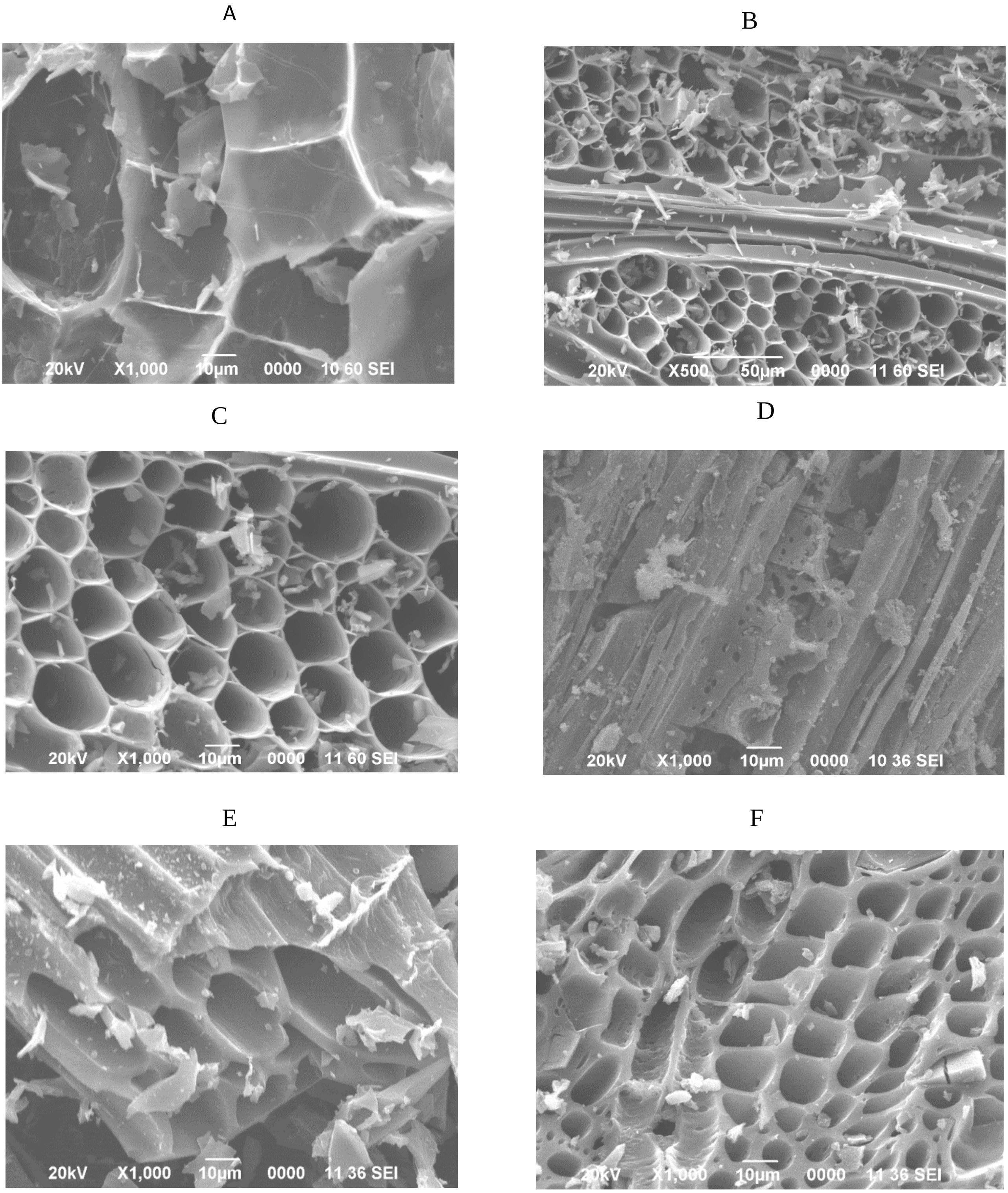
Where, TLC = tea litter conventional, TLG = tea litter gasified, TLP = tea litter pyrolyzed, WCC = wood chips conventional, WCG = wood chips gasified, WCP = wood chips pyrolyzed.

Figure 4.2. Temperature programmed oxidation (thermo-gravimetric analysis) of biochars



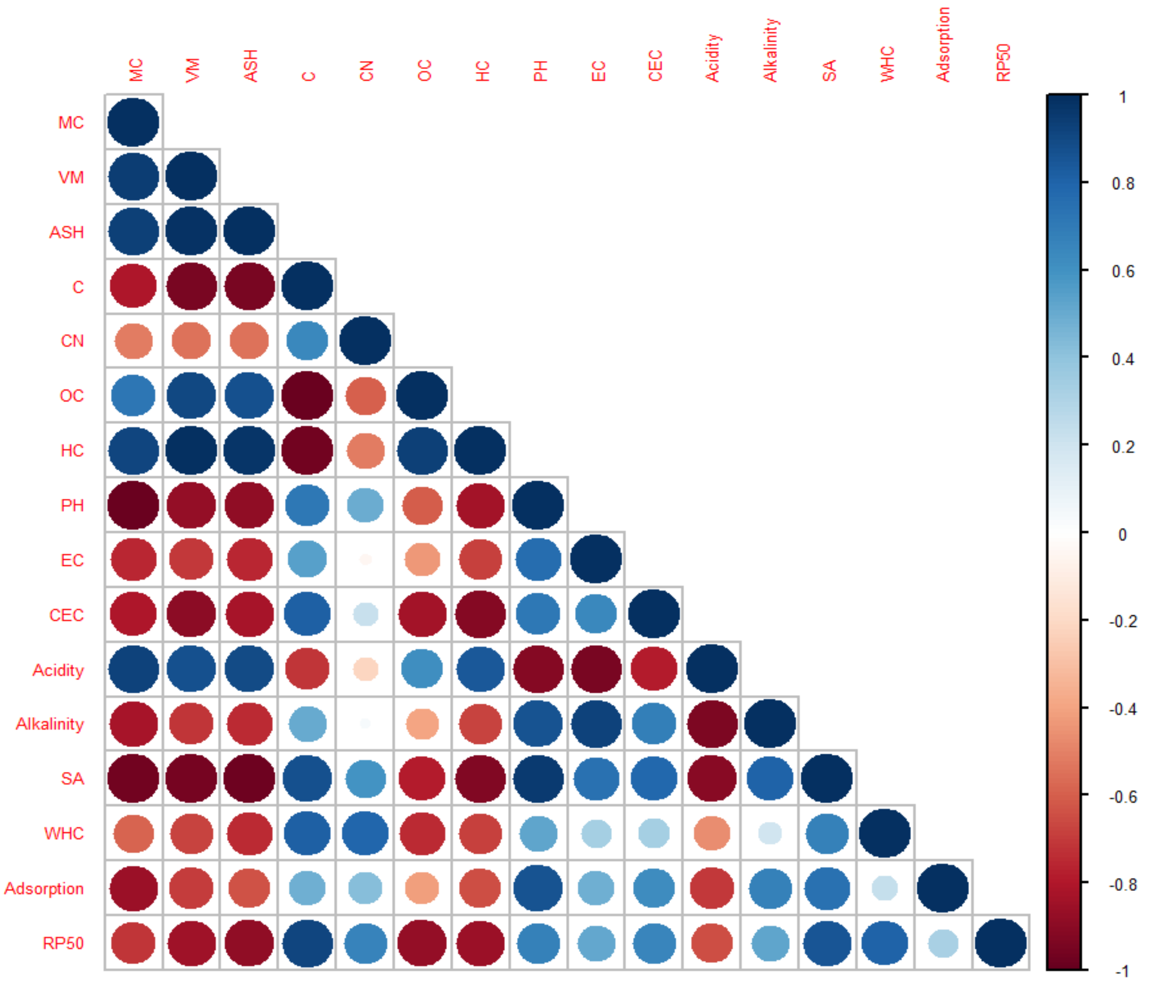
Where, TLC = tea pruning conventional, TLG = tea pruning gasified, TLP = tea pruning pyrolyzed, WCC = mixed wood conventional, WCG = mixed wood gasified, WCP = mixed wood pyrolyzed.

Image 4.1. Scanning electron microscope (SEM) images of the biochar surfaces



Where, A = TLC, B = TLG, C = TLP, D = WCC, E = WCG, F = WCP

Image 4.2. Pearson correlation matrix of studied biochar properties



Where, MC = moisture content, VM = volatile matter content, C = carbon, CN = C/N ratio, OC = O/C ratio, HC = H/C ratio, WHC = water holding capacity, EC = electrical conductivity, CEC = cation exchange capacity, SA = specific surface area, RP50 = recalcitrance potential.

4 .2. Objective 2: To investigate the impact of biochar application on soil properties and crop health

4.2.1. Effect of biochar on seed germination of mustard (*Brassica juncea* L.) variety TS 38 and french bean (*Phaseolus vulgaris* L.) variety Arka Anoop

4.2.1.1. Germination performance of mustard and bean seeds under biochar application

Germination performance of mustard and french bean seeds were displayed in the Tables 4.5, 4.6, 4.7, 4.8 and Figure 4.3. Addition of TLC biochar at 10 t ha^{-1} increased the germination percentage (86.67%), germination index (118.00), vigor index (188.67) and dry seedling biomass (92.1 mg $seedling^{-1}$) of mustard seeds. While, equal doses of wood chips biochars made by pyrolysis and gasification method (WCP and WCG) lowered the germination percentage (80.00%). Germination index (108.67) and dry matter yield (48.2 mg $seedling^{-1}$) were lowest under WCP biochar application at the same rate whereas, recorded vigor index (167.67) was lesser under WCG biochar application at 10 t ha^{-1}. The order of percent inhibition of germination (PIG) for mustard seed under application of biochar at 10 t ha^{-1} are as follows WCP > TLP > TLG > WCG > WCC > TLC.

However, increasing the application dose of WCP biochar to 20 t ha^{-1} improved germination percentage (73.33%), germination index (101.33) and dry biomass yield (45.3 mg $seedling^{-1}$) of mustard seeds. Under the same application dose, lowest germination percentage (TLC = 65.00%), germination index (WCC = 87.33) and dry biomass yield (TLC = 36.2 mg $seedling^{-1}$) was documented from application of conventionally made biochars. Recorded vigor index was higher (158.83) under application of WCG biochar and lowest (135.00) of the same was documented under TLC biochar under the similar application dose. Documented percent inhibition of germination (PIG) of mustard seeds were in the following order WCG > TLC > TLP > TLG > WCC > WCP.

For french bean seeds, addition of 10 t ha^{-1} of TLC biochar improved germination percentage (90%), germination index (181.33), vigor index (1064.00) and dry seedling biomass (186.4 mg $seedling^{-1}$). Whereas, similar doses of TLP and WCG biochar lowered germination percentage (81.67%) of the same. Lowest germination index, vigor index and dry matter yield (163.33, 879.00 and 135.00 mg seedling$^{-1,}$ ^{respectively}) were noted under application of WCP biochar at 10 t ha^{-1}. Similarly, recorded percent inhibition of french bean seed germination (PIG) under application of biochars at 10 t ha^{-1} is in the following order WCP > TLP > WCG > TLG > WCC > TLC.

Under higher application dose (20 t ha^{-1}) of WCP biochar, french bean seeds documented highest (81.67%) germination percentage and lowest (74.00%) of the same was recorded under application of TLC biochar. Highest (148.00) and lowest (131.67) germination index was recorded under application of TLP and WCC biochar, respectively at 20 t ha^{-1}. Vigor index was maximum (828.67) under application of WCG and minimum (740.33) of the same was documented from application of TLC biochar at the same dose. Similarly, application of TLP biochar at the same rate revealed higher dry matter yield (125 mg seedling^{-1}) of bean seedling and lower (111.3 mg seedling^{-1}) dry matter yield was noted when TLC biochar was added. The percent inhibition of germination (PIG) for french bean seed under 20 t ha^{-1} biochar application displayed the following order TLC > WCC > TLG > TLP > WCG > WCP.

4.2.1.2. Influence of applied biochars on soil properties

pH, EC, water holding capacity (WHC) and bulk density (BD) of biochar amended soil is presented in Table 4.9. Biochar application increased the pH of the slightly acidic soil to near neutral and basic. The highest soil pH (8.73), EC (0.792 mS cm^{-1}) and WHC (76.59%) was noted under application of WCP biochar at 20 t ha^{-1}. Whereas, lowest of the same (6.4, 0.418 mS cm^{-1} and 63.84% pH, EC and WHC, respectively) was documented under addition of TLC biochar at 10 t ha^{-1}. Irrespective of the biochar types, reduced soil BD was documented as compared to control. The lowest soil BD (0.68 mg m^{-3}) was found under addition of 20 t ha^{-1} of WCP biochar.

4.2.1.3. Correlation analysis of germination performance and biochar properties

Correlations analysis of germination performance of mustard and french bean seeds with the biochar properties were showed in the Image 4.3. In both the seeds strong positive correlations were documented among germination percentage and vigor index with MC, VM and ash content of biochars at 10 t ha^{-1} application dose at both *$p<0.05$* and *$p<0.01$* significance level. Strong negative correlations were noted between germination percentage and vigor index with pH and SA of biochars (at 10 t ha^{-1} application dose) at *$p<0.01$*. Whereas, contrasting correlations were noted among germination percentage and vigor index with MC, VM, and ash content, pH and SA of the biochars when applied at the rate of 20 t ha^{-1}.

Table 4.5. Germination percentage of french bean and mustard seeds as influenced by the biochars and its application doses

Treatments (10 t ha^{-1})	Bean	Inc (%)	Mustard	Inc (%)	Treatments (20 t ha^{-1})	Bean	Dec (%)	Mustard	Dec (%)
C	81.67±1.7^{c}		75.00±2.9^{c}		C	81.67±1.7^{a}		75.00±2.9^{a}	
TLC10	90.00±0.0^{a}	10.21	86.67±1.7^{a}	15.56	TLC20	74.00±1.0^{a}	9.38	65.00±2.9^{b}	13.33
TLG10	83.33±1.7^{bc}	2.05	83.33±1.7^{ab}	11.11	TLG20	79.33±0.7^{a}	2.85	70.00±2.9^{ab}	6.67
TLP10	81.67±1.7^{c}	0.01	76.67±1.7^{bc}	2.22	TLP20	77.33±2.7^{a}	5.30	71.67±1.7^{ab}	4.44
WCC10	86.67±1.7^{ab}	6.13	85.00±2.9^{a}	13.33	WCC20	75.33±3.2^{a}	7.75	65.00±2.9^{b}	13.33
WCG10	81.67±1.7^{c}	0.01	80.00±2.9^{abc}	6.67	WCG20	78.33±4.4^{a}	4.07	72.33±1.5^{ab}	3.56
WCP10	82.00±0.0^{c}	0.33	80.00±2.9^{abc}	6.67	WCP20	81.67±1.7^{a}	0.00	73.33±1.8^{a}	2.22
				p values of three way-ANOVA					
B	0.091	S	0.010		B_L	0.007	S×B	0.180	
B×B_L	0.027	S×B_L	0.025		B×S×B_L	0.09			

Where, C= control, Inc = increased, Dec = decreased. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$

Table 4.6. Germination index of french bean and mustard seeds as influenced by the biochars and its application doses

Treatments ($10\ t\ ha^{-1}$)	Bean	Inc (%)	Mustard	Inc (%)	Treatments ($20\ t\ ha^{-1}$)	Bean	Dec (%)	Mustard	Dec (%)
C	161.33±4.4^{b}		107.33±0.9^{e}		C	161.33±4.4^{a}		107.33±0.9^{a}	
TLC10	181.33±2.4^{a}	12.40	118.00±1.7^{a}	9.94	TLC20	136.33±2.2^{cd}	15.49	90.67±0.9^{cd}	15.53
TLG10	166.33±0.9^{b}	3.10	113.00±1.5^{bc}	5.28	TLG20	145.33±0.9^{b}	9.92	95.67±2.7^{bc}	10.87
TLP10	164.00±0.6^{b}	1.66	114.67±0.7^{abc}	6.84	TLP20	148.00±2.5^{b}	8.26	95.67±2.0^{bc}	10.87
WCC10	175.00±1.2^{a}	8.47	116.33±1.5^{ab}	8.39	WCC20	131.67±1.5^{d}	18.39	87.33±2.9^{d}	18.63
WCG10	163.33±1.8^{b}	1.24	112.00±1.7^{cd}	4.35	WCG20	146.33±1.5^{b}	9.30	98.00±2.3^{b}	8.69
WCP10	162.33±1.8^{b}	0.62	108.67±0.3^{de}	1.25	WCP20	141.67±2.3^{bc}	12.19	101.33±1.7^{ab}	5.59
p values of three way-ANOVA									
B	0.986	S	0.069		B_L	0.183	S×B	0.100	
B×B_L	0.701	S×B_L	0.706		B×S×B_L	0.984			

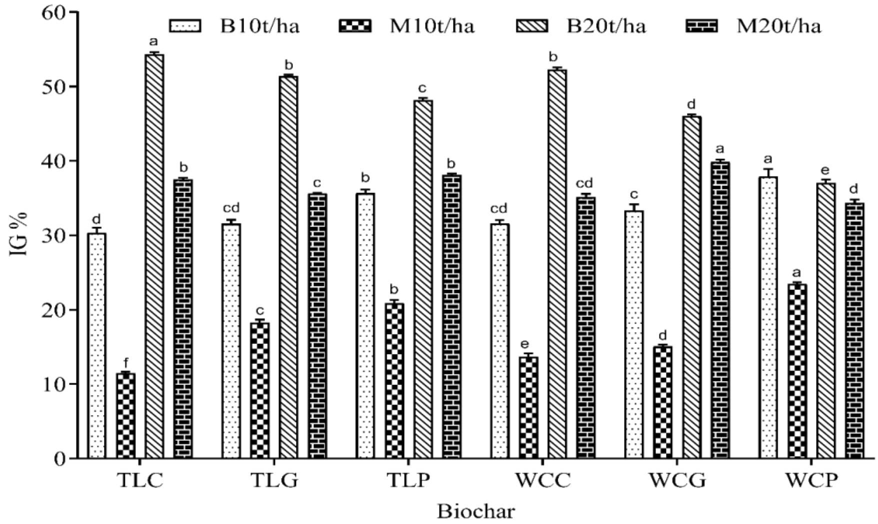
Where, C= control, Inc = increased, Dec = decreased. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.7. Vigor index of bean and mustard seeds as influenced by the biochars and its application doses

Treatment (10 t ha^{-1})	Bean	Inc (%)	Mustard	Inc (%)	Treatment (20 t ha^{-1})	Bean	Dec (%)	Mustard	Dec (%)
C	862.67±4.3^{f}		167.33±2.8^{b}		C	862.67±4.3^{a}		167.33±2.8^{a}	
TLC10	1064.00±3.8^{a}	23.34	188.67±5.0^{a}	12.75	TLC20	740.33±2.6^{d}	14.18	135.00±1.7^{d}	19.32
TLG10	947.33±1.8^{c}	9.82	174.67±2.4^{b}	4.38	TLG20	803.00±1.7^{c}	6.92	143.67±1.2^{c}	14.14
TLP10	882.33±4.1^{e}	2.28	172.33±4.7^{b}	2.99	TLP20	800.83±5.2^{c}	7.17	154.17±1.0^{b}	7.87
WCC10	992.33±3.2^{b}	15.03	187.33±1.5^{a}	11.95	WCC20	751.33±2.3^{d}	12.91	138.67±3.4^{cd}	17.13
WCG10	905.00±2.3^{d}	4.91	167.67±1.9^{b}	0.20	WCG20	828.67±3.5^{b}	3.94	158.83±1.9^{b}	5.08
WCP10	879.33±4.7^{e}	1.93	168.00±1.5^{b}	0.40	WCP20	831.00±4.5^{b}	3.67	158.67±3.5^{b}	5.18
				p values of three way-ANOVA					
B	0.815	S	0.012		B_L	0.103	S×B	0.797	
B×B_L	0.386	S×B_L	0.148		B×S×B_L	0.483			

Where, C= control, Inc = increased, Dec = decreased. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Fig 4.3. Percent inhibition of seed germination in bean (B) and mustard (M) as influenced by different doses of tested biochars



Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.8. Dry matter yield (mg seedling^{-1}) of bean and mustard seedlings as influenced by the biochars and its application doses

Treatments (10 t ha^{-1})	Bean	Mustard	Treatments (20 t ha^{-1})	Bean	Mustard
TLC10	186.4±3.5^{a}	92.1±2.5^{a}	TLC20	111.3±2.1^{c}	36.2±1.9^{c}
TLG10	166.7±5.5^{b}	68.5±2.5^{b}	TLG20	120.6±3.6^{b}	44.3±0.9^{b}
TLP10	144.1±3.6^{d}	56.8±2.3^{d}	TLP20	125.3±4.4^{a}	42.6±2.0^{b}
WCC10	153.5±4.1^{c}	51.4±4.0^{e}	WCC20	112.3±4.1^{c}	37.2±1.2^{c}
WCG10	142.8±4.1^{d}	59.1±2.6^{c}	WCG20	121.8±3.6^{b}	43.4±0.9^{b}
WCP10	135.0±2.2^{e}	48.2±1.5^{f}	WCP20	119.7±4.1^{b}	45.3±1.2^{ab}
C	127.9±0.41	47.2±0.15	C	127.9±0.41	47.2±0.15

Where, C = control. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

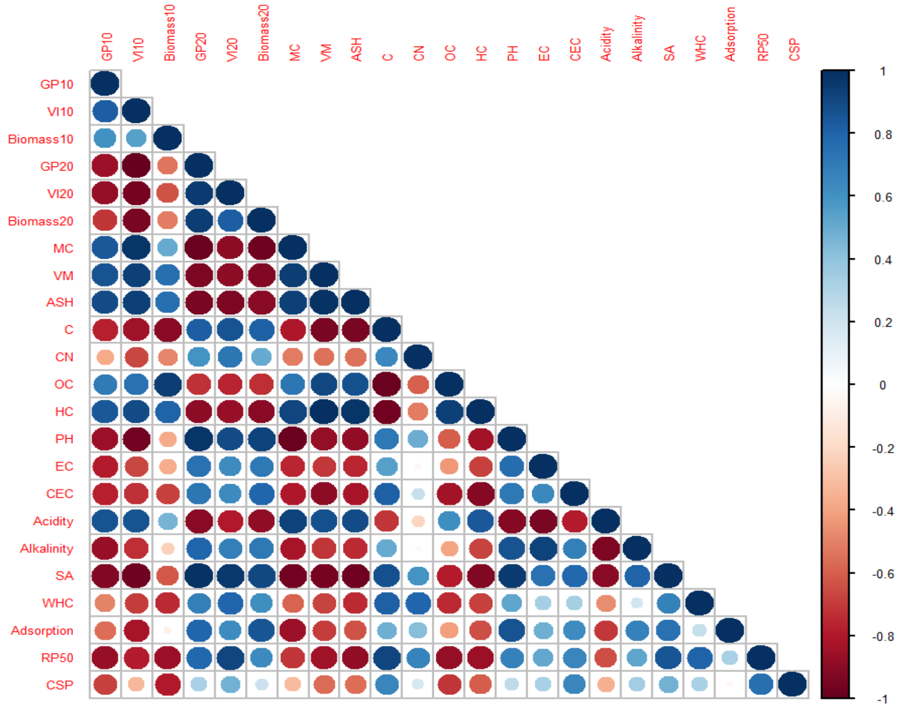
Table 4.9. Influence of biochar on soil physico chemical parameters of the french bean and mustard seedbed

Treatments (10 t ha^{-1})	pH	EC (mS cm^{-1})	WHC (%)	BD (mg m^{-3})	Treatments (20 t ha^{-1})	pH	EC (mS cm^{-1})	WHC (%)	BD (mg m^{-3})
C	5.90±0.17^{d}	0.343±0.00^{e}	54.73±1.1^{d}	1.12±0.09^{a}	C	5.90±0.17^{d}	0.343±0.00^{e}	54.73±1.1^{d}	1.12±0.09^{a}
TLC10	6.40±0.06^{c}	0.418±0.01^{d}	63.84±0.7^{c}	0.86±0.02^{b}	TLC20	6.90±0.16^{c}	0.614±0.01^{d}	66.96±0.7^{c}	0.75±0.01^{b}
TLG10	7.43±0.09^{a}	0.476±0.01^{c}	65.78±0.4^{c}	0.81±0.03^{bc}	TLG20	7.67±0.09^{b}	0.675±0.09^{c}	73.69±0.6^{b}	0.71±0.02^{bc}
TLP10	7.73±0.15^{a}	0.531±0.01^{a}	68.41±1.3^{b}	0.80±0.03^{bc}	TLP20	7.87±0.15^{b}	0.729±0.06^{b}	77.46±0.5^{a}	0.69±0.01^{c}
WCC10	6.93±0.17^{b}	0.489±0.01^{bc}	64.05±0.7^{c}	0.82±0.02^{bc}	WCC20	7.50±0.17^{b}	0.670±0.03^{c}	66.68±0.4^{c}	0.71±0.04^{bc}
WCG10	7.77±0.09^{a}	0.506±0.01^{b}	68.78±1.5^{b}	0.78±0.01^{c}	WCG20	8.37±0.09^{a}	0.792±0.12^{a}	77.35±1.2^{a}	0.69±0.06^{c}
WCP10	7.77±0.19^{a}	0.495±0.01^{bc}	71.96±0.8^{a}	0.78±0.01^{d}	WCP20	8.73±0.19^{a}	0.738±0.03^{b}	76.59±0.7^{a}	0.68±0.05^{c}

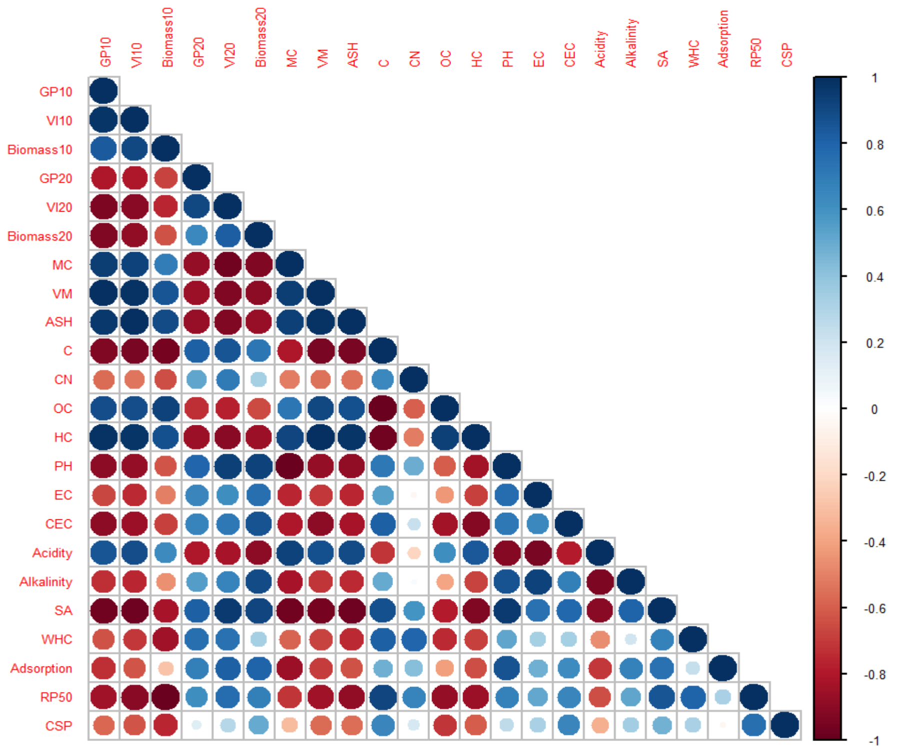
Where, EC = electrical conductivity, WHC = water holding capacity, C = control. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Image 4.3. Pearson correlation matrix of germination performance and biochar properties

A



B



Where, A = mustard, B = french bean, GP = germination percentage, VI= vigor index, 10 = 10 t ha^{-1}, 20 = 20 t ha^{-1}, MC = moisture, VM = volatile matter, C = carbon, CN = C/N ratio, OC = O/C ratio, HC = H/C ratio, WHC = water holding capacity, EC = electrical conductivity, CEC = cation exchange capacity, SA =

specific surface area, RP50 = recalcitrance potential, CSP = carbon sequestration potential.

4.2.2. To investigate the impacts of biochar application on growth and yield of mustard (*Brassica juncea* L.) variety TS 38 and french bean (*Phaseolus vulgaris* L.) variety Arka Anoop

4.2.2.1. Leaf photosynthesis (µmol CO_2 m^{-2} s^{-1}), transpiration (µmol H_2O m^{-2} s^{-1})

Photosynthesis rate of mustard crop at various growth stages are presented in the Figure 4.4. Irrespective of the treatments, the highest photosynthesis rate was noted during flowering stage followed by vegetative and maturity stage of the crop (15.326 µmol CO_2 m^{-2} s^{-1}, 24.866 µmol CO_2 m^{-2} s^{-1} and 8.464 µmol CO_2 m^{-2} s^{-1}, respectively). During flowering stage, the highest (24.866 µmol CO_2 m^{-2} s^{-1}) photosynthesis rate was observed under application of inorganic fertilizers (NPKR) whereas control recorded the lowest (14.020 µmol CO_2 m^{-2} s^{-1}) of the same. Among the plots treated with the tested biochars, the highest photosynthesis rate (22.35 µmol CO_2 m^{-2} s^{-1}) was documented from the treatment TLC10 followed by WCC10 (21.02 µmol CO_2 m^{-2} s^{-1}) at flowering stage of mustard crop. The lowest of the same (18.93 µmol CO_2 m^{-2} s^{-1}) was recorded from treatment TLG10. Treatments with FYM at 10 t ha^{-1} (FYM10) recorded photosynthesis rate of 15.70 µmol CO_2 m^{-2} s^{-1} in mustard leaf. Moreover, co-addition of biochars with FYM (5 t ha^{-1} each) showed the photosynthesis rate of 17.49 µmol CO_2 m^{-2} s^{-1} (TGFYM) to 21.82 µmol CO_2 m^{-2} s^{-1} (WCFYM). Whereas, addition of biochars (at 5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) exhibited the photosynthesis of 21.13 µmol CO_2 m^{-2} s^{-1} (WCNPK) to 24.52 µmol CO_2 m^{-2} s^{-1} (TCNPK).

Photosynthesis activity of french bean crop at all the growth stages are displayed in the Figure 4.5. Similar to mustard, french bean plants also showed maximum photosynthesis rate at flowering stage, followed by vegetative and maturation stages of the crop. The photosynthesis efficiency of french bean plant was observed best under the treatment NPKR (15.093 µmol CO_2 m^{-2} s^{-1}, 27.765 µmol CO_2 m^{-2} s^{-1} and 12.645 µmol CO_2 m^{-2} s^{-1} at vegetative, flowering and maturation stage, respectively). While, lowest of the same were noted under treatment WCG5 (7.896 µmol CO_2 m^{-2} s^{-1},16.590 µmol CO_2 m^{-2} s^{-1} and 8.58 µmol CO_2 m^{-2} s^{-1}, respectively). Among the tested biochars, treatment TLC10 recorded higher (25.29 µmol CO_2 m^{-2} s^{-1}) photosynthesis rate at flowering stage while lowest (21.81 µmol CO_2 m^{-2} s^{-1}) of the same was recorded from treatment TLG10. Treatment FYM10 recorded photosynthesis rate of 18.27 µmol CO_2 m^{-2} s^{-1} at the same crop growth stage. Co-addition of biochar and FYM (5 t ha^{-1} each) from treatment TGFYM and WCFYM noted photosynthesis rate of 17.49 µmol CO_2 m^{-2} s^{-1} and 21.82 µmol CO_2 m^{-2} s^{-1}, respectively at flowering stage. Whereas, at the same crop growth stage, addition of biochars (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) from treatments exhibited photosynthesis rate of 21.13 µmol CO_2 m^{-2} s^{-1} (WCNPK) to 24.52 µmol CO_2 m^{-2} s^{-1} (TCNPK).

The rate of transpiration among the treatments varied significantly with crop growth stages of both the tested crops with highest at flowering stage (Figures 4.6 and 4.7). Treatment NPKR displayed highest (3.92 µmol H_2O m^{-2} s^{-1}) transpiration rate at flowering stage of mustard crop. Whereas, lowest (2.19 µmol H_2O m^{-2} s^{-1}) of the same was recorded from treatment WCC10. Application of FYM at 10 t ha^{-1} (FYM10) showed transpiration rate of 2.96 µmol H_2O m^{-2} s^{-1}. Co-application of biochar and FYM (5 t ha^{-1} each) noted the transpiration rate of 2.96 µmol H_2O m^{-2} s^{-1} to 3.19 µmol H_2O m^{-2} s^{-1} in treatments WGFYM and TCFYM, respectively. Whereas, addition of biochars (at 5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) exhibited 3.68 µmol H_2O m^{-2} s^{-1} to 3.77 µmol H_2O m^{-2} s^{-1} of the same from treatment TCNPK and WGNPK, respectively.

Moreover, at the flowering stage of french bean, maximum (3.53 µmol H_2O m^{-2} s^{-1}) transpiration was recorded from treatment NPKR and minimum (1.90 µmol H_2O m^{-2} s^{-1}) of the same was recorded from treatment TLG10. Application of FYM at 10 t ha^{-1} (FYM10) showed transpiration rate of 2.78 µmol H_2O m^{-2} s^{-1}. Co-application of biochar with FYM (5 t ha^{-1} each) showed the transpiration rate of 2.89 µmol H_2O m^{-2} s^{-1} to 2.94 µmol H_2O m^{-2} s^{-1} from treatments TCFYM and TGFYM, respectively. Whereas, addition of biochars (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) exhibited transpiration rate of 3.27 µmol H_2O m^{-2} s^{-1} to 3.37 µmol H_2O m^{-2} s^{-1} under treatments WCNPK and TGNPK, respectively.

4.2.2.2. Plant biomass (g $plant^{-1}$)

At harvest, the highest plant shoots fresh biomass of mustard was observed from the treatment NPKR (13.10 g plant^{-1}). Treatment TLG5 (9.93 g plant^{-1}) recorded the lowest plant shoot fresh biomass. However, maximum plant shoots dry biomass was found under treatment TLC10 (7.59 g plant^{-1}) and the lowest was documented in treatment WCC5 (4.92 g plant^{-1}). Moreover, recorded fresh and dry shoot biomass of mustard under treatment FYM10 was 10.17 g plant^{-1} and 3.54 g plant$^{-1, \text{ respectively}}$. Coming to the root biomass, the maximum fresh root biomass was noted from treatment NPKR (5.70 g plant^{-1}) and the lowermost result was recorded from control (3.10 g plant^{-1}). However, maximum dry root biomass was noted from treatment TLC10 (3.30 g plant^{-1}) and lowest of the same was recorded from the control (1.14 g plant^{-1}). Whereas, treatment FYM10 recorded 6.66 g plant^{-1} and 1.96 g plant^{-1} fresh and dry root biomass, respectively (Table 4.10).

Maximum (15.13 g plant^{-1}) fresh shoot biomass of french bean crop was noted from treatment NPKR and the lowest (10.89 g plant^{-1}) value was recorded from control. However, maximum (9.16 g plant^{-1}) shoot dry biomass was recorded under treatment TLC10 followed by TLG10 (8.83 g plant^{-1}) and the lowest (6.82 g plant^{-1}) was found in control. Fresh and dry shoot biomass of french bean from treatment FYM10 was 11.57 g plant^{-1} and 7.68 g plant$^{-1, \text{ respectively}}$. Moreover, treatment TLC10 also noted maximum (8.05 g plant^{-1}) fresh root biomass and the minimum (4.88 g plant^{-1}) of the same was noted from treatment FMNPK. Regarding the dry root biomass, the highest (6.43 g plant^{-1}) value was documented from treatment WCG10 and least (3.11 g plant^{-1}) of the same was noted under treatment FMNPK. Whereas, recorded fresh and dry root biomass from treatment FYM10 was 7.63 g plant^{-1} and 4.26 g plant$^{-1, \text{ respectively}}$ (Table 4.11).

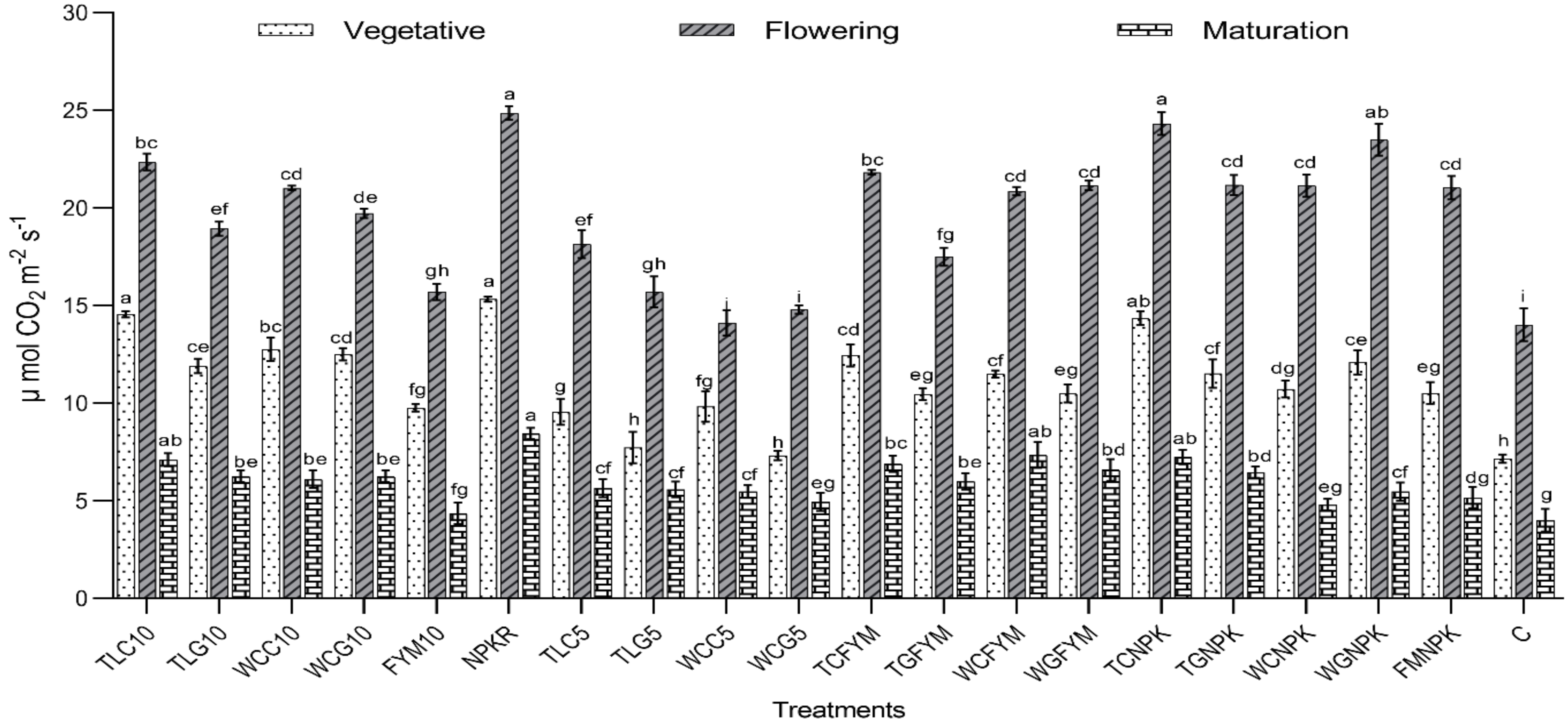
4.2.2.3. Seed yield (t ha^{-1})

Seed yield of mustard was ranged from 1.312 t ha^{-1} to 0.920 t ha^{-1}. Recorded seed yield among the treatments were as follows TLC10 > NPKR > WCC10 > FMNPK > TGNPK > FYM10 > WCG10 > TCNPK > TLC5 > TLG10 > WCC5 > WCNPK > WCFYM > WGNPK > TCFYM > TLG5 > WCG5 > TGFYM > WGFYM > C (Figure 4.8).

Pod yield of french bean were ranged 5.556 to 2.540 t ha^{-1}. Recorded pod yield among the treatments were as follows TLC10 > TGFYM > WCC10 > FMNPK > WCFYM >

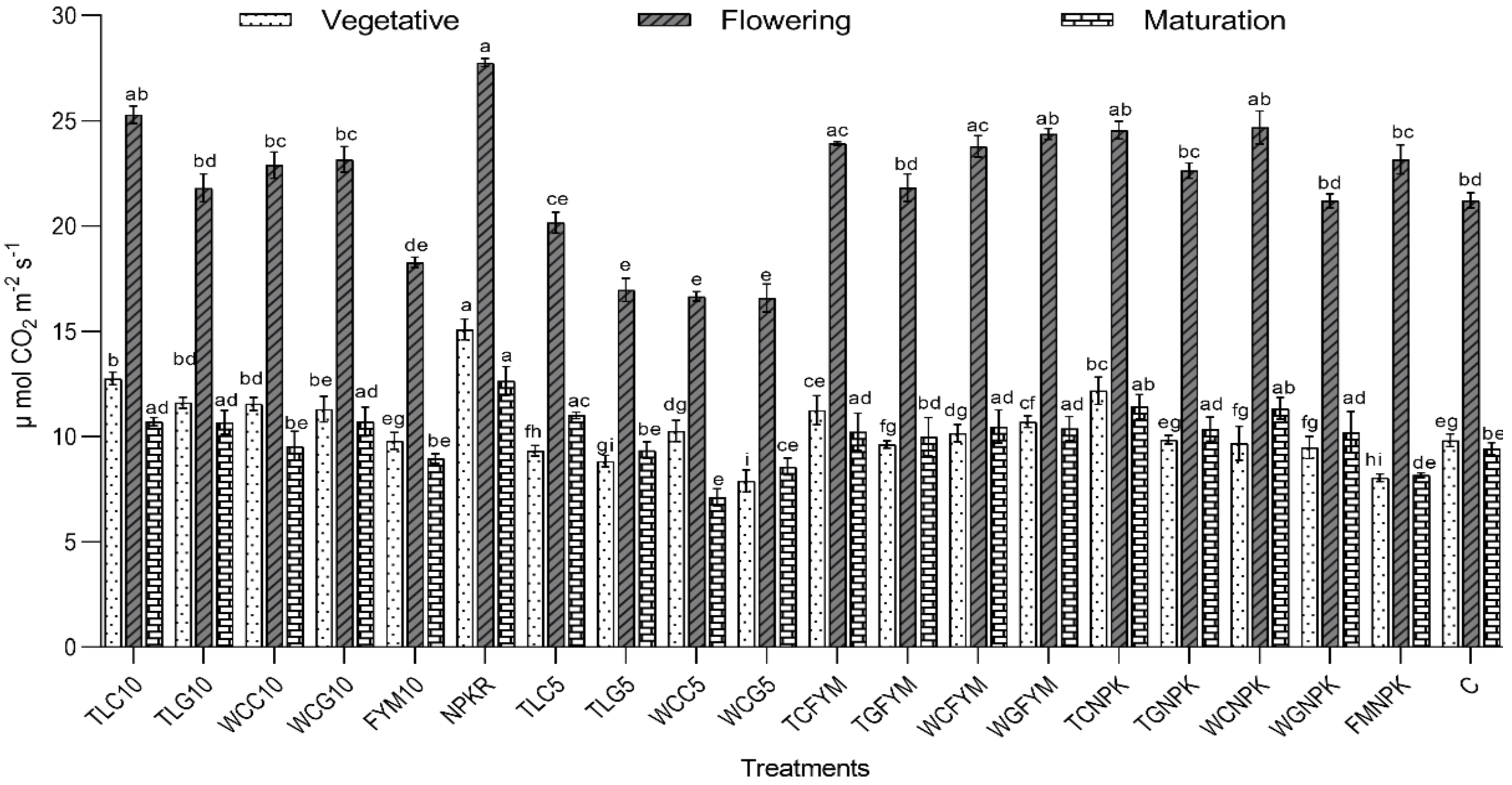
FYM10 > TCFYM > WCNPK > TCNPK > NPKR > TCNPK > TLG5 > TLG10 > TLC5 > TGNPK > WGNPK > WCG10 > WCC5 > WCG5 > C (Figure 4.9)

Figure 4.4. Photosynthetic rate of mustard plant as influenced by applied treatments



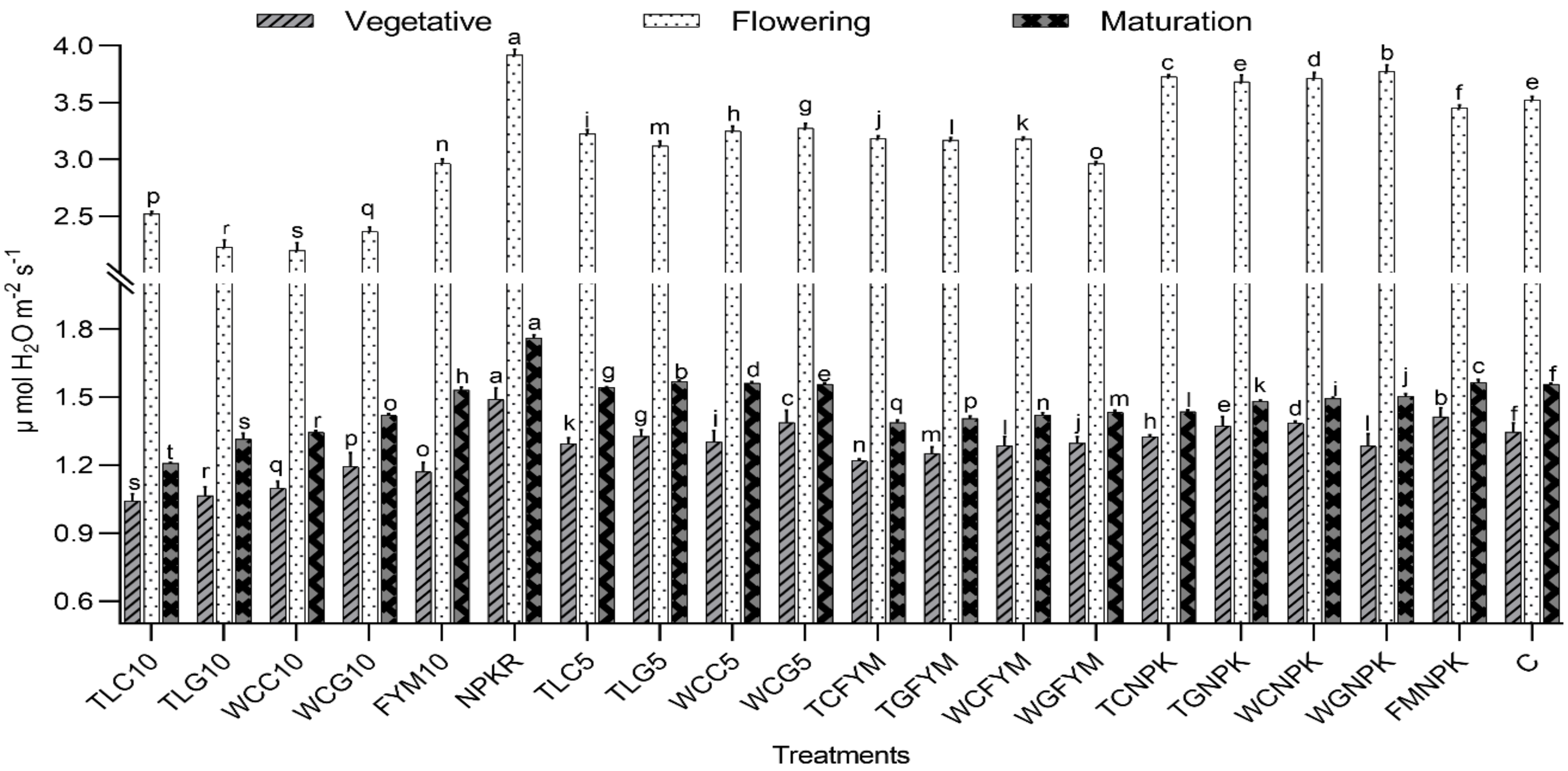
Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Figure 4.5. Photosynthesis rate of french bean plant as influenced by applied treatments



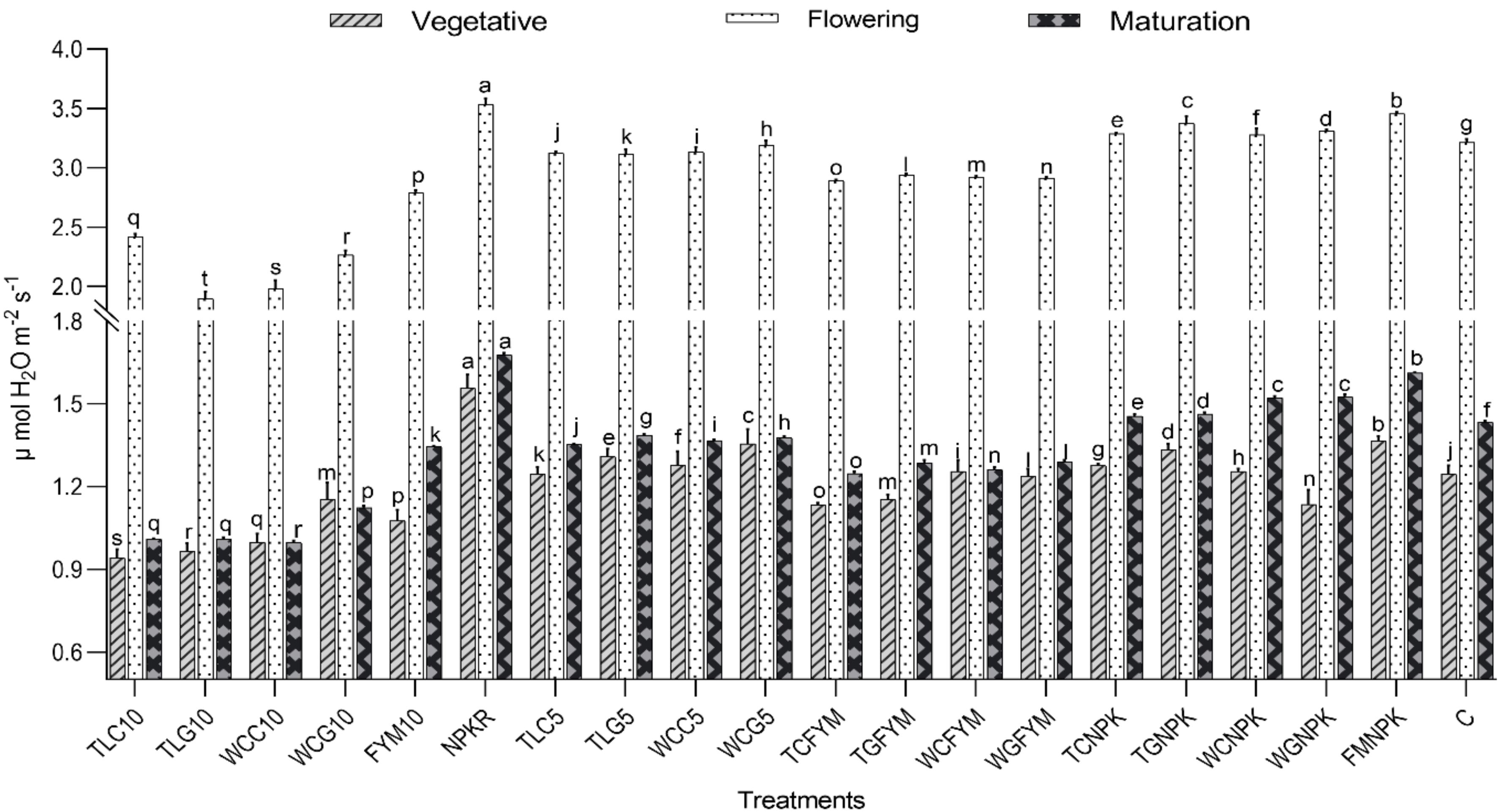
Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at *p<0.05*.

Figure 4.6. Transpiration rate of mustard plant as influenced by applied treatments



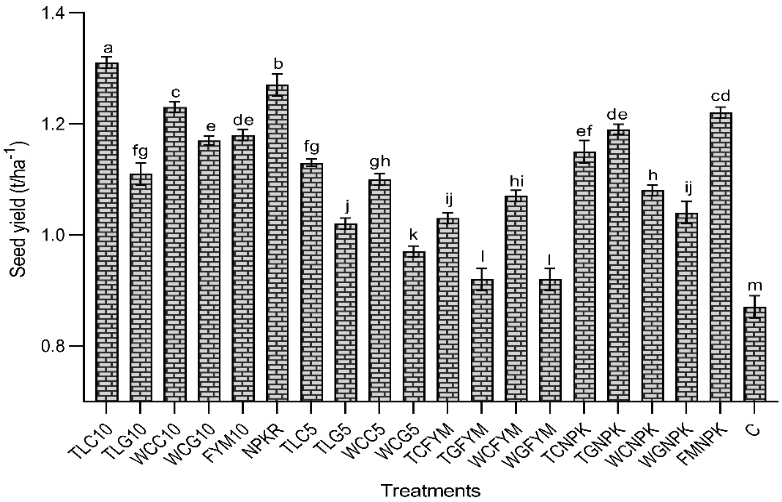
Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Figure 4.7. Transpiration rate of french bean plant as influenced by applied treatments



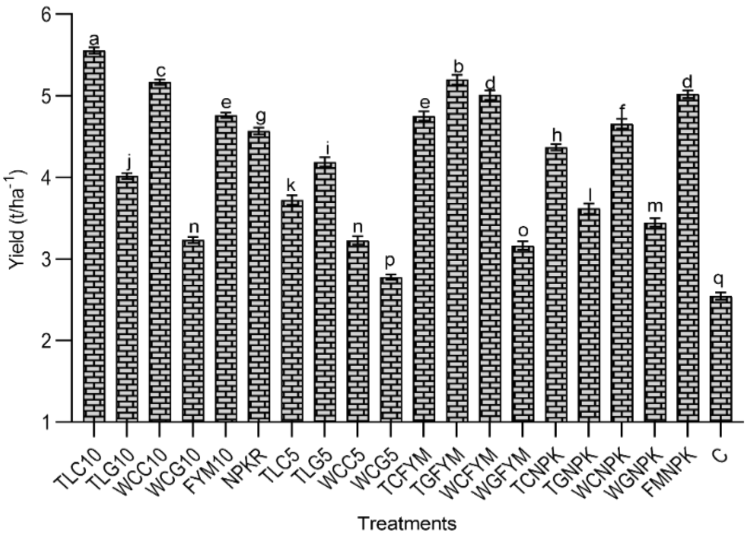
Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$

Figure 4.8. Seed yield of mustard plant as influenced by applied treatments



Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Figure 4.9. Pod yield of french bean plant as influenced by applied treatments



Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.10. Biomass yield of mustard plant as influenced by applied treatments

Treatments	Plant Biomass (g plant^{-1})			
	Fresh wt. (shoot)	Fresh wt. (root)	Dry wt. (shoot)	Dry wt. (root)
TLC10	11.75 ± 0.24^{ae}	4.69 ± 0.50^{bcd}	7.59 ± 0.40^{a}	3.30 ± 0.32^{a}
TLG10	10.84 ± 0.28^{ch}	3.60 ± 0.18^{efg}	7.03 ± 0.32^{ab}	2.20 ± 0.14^{ce}
WCC10	11.67 ± 0.56^{be}	4.53 ± 0.20^{be}	6.58 ± 0.45^{bcd}	2.40 ± 0.24^{be}
WCG10	10.74 ± 0.32^{ch}	3.65 ± 0.06^{efg}	7.01 ± 0.06^{ab}	1.92 ± 0.07^{efg}
FYM10	10.17 ± 0.57^{fgh}	3.54 ± 0.28^{efg}	6.66 ± 0.17^{bcd}	1.96 ± 0.15^{efg}
NPKR	13.10 ± 0.27^{a}	5.70 ± 0.42^{a}	6.87 ± 0.25^{abc}	2.89 ± 0.43^{abc}
TLC5	10.34 ± 0.12^{eh}	3.74 ± 0.31^{dg}	6.06 ± 0.20^{cde}	1.31 ± 0.10^{gh}
TLG5	9.93 ± 0.24^{h}	3.36 ± 0.31^{fg}	5.86 ± 0.30^{def}	1.26 ± 0.09^{gh}
WCC5	10.05 ± 0.62^{gh}	3.97 ± 0.15^{bg}	4.92 ± 0.11^{g}	1.95 ± 0.25^{efg}
WCG5	10.66 ± 0.42^{dh}	3.97 ± 0.43^{bg}	5.05 ± 0.41^{fg}	2.22 ± 0.36^{ce}
TCFYM	11.84 ± 0.55^{ad}	4.96 ± 0.12^{ab}	6.28 ± 0.16^{be}	3.03 ± 0.30^{ab}
TGFYM	10.39 ± 0.50^{eh}	4.22 ± 0.35^{bf}	6.12 ± 0.17^{be}	2.20 ± 0.20^{ce}
WCFYM	12.11 ± 0.29^{abc}	4.86 ± 0.19^{abc}	6.07 ± 0.21^{cde}	3.22 ± 0.16^{a}
WGFYM	10.01 ± 0.40^{gh}	4.15 ± 0.32^{bf}	5.99 ± 0.15^{cde}	2.74 ± 0.03^{ad}
TCNPK	12.33 ± 0.58^{ab}	4.54 ± 0.18^{be}	5.92 ± 0.10^{cde}	1.40 ± 0.07^{fgh}
TGNPK	11.71 ± 0.46^{ae}	4.25 ± 0.20^{bf}	5.99 ± 0.35^{cde}	2.08 ± 0.11^{def}
WCNPK	12.40 ± 0.24^{ab}	4.41 ± 0.48^{be}	5.97 ± 0.17^{cde}	1.82 ± 0.25^{eh}
WGNPK	11.54 ± 0.53^{bf}	3.93 ± 0.36^{cg}	6.19 ± 0.39^{be}	1.81 ± 0.30^{eh}
FMNPK	11.38 ± 0.52^{bg}	3.31 ± 0.11^{fg}	6.01 ± 0.43^{cde}	1.37 ± 0.15^{fgh}
C	10.14 ± 0.29^{fgh}	3.10 ± 0.27^{g}	5.51 ± 0.25^{efg}	1.14 ± 0.19^{h}
LSD	0.60	0.42	0.39	0.32

Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$

Table 4.11. Biomass yield of french bean plant as influenced by applied treatments

Treatments	Plant biomass (g plant^{-1})			
	Shoot fresh	Root fresh	Shoot dry	Root dry
TLC10	14.17±0.11^{ab}	8.05±0.39^{a}	9.16±0.06^{a}	5.14±0.40^{ad}
TLG10	13.94±0.48^{abc}	7.27±0.22^{ad}	8.83±0.53^{ab}	4.53±0.36^{cd}
WCC10	13.57±0.76^{ae}	7.86±0.37^{ab}	8.25±0.41^{abc}	5.30±0.45^{ad}
WCG10	13.74±0.46^{abc}	5.35±0.73^{fg}	7.88±0.38^{abc}	6.43±0.34^{a}
FYM10	11.57±0.36^{efg}	7.68±0.17^{abc}	7.63±0.20^{bc}	4.26±0.76^{cde}
NPKR	15.13±0.29^{a}	6.77±0.39^{af}	7.50±0.19^{bc}	4.29±0.29^{cde}
TLC5	11.61±0.27^{dg}	6.74±0.26^{af}	7.26±0.21^{c}	5.14±0.11^{ad}
TLG5	11.03±0.60^{fg}	7.29±0.25^{ad}	6.90±0.24^{c}	4.59±0.26^{cd}
WCC5	11.95±0.41^{cg}	6.27±0.49^{bg}	7.89±0.49^{abc}	5.59±0.34^{abc}
WCG5	11.46±0.38^{fg}	5.53±0.86^{efg}	7.05±0.26^{c}	5.22±0.51^{ad}
TCFYM	13.04±0.96^{bf}	6.93±0.10^{af}	7.88±0.30^{abc}	4.20±0.19^{de}
TGFYM	12.86±0.74^{bg}	7.55±0.80^{abc}	7.76±0.75^{abc}	5.06±0.27^{bd}
WCFYM	12.61±0.67^{bg}	5.86±0.20^{dg}	7.40±0.67^{bc}	5.13±0.11^{ad}
WGFYM	11.51±0.78^{fg}	5.82±0.38^{dg}	7.01±0.44^{c}	4.09±0.30^{de}
TCNPK	13.60±0.39^{ad}	8.17±0.50^{a}	7.92±0.47^{abc}	5.95±0.58^{ab}
TGNPK	13.82±0.17^{abc}	6.02±0.86^{cg}	6.99±0.43^{c}	4.25±0.74^{cde}
WCNPK	11.65±1.37^{dg}	7.04±0.42^{ae}	7.63±0.72^{bc}	5.13±0.15^{ad}
WGNPK	12.37±0.64^{bg}	6.58±0.67^{af}	7.59±0.79^{bc}	4.14±0.51^{de}
FMNPK	12.56±0.23^{bg}	4.88±0.23^{g}	7.37±0.32^{bc}	3.11±0.22^{e}
C	10.89±0.35^{g}	6.70±0.44^{af}	6.82±0.26^{c}	4.83±0.23^{bd}
LSD	0.84	0.69	0.64	0.56

Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

4.2.3 To investigate the impacts of biochar application on soil properties of mustard (*Brassica juncea* L., variety TS 38) and french bean (*Phaseolus vulgaris* L., variety Arka Anoop) field

4.2.3.1. Basic soil properties of the experimental fields

The study was carried out in an acidic sandy loam soil of north bank plain agroclimatic zones of Assam, India. Experimental soil had sand, silt and clay percentage of 54.4%, 18.3% and 27.9%, respectively. Recorded soil pH = 6.1, EC = 0.32 mS cm^{-1}, total nitrogen = 0.87% total C = 2.70%, SOC = 0.95%, HAC = 0.37%, FAC = 0.33%, MBC = 281.45 mg kg^{-1}, bacterial count = 3.70 log cfu g^{-1} soil and available N, P, K = 197.3 kg ha^{-1}, 39.3 kg ha^{-1}, 172.8 kg ha^{-1}, respectively (Table 4.12).

4.2.3.2. Basic properties of farmyard manure (FYM)

Basic properties of tested FYM are displayed in the Table 4.12. The applied FYM recorded pH = 6.98, EC = 0.537 mS cm^{-1}, total nitrogen = 1.82%, total C = 29.87%, organic carbon (OC) = 26.3%, HAC = 0.53%, FAC = 0.567%, MBC = 628.76 mg kg^{-1}, bacterial count = 4.61 log cfu g^{-1} soil, and available N, P, K was 689.5 kg ha^{-1}, 211.49 kg ha^{-1}, 267.53 kg ha^{-1}, respectively.

4.2.3.3. Soil pH and electrical conductivity (EC)

pH and EC of the collected soils from mustard field are presented in the Table 4.13. Addition of biochars significantly increased the soil pH (C = 5.9 to TLG10 = 6.63). However, with the application of NPK a decreased value of pH (5.87) was observed. Furthermore, FYM at 10 t ha^{-1} (FYM10) raised the soil pH to 6.13. Mixing of biochar and FYM (at 5 t ha^{-1} each) increased the soil pH upto 6.23. Nevertheless, mixing of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) increased the same upto 6.10. Highest EC (0.690 mS cm^{-1}) was recorded from the treatment TLG10 followed by treatments TLC10 and TGFYM (0.643 mS cm^{-1} in both). Treatment FYM10 and NPKR recorded EC of 0.523 mS cm^{-1} and 0.530 mS $cm^{-1, respectively}$. Whereas, the lowest (0.333 mS cm^{-1}) EC was observed in control (C).

Similarly, pH and EC of soils collected from french bean field are presented in Table 4.14. Recorded soil pH ranges between 5.87 to 6.57 (from treatment NPKR and

TLG10, WCG10, respectively). Compared to control, biochar amendment at 10 t ha^{-1} significantly increased the soil pH (C = 5.93 to TLG10, WCG10 = 6.57 in both). Furthermore, FYM at 10 t ha^{-1} (FYM10) raised the soil pH to 6.10. Mixing of biochar (5 t ha^{-1}) along with inorganic NPK fertilizers (50% of recommended dose) increased the same to 6.17. The highest (0.683 mS cm^{-1}) soil EC was noted under treatment TLG10 followed by TLC10 (0.647 mS cm^{-1}) and the lowest (0.337 mS cm^{-1}) of the same was noted in C. Whereas, Treatment FYM10 and NPKR recorded same EC value of 0.530 mS cm^{-1}.

4.2.3.4. Soil water holding capacity (WHC%) and Bulk density (BD mg m^{-3})

WHC and BD of the soils collected from mustard and french bean field are presented in the Tables 4.13 and 4.14. The highest WHC was documented in treatment TLG10 (63.46%) followed by WCG10 (63.03%). In control (C), WHC was found to be lowest (53.82%). Treatment FYM10 and NPKR recorded 58.42% and 57.87% of WHC, respectively. Whereas, co-application of biochars and FYM (at 5 t ha^{-1} each) showed soil WHC in the range 59.22% (WCFYM) to 59.82% (WGFYM). While, addition of biochar (at 5 t ha^{-1}) with inorganic NPK fertilizer (50% of recommended dose) exhibited 58.27% (WCNPK) to 58.58% (WGNPK) of the same.

Application of tested amendments lowered down the soil BD of mustard field to a noticeable extend. Controlled plots showed BD of 0.98 mg m^{-3}. While, biochar treated plots (at 10 t ha^{-1}) recorded the maximum reduction in BD where higher reduction was observed under treatment WCG10 (0.78 mg m^{-3}) followed by treatments WCC10 (0.82 mg m^{-3}), TLG10 (0.84 mg m⁻3) and TLC10 (0.86 mg m^{-3}). While, recorded BD from FYM treated (at 10 t ha^{-1}) plots (FYM10) was 0.86 mg m^{-3}. Co-application of biochars and FYM (5 t ha^{-1} each) displayed BD in the range of 0.82 mg m^{-3} (WGFYM) to 0.88 mg m^{-3} (TCFYM, WCFYM). Whereas, addition of biochar (5 t ha^{-1}) with inorganic NPK fertilizer (50% of recommended dose) exhibited 0.89 mg m^{-3} (WGNPK) to 0.96 mg m^{-3} (WCNPK) of the same.

Similar to the soils of mustard field, the highest (63.59%) WHC of the soils collected from french bean field was documented in treatment TLG10 followed by WCG10 (63.06) and the lowest (53.82%) of the same was recorded from control. Treatment FYM10 and NPKR recorded 58.52% and 57.69% of WHC, respectively. Whereas, co-application of biochars and FYM (at 5 t ha^{-1} each) displayed soil WHC in the range of 59.32% (TGFYM) to 59.82% (WGFYM). While, addition of biochar (at 5 t ha^{-1}) with inorganic NPK fertilizer (50% of recommended dose) exhibited 58.45% (WCNPK) to 59.53% (WGNPK) of soil WHC.

Likewise, in french bean field soils, control plots exhibited highest (0.98 mg m^{-3}) soil BD whereas, use of biochars reduced it upto 20.4%. Biochar treated (at 10 t ha^{-1}) plots showed the highest reduction in BD where, higher reduction was observed under treatment WCG10 (0.77 mg m^{-3}) followed by treatments WCC10 (0.82 mg m^{-3}), TLG10 (0.85 mg m^{-3}) and TLC10 (0.87 mg m^{-3}). Whereas, treatment FYM10 documented 0.88 mg m^{-3} of the same. Co-application of biochars and FYM (5 t ha^{-1} each) displayed BD in the range 0.80 mg m^{-3} (WGFYM) to 0.89 mg m^{-3} (TCFYM). Whereas, addition of biochar (at 5 t ha^{-1}) with inorganic NPK fertilizer (50% of recommended dose) exhibited 0.89 mg m^{-3} (WGNPK) to 0.95 mg m^{-3} (TCNPK) of the same.

4.2.3.5. Soil cation exchange capacity (CEC) ($cmol_{+}kg^{-1}$)

CEC of soils collected from both the fields were influenced by the applied treatments and are presented in Tables 4.13 and 4.14. In mustard fields, biochar application at 10 t ha^{-1} improved the CEC upto 37.53% as compared to control. Whereas FYM application at equal rate raised it upto 19.6%. On the other hand, inorganic NPK treatment at recommended dose increased the same upto 3%. Co-application of biochars and FYM (at 5 t ha^{-1} each) increased CEC upto 28.88%. Whereas, addition of biochar (at 5 t ha^{-1}) with inorganic NPK fertilizer (50% of recommended dose) enhanced the soil CEC upto 14.18%

In french bean field, compared to control, upto 42.48% hike in soil CEC was recorded under application of biochars at 10 t ha^{-1}. While use of FYM at the same rate increased the CEC up to 26.7%. Besides, application of inorganic NPK fertilizers at recommended dose hiked the same upto 7.97%. Moreover, co-application of biochars and FYM (at 5 t ha^{-1} each) improved the same up to 30.37%. Whereas, addition of biochar (5 t ha^{-1}) with inorganic NPK fertilizer (50% of recommended dose) enhanced the soil CEC upto 15.84%.

4.2.3.6. Soil nitrogen fractions (total nitrogen (%), available N (kg ha^{-1}), NO_3 –N (mg kg^{-1}), NH_4 –N (mg kg^{-1})

In mustard field, the estimated total N content was highest (2.04%) under treatment NPKR followed by treatment TLG10 (1.82%). Treatment FYM10 recorded 1.2% of the same. Co-application of inorganic NPK fertilizers (50% of recommended dose) and biochar (5 t ha^{-1}) exhibited total N content in the range of 1.42% (WGNPK) to 1.67% (TCNPK, WCNPK). Moreover, co-addition of biochars and FYM (5 t ha^{-1} each) noted 1.31% (TGFYM, WCFYM) to 1.51% (TCFYM) of total N content. Whereas, control showed the lowest (1.01%) total N content (Table 4.15).

Similarly, available soil nitrogen content was highest (663.23 kg ha^{-1}) in treatment NPKR and the lowest (203 kg ha^{-1}) of the same was documented in control. Application of biochars (10 t ha^{-1}) recorded available N in the range of 340.20 kg ha^{-1} (WCG10) to 418.87 kg ha^{-1} (TLG10). Whereas, FYM application at 10 t ha^{-1} (FYM10) documented 572.57 kg ha^{-1} of the same. Co-application of inorganic NPK fertilizer (50% of recommended dose) and biochar (5 t ha^{-1}) exhibited available N in the range of 505.07 kg ha^{-1} (WGNPK) to 564.24 kg ha^{-1} (TCNPK). Moreover, co-addition of biochars and FYM (5 t ha^{-1} each) recorded the same from 431.52 kg ha^{-1} (WGFYM) to 515.32 kg ha^{-1} (TCFYM) (Figure 4.10).

Soils from mustard field recorded NH_4–N in the range between 44.98 mg kg^{-1} to 149.64 mg kg^{-1} and NO_3–N from 156.83 mg kg^{-1} to 509.71 mg kg^{-1} in control and treatment NPKR, respectively. Whereas, sole application of FYM at 10 ha^{-1} (FYM10) showed 131.86 mg kg^{-1} and 438.84 mg kg^{-1} of NH_4–N and NO_3–N, respectively. However, among the biochars treatments (at 10 t ha^{-1}) TLC10 displayed the highest (93.79 mg kg^{-1}) content of NH_4–N and treatment TLG10 showed the highest (321.42 mg kg^{-1}) NO_3–N content. Lowest NH_4–N and NO_3–N (75.90 mg kg^{-1} and 260.13 mg kg^{-1}, respectively) were documented from treatment WCG10. Mixed application of biochar and FYM (5 t ha^{-1} each) showed NH_4–N in the range of 96.19 mg kg^{-1} to 116.30 mg kg^{-1} from treatment WGFYM and TCFYM, respectively. Whereas, mixed application of biochar (5 t ha^{-1}) with NKP fertilizer (50% of recommended dose) exhibited the same in the range 113.19 mg kg^{-1} to 126.58 mg kg^{-1} under treatments WGNPK and WCNPK, respectively. Furthermore, Mixed application of biochar and FYM (5 t ha^{-1} each) showed NO_3–N of 332.51 mg kg^{-1} to 395.95 mg kg^{-1} from treatment WGFYM and TCFYM, respectively. Whereas, mixed application of biochar

(5 t ha^{-1}) with NKP fertilizer (50% of recommended dose) exhibited the same in the range 387.35 mg kg^{-1} (WGNPK) to 434.95 mg kg^{-1} (TCNPK) (Table 4.15).

Soils collected from french bean field recorded maximum (2.02%) total N in treatment NPKR which was followed by TLG10 (1.77%). Treatment FYM10 recorded 1.22% of the same. Co-application of inorganic NPK fertilizers (50% of recommended dose) and biochar (5 t ha^{-1}) exhibited total N in the range of 1.44% (WGNPK) to 1.70 (WCNPK). Moreover, co-addition of biochars and FYM (5 t ha^{-1} each) recorded the same as 1.23% (WGFYM) to 1.54% (TCFYM). However, lowest total soil N was found from control (0.98%) (Table 4.16).

Total available soil nitrogen in french bean field were maximum (630.84 kg ha^{-1}) in treatment NPKR and the lowest (209.92 kg ha^{-1}) was documented in control (Figure 4.11). Biochars application at 10 t ha^{-1} displayed the available N in the range of 337.53 kg ha^{-1} (WCG10) to 402.38 kg ha^{-1} (TLG10) and FYM application at 10 t ha^{-1} (FYM10) documented 556.43 kg ha^{-1} of the same. Co-application of NPK (50% of recommended dose) and biochar (5 t ha^{-1}) exhibited the available soil N in the range of 499.48 kg ha^{-1} (WGNPK) to 555.05 kg ha^{-1} (WCNPK). Moreover, co-addition of biochars and FYM (5 t ha^{-1} each) recorded 438.76 kg ha^{-1} (WGFYM) to 501.14 kg ha^{-1} (WCFYM) of the same.

Besides, soils from french bean field documented NH_4–N in the ranged between 45.97 mg kg^{-1} to 141.78 mg $kg^{-1}$and NO_3–N in the range of 160.51 mg kg^{-1} to 485.70 mg kg^{-1} from control and treatment NPKR, respectively. Among the biochar treatments (at 10 t ha^{-1}), highest NH_4–N and NO_3–N was documented from treatment TLC10 (90.72 mg kg^{-1} and 307.61 mg $kg^{-1,\ respectively}$) and lowest of the same was found from treatment WCG10 (74.98 mg kg^{-1} and 259.40 mg $kg^{-1,\ respectively}$). Whereas, treatment FYM10 recorded NH_4–N of 123.05 mg kg^{-1} and NO_3–N of 428.26 mg kg^{-1}. Mixed application of biochar and FYM (5 t ha^{-1} each) showed NH_4–N in the range (WGFYM = 98.07 mg kg^{-1} to 112.30 mg kg^{-1} from treatments WGFYM and WCFYM, respectively. Whereas, mixed application of biochar (5 t ha^{-1}) and NKP fertilizer (50% of recommended dose) exhibited the same in the range of 111.16 mg kg^{-1} (WGNPK) to 124.91 mg kg^{-1} (WCNPK). Furthermore, Mixed application of biochar and FYM (5 t ha^{-1} each) showed NO_3–N in the range of 337.80 mg kg^{-1} to 385.72 mg kg^{-1} from treatments WGFYM and WCFYM, respectively. Whereas, mixed application of biochar (5 t ha^{-1}) with NKP fertilizer (50% of recommended dose) exhibited the same in the range of 384.64 mg kg^{-1} (WGNPK) to 426.46 mg kg^{-1} (WCNPK) (Table 4.16).

4.2.3.7. Nutrients and heavy metal concentration in soil after crop harvest

Soils collected from mustard field recorded maximum (60.58 kg ha^{-1}) available phosphorus from treatment NPKR and minimum (39.8 kg ha^{-1}) was found from control. Likewise, available potassium ranged from 208.05 to 174.4 kg ha^{-1} (NPKR and C, respectively). Among the biochar treatments (at 10 t ha^{-1}), highest available phosphorus and potassium were recorded from the treatment TLC10 (60.40 kg ha^{-1} and 197.50 kg ha^{-1}, respectively) and the lowest were recorded from treatments WCG10 (P = 52.18 kg ha^{-1}) and TLG10 (K = 186.11 kg ha^{-1}). Moreover, treatment FYM10 recorded available P and K of 57.55 kg ha^{-1} and 186.11 kg ha^{-1}, respectively. When biochar was applied with FYM (5 t ha^{-1} each), the available P was recorded upto 56.25 kg ha^{-1} from treatment TCFYM and available K was noted upto 192.5 kg ha^{-1} from treatment WGFYM. Furthermore, co-application of biochar (5 t ha^{-1}) and inorganic NPK fertilizers (50% of recommended dose) noted available P of 58.64 kg ha^{-1} from treatment WGNPK and available K of 201.66 kg ha^{-1} from treatment TCNPK (Figure 4.10).

Plant essential elementals (Na, Mg, Ca, K, P, Fe, Zn, Mn) recorded from mustard field were listed in Table 4.17. Biochar amended plots (at 10 t ha^{-1}) showed the maximum hike (upto 2.5 fold) in elemental composition than control. Co-addition of biochars and FYM also displayed fair enhancement (upto1.5 fold) in soil nutrient concentrations compared to control. Furthermore, addition of FYM at the rate of 10 t ha^{-1} also showed considerable increment (upto 1.5 fold) in soil elemental concentration compared to control. Whereas, mixed application of biochar (5 t ha^{-1}) and inorganic NPK fertilizers (50% of recommended dose) showed upto one fold hike of the same. However, compared to control biochar application increased the studied soil heavy metals (Pb, Cd, Cu, Cr) concentrations upto 4 folds.

In french bean fields, available soil phosphorus was observed to be maximum (63.58 kg ha^{-1}) in treatment NPKR and least (41.01 kg ha^{-1}) was found in control. Similarly, soil available potassium was higher (213.88 kg ha^{-1}) in treatment NPKR and the lowest (173.89 kg ha^{-1}) of the same was documented in control. Elevated quantities of both available P and K were noted when inorganic fertilizers were added with biochars than the sole application. Among the biochar treatments (at 10 t ha^{-1}), highest available soil P (62.56 kg ha^{-1}) and K (200.27 kg ha^{-1}) were noted from treatment WCC10 and the lowest (P = 53.85 kg ha^{-1} and K = 196.94 kg ha^{-1}) of the same were documented from treatments WCG10 and TLG10, respectively. Moreover, treatment FYM10 recorded 57.95 kg ha^{-1} and 186.11 kg ha^{-1} of available soil P and K, respectively. Mixed application of biochar and FYM (5 t ha^{-1} each) displayed 56.43 kg ha^{-1} (WCFYM) of available P and 193.88 kg ha^{-1} (TCFYM) of available K. Furthermore, co-application of biochar (5 t ha^{-1}) and inorganic NPK fertilizers (50% of recommended dose) exhibited the available P and K upto 60.47 kg ha^{-1} (WCNPK) and 200.56 kg ha^{-1} (TCNPK), respectively (Figure 4.11).

Moreover, documented plant essential elements (Na, Mg, Ca, K, P, Fe, Zn, Mn) in soils from french bean field were listed in Table 4.18. Compared to control, biochar addition at the rate of 10 t ha^{-1} displayed the maximum hike (upto 2 fold) in plant essential nutrients. Whereas, addition of biochar with FYM (at 5 t ha^{-1} each) showed upto 1.8 fold improvement than control. FYM at 10 t ha^{-1} (FYM10) also showed higher (upto 1.7 fold) elemental content as compared to control. However, mixed application of biochar (5 t ha^{-1}) and inorganic NPK fertilizers (50% of recommended dose) showed upto 1 fold hike of the same. However, biochar application (at 10 t ha^{-1}) increased the soil heavy metals (Pb, Cd, Cu, Cr) upto 3.5 fold as compared to control.

4.2.3.8. Soil organic carbon (%), HAC (%), FAC (%) and HAC:FAC ratio

Organic carbon fractions of the soils collected from mustard field are presented in Table 4.19. The highest (0.99%) SOC was documented under application of 10 t ha^{-1} of TLC biochar (TLG10) and lowest (0.787%) of the same was noted from inorganically fertilized (NPKR) and control plots. Compared to control, application of biochars (at 10 t ha^{-1}) increased (upto 25.79%) SOC. Similarly, FYM application at 10 t ha^{-1} (FYM10) also increased the same upto 24%. Co-addition of biochar and FYM (5 t ha^{-1} each) enhanced SOC up to 20.33%. However, application of biochars (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) increase the SOC content upto 6%.

Significant increase in HAC was noted in both biochar and FYM treated plots (at 10 t ha^{-1}) compared to control. Highest (38.56%) increase in soil HAC was recorded under treatment WCG10, while no significant improvement was observed from inorganically treated plots (NPKR) as compared to control. Treatment FYM10 increased HAC upto 19.68% than control. Addition of biochar and FYM (5 t ha^{-1} each) enhanced the same upto 28.98%. Improvement of soil HAC content upto 6.64% was noted when biochars (5 t ha^{-1}) were applied with inorganic NPK fertilizers (50% of recommended dose).

Additionally, highest (0.456%) FAC was noted in treatment TGFYM of mustard field. Whereas, treatment WGNPK (0.331%) noted the lowest FAC content. Compared to control, increment of 4.19% FAC content was noted when FYM was added at 10 t ha^{-1} (FYM10). Whereas, co-addition of biochar and FYM (5 t ha^{-1} each) enhanced the same upto 36.52% than control. Similarly, compared to control increased FAC content upto 9.58% was recorded under co-addition of biochars (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose).

In the same field, calculated HAC:FAC ratio showed greater values under addition of biochars (at 10 t ha^{-1}). Treatment TLC10 noted highest (1.48) HAC:FAC ratio followed by treatment FYM10 (1.29). Whereas, lowest (1.02) of the same was documented from treatment NPKR.

Likewise, organic carbon fractions of soil collected from french bean field were presented in Table 4.20. Greater (0.993%) SOC was noted under the treatment TLG10 and the control documented lowest (0.787%) of the same. Compared to control, an upsurge (upto 26.17%) of SOC was documented under biochar application at 10 t ha^{-1} (TLG10). Whereas, FYM application at same dose (FYM10) hiked the SOC level up to 24.90%. Co-application of biochar and FYM (5 t ha^{-1} each) increased the same upto 21.98%. Moreover, addition of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) hiked the SOC upto 7.11% as compared to control.

Similarly, greater (48.61%) improvement in HAC was recorded in treatment WCG10 as compared to control. However, no significant change in HAC level was documented in treatment NPKR than C. Treatment FYM10 increased 19.33% of soil HAC compared to control. Whereas, co-addition of biochar and FYM (5 t ha^{-1} each) enhanced the same upto 41.43%. Biochars (5 t ha^{-1}) application with inorganic NPK fertilizers (50% of recommended dose) increased the same upto 11.87%.

Highest FAC content in the soils collected from french bean field was recorded from treatment WGFYM (0.398%). Whereas treatment WCFYM (0.325%) noted lowest of the same. Compared to control biochar treatments (at 10 t ha^{-1}) increased the soil FAC upto 8.33%. Addition of FYM at 10 t ha^{-1} (FYM10) increased 14.36% of the same. Co-addition of biochar and FYM (5 t ha^{-1} each) enhanced FAC content upto 36.52% than control. Whereas, compared to control co-application of biochars (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) increased the FAC content upto 5.17%.

Highest (1.41) HAC:FAC ratio was recorded under the treatments TLG10 and WCG10 while, the lowermost (1.03) was documented from treatment TCNPK. Treatment FYM10 exhibited HAC:FAC ratio of 1.14 and treatment NPKR exhibited 1.06 of the same.

4.2.3.9. Soil organic carbon storage after harvest (SOCS) (mg C ha^{-1})

Storage (SOC after harvest – SOC before the experiment) of soil organic carbon (SOCS) for mustard and french bean field are represented in the Tables 4.19 and 4.20. Highest SOCS of 2.97 mg C ha^{-1} and 3.73 mg C ha^{-1} were noted from treatment TLG10 in mustard and french bean, respectively. While the lowest SOCS of 0.21 mg C ha^{-1} and 0.60 mg C ha^{-1} were found from treatment NPKR in mustard and french bean, respectively. Whereas, treatment FYM10 displayed 2.40 mg C ha^{-1} and 3.06 mg C ha^{-1} of the same in mustard and french bean, respectively.

4.2.3.10. Soil bacterial colony count (log cfu g^{-1} soil) and Microbial biomass carbon (MBC) (mg kg^{-1})

Colony forming unit of soil bacteria in mustard field (Table 4.19) were ranged from 3.70 log cfu g^{-1} soil to 4.54 log cfu g^{-1} soil in treatments C and FYM10, respectively. Addition of FYM at 10 t ha^{-1} (FYM10) increased the soil bacterial colony growth upto 22.70% as compared to control. Biochar application at 10 t ha^{-1} enhanced the bacterial colony growth upto 15.40%. Whereas, co-application of biochar and FYM (at 5 t ha^{-1} each) showed upto 21.89% higher bacterial colony growth compared to control. Application of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) showed upto 6.48% hike in bacterial colony growth compared to control.

Soil MBC content in mustard field was highest under treatment FYM10 (43.94% hike than control). Treatment with biochar (10 t ha^{-1}) enhanced the soil MBC upto 41.45% as compared to control. Application of biochar and FYM (5 t ha^{-1} each) showed upto

28.96% higher MBC content than control. Whereas, co-application of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) showed upto 17.24% hike of the same compared to control (Table 4.19).

Similarly, recorded bacterial colony forming units in french bean field ranged from 3.70 log cfu g^{-1} soil to 4.49 log cfu g^{-1} soil (C and FYM10, respectively). FYM at 10 t ha^{-1} (FYM10) exhibited increase (21.35%) in soil bacterial colony growth compared to control. Addition of biochars at 10 t ha^{-1} enhanced the bacterial colony growth upto 14.59% than control. Co-application of biochar and FYM at 5 t ha^{-1} each showed upto 17.83% higher bacterial colony growth than control. Whereas, addition of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) showed upto 4.59% higher bacterial colony growth compared to control (Table 4.20).

Recorded MBC content of french bean field was highest in treatment FYM10 (34.50% hike than control). Compared to control, treatments with biochars (10 t ha^{-1}) enhanced soil MBC upto 34.37%. Addition of biochar and FYM (5 t ha^{-1} each) showed upto 27.61% higher MBC compared to control. Whereas, co-application of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) noted upto 11.11% hike of the same as compared to control (Table 4.20).

4.2.3.11. Soil enzyme activities

Studied soil enzymatic activities (urease, phosphatase and dehydrogenase) of mustard field are displayed in Figure 4.12. In mustard field, greater improvement (307.0 μg NH_4-N h^{-1} g^{-1} dw soil) in soil urease activity was noted under addition of inorganic NPK fertilizers. Among the biochar amended plots (at 10 t ha^{-1}), greater (251.7 μg NH_4-N h^{-1} g^{-1} dw soil) urease activity was noted from treatment WCC10 and lowest (217.7 μg NH_4-N h^{-1} g^{-1} dw soil) was recorded in treatment TLG10. Whereas, treatment with FYM at 10 t ha^{-1} (FYM10) showed urease activity of 283.0 μg NH_4-N h^{-1} g^{-1} dw soil. Moreover, co-application of biochar with FYM (5 t ha^{-1} each) noted urease activity upto 219.3 μg NH_4-N h^{-1} g^{-1} dw soil (TCFYM). Under mixed application of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) noted the urease activity upto 289.3 μg NH_4-N h^{-1} g^{-1} dw soil (TCNPK).

Correspondingly, highest soil dehydrogenase activity was noted in mustard field from treatment NPKR (48.20 mg INFT g^{-1} h^{-1}) and the lowermost value was documented from C (23.73 mg INFT g^{-1} h^{-1}). Treatment FYM10 recorded dehydrogenase activity of 42.5 mg INFT g^{-1} h^{-1} and among the biochar treated plots (10 t ha^{-1}), treatment WCC10 noted the highest (35.5 mg INFT g^{-1} h^{-1}) dehydrogenase activity and the lowest (30.5 mg INFT g^{-1} h^{-1}) was observed from treatment WCG10. Moreover, co-application of biochar with FYM (5 t ha^{-1} each) showed upto 37.3 mg INFT g^{-1} h^{-1} of dehydrogenase activity in treatment TCFYM. Application of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) increased the same upto 41.0 mg INFT g^{-1} h^{-1} (TCNPK).

Superior (3.40 µmol g^{-1} h^{-1}) phosphatase activity was found in mustard field in inorganically fertilized plots (NPKR) and control showed the least (0.83 µmol g^{-1} h^{-1}). Treatment FYM10 exhibited phosphatase activity of 2.32 µmol g^{-1} h^{-1}. While among the biochar treated (10 t ha^{-1}) plots, treatment WCC10 exhibited highest (1.92 µmol g^{-1} h^{-1}) and treatment WCG10 showed the lowest (1.67 µmol g^{-1} h^{-1}) phosphatase activity. Moreover, co-application of biochar with FYM (5 t ha^{-1} each) showed upto 2.71 µmol g^{-1} h^{-1} (TCFYM) of soil phosphatase activity. Mixed application of biochar (5 t ha^{-1}) and inorganic NPK fertilizers (50% of recommended dose) noted upto 3.15 µmol g^{-1} h^{-1} (TCNPK) of the same.

Similarly, in french bean field also, higher (approximately two fold) urease activity was noted in treatment NPKR (307.0 µg NH_4-N h^{-1} g^{-1} dw soil) compared to control. Among the biochar amended (at 10 t ha^{-1}) plots, greater (239.7 µg NH_4-N h^{-1} g^{-1} dw soil) soil urease was noted in treatment WCC10 and lowest (208.7 µg NH_4-N h^{-1} g^{-1} dw soil) was recorded in treatment TLG10. Addition of FYM at 10 t ha^{-1} (FYM10) in french bean field showed urease activity of 282.3 µg NH_4-N h^{-1} g^{-1} dw soil. Moreover, co-application of biochar with FYM (5 t ha^{-1} each), recorded upto 219.3 µg NH_4-N h^{-1} g^{-1} dw soil of urease activity from TCFYM. Whereas, under mixed application of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) recorded the same upto 285.7 µg NH_4-N h^{-1} g^{-1} dw soil from TCNPK.

Maximum soil dehydrogenase activity was documented under treatment NPKR (45.20 mg INFT g^{-1} h^{-1}) and the lowest (23.73 mg INFT g^{-1} h^{-1}) was recorded from control in french bean field. Whereas, among the tested biochars (at 10 t ha^{-1}), treatment TLC10 recoded highest (36.1 mg INFT g^{-1} h^{-1}) dehydrogenase activity and lowest (29.8 mg INFT g^{-1} h^{-1}) was found from treatment WCG10. Moreover, treatment FYM10 exhibited dehydrogenase activity of 39.8 mg INFT g^{-1} h^{-1}. Addition of biochar with FYM (5 t ha^{-1} each) recorded upto 36.2 mg INFT g^{-1} h^{-1} of dehydrogenase activity from TCFYM. Whereas, mixed application of biochar (5 t ha^{-1}) and inorganic NPK fertilizers (50% of recommended dose) recorded the dehydrogenase activity upto 38.0 mg INFT g^{-1} h^{-1} from TCNPK.

Recorded soil phosphatase activity in french bean field was greater (3.39 µmol g^{-1} h^{-1}) in treatment NPKR followed by treatment FMNPK (3.37 µmol g^{-1} h^{-1}) and the controlled plots exhibited minimum (0.83 µmol g^{-1} h^{-1}) of the same. While among the biochar treatments (at 10 t ha^{-1}), treatment TLC10 showed the highest (1.93 µmol g^{-1} h^{-1}) and the lowest (1.72 µmol g^{-1} h^{-1}) was documented from treatment WCG10. Whereas, recorded phosphatase activity in treatment FYM10 was 2.53 µmol g^{-1} h^{-1}. Treatment WCFYM recorded highest (2.51 µmol g^{-1} h^{-1} of soil) phosphatase activity when biochar and FYM was added at the rate of 5 t ha^{-1} each. Whereas, mixed application of biochar (5 t ha^{-1}) with inorganic NPK fertilizers (50% of recommended dose) displayed the phosphatase activity upto 3.27 µmol g^{-1} h^{-1} (TCNPK) (Figure 4.13).

4.2.3.12. Correlation analysis of applied soil amendments on soil and plant parameters in mustard field

Photosynthesis rate and mustard yield documented strong positive correlation (r = 0.465) at $p<0.05$ significance level. Similarly, strong positive correlation of photosynthesis was found with the studied soil parameters. Irrespective of the treatments, SOC were found to be significantly influenced by the biochar properties at both $p<0.05$ and $p<0.01$ level. Biochar specific surface area has a significant positive relationship with soil bacterial colony count and soil microbial biomass carbon (r = 0.551 at p<0.05 and 0.583 at p<0.01, respectively). Strong positive correlation has been documented between pH of the added biochars with the soil pH at harvest (r = 0.594) at $p<0.01$. Similarly, water holding capacity of both biochar and soil showed positive interaction (r = 0.561) at $p<0.05$. Besides, soil cation exchange capacity displays a substantial positive link with soil pH, EC (r = 0.924 and 0.691, respectively) at $p<0.05$. Observed soil urease activity documented positive correlation with soil available nitrogen (r = 0.772) at $p<0.01$ significance level. Furthermore, a notable connection was observed between soil available phosphorus (r = 0.710 and 0.597, respectively) and potassium (r = 0.845 and 0.666, respectively) with photosynthetic activity and yield of the mustard crop at $p<0.01$. Strong negative correlations were noted among transpiration rate of mustard with SOC (r =-0.885), soil pH (r = -0.903), CEC (r = -0.861), bacterial colony forming unit (r = -0.864) and MBC (r = -0.546) at both $p<0.05$ and $p<0.01$ level (Image 4.4).

4.2.3.13. Correlation analysis of applied soil amendments on soil and plant parameters in french bean field

Photosynthesis rate and french bean yield documented positive correlation (r = 0.432) at $p<0.05$ significance level. Irrespective of the treatments, SOC was found to be influenced by the biochar properties at both $p<0.05$ and $p<0.01$ level. Biochar specific surface area has a significant positive relationship with soil bacterial colony count and soil microbial biomass carbon (r = 0.538 at $p<0.05$ and 0.583 at $p<0.01$ level, respectively). Strong positive correlation has been documented between pH of added biochars with the soil pH at harvest (r = 0.550) at $p<0.05$. Likewise, soil cation exchange capacity displays a substantial positive link with soil pH, EC (r = 0.550 and 0.475, respectively) at $p<0.05$. Observed soil urease activity documented positive correlation with soil available nitrogen (r = 0.795) at $p<0.01$ significance level. Furthermore, a noteworthy connection was observed between soil available phosphorus (r = 0.622 and 0.677, respectively) and potassium (r = 0.731 and 0.451, respectively) with photosynthetic activity and yield of french bean crop at $p<0.01$. Strong negative correlations were noted between transpiration rate of mustard with SOC (r =-0.868), soil pH (r = -0.867), CEC (r = -0.832), bacterial colony forming unit (r = -0.908) and MBC (r = -0.708) at $p<0.05$ level (Image 4.5).

Table 4.12. Physiochemical properties of the FYM and experimented soil

Parameters	FYM	Soil
Sand (%)	-	54.4 ± 0.5
Silt (%)	-	18.3 ± 0.2
Clay (%)	-	27.9 ± 0.2
Bulk density (mg m^{-3})	0.86 ± 0.01	0.94 ± 0.07
pH (H_2O)	6.9 ± 0.05	6.1 ± 0.08
EC (mS cm^{-1})	.53 ± 0.04	0.32 ± 0.03
WHC (%)	48.3 ± 2.01	52.6 ± 1.23
OC (%)	26.3 ± 0.25	0.95 ± 0.03
HAC (%)	0.53 ± 0.02	0.37 ± 0.01
FAC (%)	.567 ± 0.06	0.33 ± 0.00
MBC (mg kg^{-1})	628.7± 6.3	281.4 ± 3.8
B. count (log cfu g^{-1} soil)	4.61±0.32	3.70±0.41
Total C (%)	29.87 ± 0.21	2.70 ± 0.01
Total N (%)	1.82 ± 0.05	0.87 ± 0.00
Available N (kg ha^{-1})	689.5 ± 2.4	197.3 ± 1.1
Available P (kg ha^{-1})	211.4 ± 1.6	39.3 ± 1.0
Available K (kg ha^{-1})	267.5 ± 1.8	172.8 ± 1.2

Data shown are mean ± S.D. (n = 3). FYM = farmyard manure, EC = electrical conductivity, WHC = water holding capacity, OC = organic carbon; HAC = humic acid carbon, FAC = fulvic acid carbon, MBC = microbial biomass carbon, B. count = bacterial count.

Table 4.13. Physicochemical properties of the soil as influenced by applied treatments in mustard field

Treatments	pH	EC (mS cm^{-1})	WHC (%)	BD (mg m^{-3})	CEC (cmol$_{+}$kg^{-1})
TLC10	6.53±0.39^{ab}	0.643±0.01^{b}	62.62±0.66^{a}	0.86±0.03^{bf}	13.47±0.20^{ab}
TLG10	6.63±0.35^{a}	0.690±0.01^{a}	63.46±0.76^{a}	0.84±0.04^{def}	13.96±0.24^{a}
WCC10	6.43±0.29^{b}	0.540±0.02^{jkl}	61.99±1.16^{a}	0.82±0.04^{ef}	12.81±0.10^{ad}
WCG10	6.50±0.50^{ab}	0.620±0.01^{be}	63.03±1.20^{a}	0.78±0.03^{f}	13.46±0.12^{ab}
FYM10	6.13±0.99^{cde}	0.523±0.01^{kl}	58.42±2.82^{bc}	0.86±0.01^{cf}	12.14±0.31^{bd}
NPKR	5.87±0.65^{g}	0.530±0.01^{kl}	57.87±3.10^{bc}	0.91±0.04^{ae}	10.51±0.14^{ef}
TLC5	6.07±0.69^{cf}	0.570±0.01^{fj}	58.81±1.45^{bc}	0.93±0.07^{ae}	12.01±0.32^{cd}
TLG5	6.13±0.98^{cde}	0.590±0.01^{dh}	59.04±1.39^{bc}	0.90±0.06^{ae}	12.63±0.21^{ad}
WCC5	6.03±0.75^{dg}	0.550±0.02^{hl}	58.13±2.55^{bc}	0.95±0.03^{ad}	11.70±0.11^{cde}
WCG5	6.10±0.85^{cde}	0.573±0.00^{fj}	59.43±2.68^{bc}	0.87±0.04^{bf}	11.98±0.20^{cd}
TCFYM	6.17±0.79^{cd}	0.543±0.02^{il}	59.78±1.53^{b}	0.88±0.02^{bf}	12.48±0.23^{bd}
TGFYM	6.23±0.09^{c}	0.643±0.00^{b}	59.28±1.54^{bc}	0.87±0.02^{bf}	12.98±0.13^{abc}
WCFYM	6.17±0.04^{cd}	0.610±0.01^{bf}	59.22±1.42^{bc}	0.88±0.03^{bf}	11.95±0.31^{cde}
WGFYM	6.23±0.95^{c}	0.623±0.04^{bcd}	59.82±2.11^{b}	0.82±0.01^{ef}	12.60±0.30^{ad}
TCNPK	6.03±0.65^{dg}	0.567±0.00^{gk}	58.35±3.03^{bc}	0.92±0.04^{ae}	11.36±0.25^{edf}
TGNPK	6.10±0.85^{cde}	0.630±0.01^{bc}	59.11±1.77^{bc}	0.91±0.01^{ae}	11.33±0.18^{def}
WCNPK	5.97±0.82^{eg}	0.583±0.02^{ei}	58.27±1.75^{bc}	0.96±0.07^{abc}	11.59±0.20^{cde}
WGNPK	6.10±0.85^{cde}	0.593±0.03^{cg}	59.58±1.00^{b}	0.89±0.03^{bf}	11.43±0.16^{def}
FMNPK	6.03±0.89^{dg}	0.573±0.01^{fj}	57.47±2.28^{c}	0.98±0.01^{ab}	11.36±0.14^{def}
C	5.90±0.57^{fg}	0.333±0.01^{l}	53.82±3.54^{d}	0.98±0.06^{ab}	10.15±0.21^{f}
LSD	0.077	0.017	0.867	0.050	0.62

Where, EC = electrical conductivity, WHC = water holding capacity, BD = bulk density, CEC = cation exchange capacity. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.14. Physicochemical properties of the soil as influenced by applied treatments in french bean field

Treatments	pH	EC (mS cm^{-1})	WHC (%)	BD (mg m^{-3})	CEC (cmol$_{+}$kg^{-1})
TLC10	6.40±0.31^{abc}	0.647±0.00^{b}	62.33±0.15^{a}	0.87±0.03^{be}	13.66±0.11^{ab}
TLG10	6.57±0.03^{a}	0.683±0.01^{a}	63.59±0.62^{a}	0.85±0.03^{eh}	14.12±0.27^{a}
WCC10	6.50±0.10^{ab}	0.543±0.01^{f}	62.23±0.36^{a}	0.82±0.04^{def}	12.85±0.16^{ad}
WCG10	6.57±0.07^{a}	0.610±0.01^{cd}	63.06±0.15^{a}	0.77±0.03^{f}	13.46±0.26^{ab}
FYM10	6.10±0.06^{cde}	0.530±0.02^{f}	58.52±0.71^{bc}	0.88±0.02^{ae}	12.56±0.25^{be}
NPKR	5.87±0.03^{e}	0.530±0.01^{f}	57.69±0.47^{bc}	0.95±0.05^{ab}	10.70±0.29^{gh}
TLC5	6.13±0.09^{cde}	0.573±0.00^{e}	58.62±0.43^{bc}	0.89±0.06^{ae}	11.80±0.14^{bf}
TLG5	6.20±0.06^{bcd}	0.580±0.02^{de}	58.83±0.49^{bc}	0.85±0.03^{eh}	12.35±0.20^{cg}
WCC5	6.17±0.07^{cde}	0.537±0.01^{f}	57.85±0.64^{bc}	0.91±0.02^{ad}	11.79±0.14^{cg}
WCG5	6.13±0.03^{cde}	0.583±0.00^{de}	59.26±0.83^{bc}	0.88±0.02^{ae}	12.35±0.17^{bf}
TCFYM	6.10±0.10^{cde}	0.543±0.02^{f}	59.57±0.65^{b}	0.89±0.01^{ae}	12.48±0.23^{be}
TGFYM	6.20±0.10^{bcd}	0.630±0.03^{bc}	59.32±0.51^{bc}	0.84±0.05^{eh}	12.92±0.22^{abc}
WCFYM	6.10±0.06^{cde}	0.610±0.01^{cd}	59.64±0.66^{b}	0.88±0.03^{ae}	11.87±0.28^{cg}
WGFYM	6.23±0.07^{bcd}	0.623±0.03^{bc}	59.82±0.13^{b}	0.80±0.01^{ef}	12.79±0.25^{abc}
TCNPK	6.10±0.10^{cde}	0.577±0.00^{e}	58.75±1.28^{bc}	0.95±0.04^{ab}	11.38±0.05^{efg}
TGNPK	6.17±0.03^{cde}	0.630±0.01^{bc}	59.10±0.91^{bc}	0.90±0.03^{ad}	10.79±0.23^{gh}
WCNPK	6.00±0.06^{de}	0.590±0.02^{de}	58.45±0.76^{bc}	0.94±0.04^{ab}	11.19±0.21^{eh}
WGNPK	6.17±0.09^{cde}	0.593±0.00^{de}	59.53±1.13^{b}	0.89±0.04^{ae}	11.48±0.19^{dg}
FMNPK	6.10±0.06^{cde}	0.580±0.01^{de}	57.23±0.04^{c}	0.93±0.03^{abc}	11.05±0.25^{fgh}
C	5.93±0.03^{de}	0.337±0.01^{g}	53.82±0.54^{d}	0.97±0.02^{a}	9.91±0.12^{h}
LSD	0.135	0.013	0.931	0.928	0.596

Where, EC = electrical conductivity, WHC = water holding capacity, BD = bulk density, CEC = cation exchange capacity. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.15. Soil nitrogen fractions in mustard field as influenced by applied treatments.

Treatments	Total N (%)	NO_3 -N(mg kg^{-1})	NH_4-N (mg kg^{-1})
TLC10	1.73 ± 0.01^{cd}	309.30 ± 4.05^{m}	93.79 ± 2.67^{l}
TLG10	1.83 ± 0.00^{b}	321.42 ± 5.24^{l}	93.33 ± 3.51^{l}
WCC10	1.65 ± 0.02^{e}	276.04 ± 3.28^{n}	81.81 ± 3.78^{m}
WCG10	1.35 ± 0.01^{h}	260.13 ± 3.15^{o}	75.90 ± 2.91^{n}
FYM10	1.23 ± 0.02^{j}	438.84 ± 5.11^{c}	131.86 ± 4.23^{c}
NPKR	2.04 ± 0.01^{a}	509.71 ± 3.36^{a}	149.64 ± 2.18^{a}
TLC5	1.02 ± 0.00^{kl}	212.83 ± 2.70^{p}	61.15 ± 1.93^{p}
TLG5	1.01 ± 0.01^{kl}	199.92 ± 3.63^{r}	56.36 ± 1.54^{q}
WCC5	1.05 ± 0.01^{kl}	210.14 ± 2.90^{q}	62.54 ± 3.76^{o}
WCG5	1.10 ± 0.02^{k}	190.63 ± 3.98^{s}	53.46 ± 1.94^{r}
TCFYM	1.52 ± 0.01^{f}	395.95 ± 3.28^{g}	116.30 ± 2.58^{g}
TGFYM	1.31 ± 0.02^{hi}	360.01 ± 3.76^{j}	103.69 ± 1.52^{j}
WCFYM	1.31 ± 0.01^{hi}	383.87 ± 3.13^{i}	110.89 ± 3.45^{i}
WGFYM	1.25 ± 0.02^{ij}	332.51 ± 2.89^{k}	96.19 ± 3.67^{k}
TCNPK	1.67 ± 0.01^{de}	434.59 ± 3.07^{d}	120.88 ± 1.90^{f}
TGNPK	1.54 ± 0.02^{f}	407.70 ± 2.97^{f}	122.49 ± 1.35^{e}
WCNPK	1.67 ± 0.01^{de}	421.93 ± 3.68^{e}	126.58 ± 4.58^{d}
WGNPK	1.42 ± 0.00^{g}	387.35 ± 3.61^{h}	113.19 ± 1.92^{h}
FMNPK	1.79 ± 0.02^{bc}	457.34 ± 4.42^{b}	132.80 ± 2.87^{b}
C	0.98 ± 0.01^{l}	156.83 ± 3.63^{t}	44.98 ± 3.51^{s}
LSD	0.032	0.244	0.235

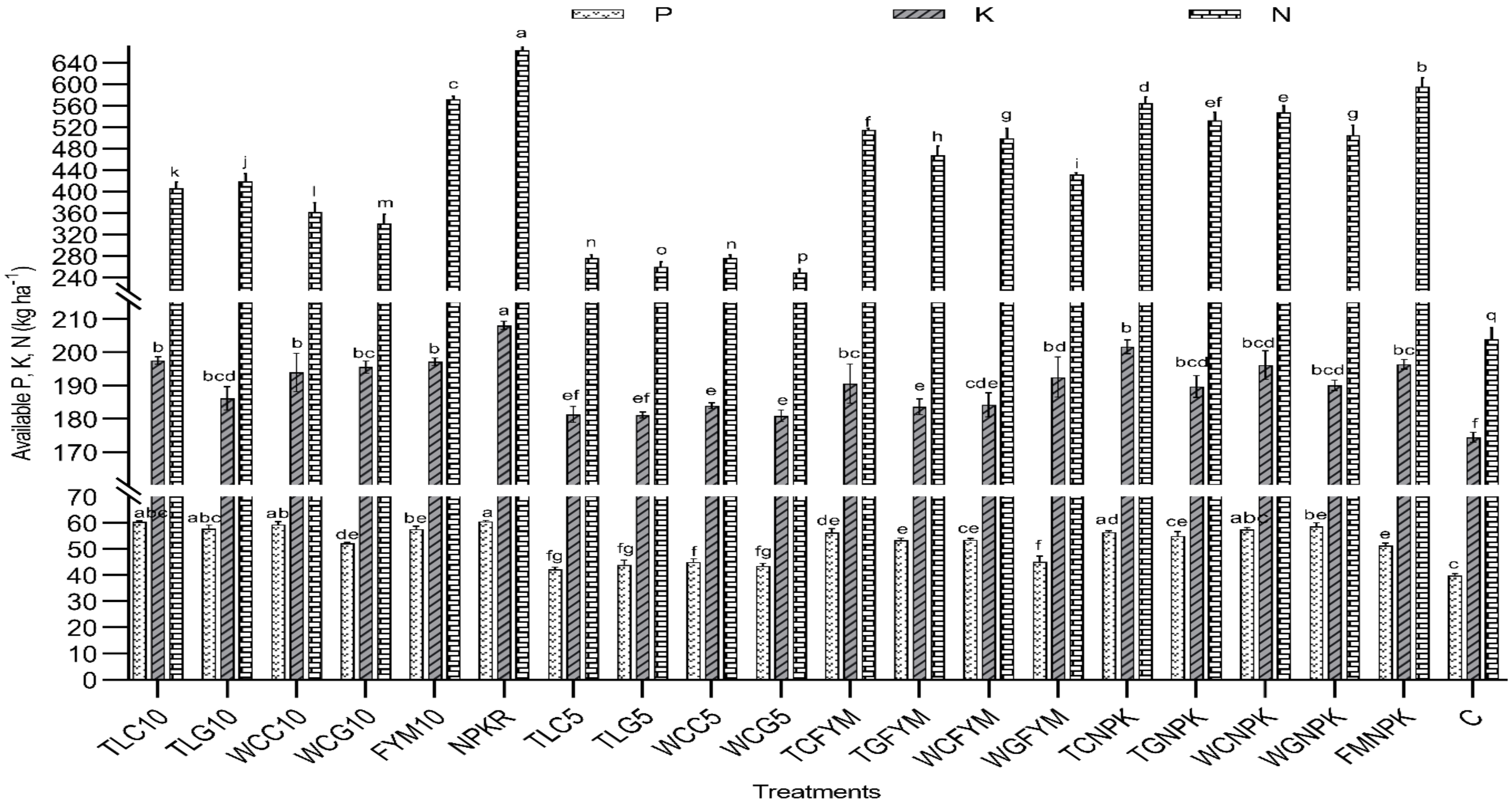
Data are the means of 3 replicates Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.16. Soil nitrogen fractions in french bean field as influenced by applied treatments

Treatments	Total N (%)	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})
TLC10	1.75±0.02^{b}	307.61±3.32^{k}	90.72±2.52^{k}
TLG10	1.77±0.01^{b}	296.40±4.12^{l}	81.23±3.76^{m}
WCC10	1.62±0.02^{cd}	275.66±4.23^{m}	85.06±4.12^{l}
WCG10	1.37±0.01^{fg}	259.40±4.17^{n}	74.98±2.31^{n}
FYM10	1.22±0.02^{hi}	428.26±1.8^{c}	123.05±1.98^{e}
NPKR	2.02±0.02^{a}	485.70±3.88^{a}	141.78±3.65^{a}
TLC5	1.02±0.01^{jk}	219.49±2.31^{o}	63.44±3.74^{o}
TLG5	1.01±0.01^{jk}	207.39±3.45^{q}	60.68±1.23^{p}
WCC5	1.05±0.02^{jk}	209.10±3.78^{p}	60.05±2.92^{q}
WCG5	1.12±0.00^{ij}	184.37±4.72^{r}	53.43±4.11^{r}
TCFYM	1.54±0.01^{de}	384.98±3.07^{h}	112.04±2.96^{g}
TGFYM	1.35±0.02^{fg}	371.48±4.08^{i}	108.68±3.92^{i}
WCFYM	1.28±0.01^{gh}	385.72±4.61^{g}	112.30±1.56^{g}
WGFYM	1.23±0.01^{h}	337.80±2.82^{j}	98.07±2.93^{j}
TCNPK	1.67±0.02^{bc}	421.54±2.78^{e}	123.82±3.67^{d}
TGNPK	1.52±0.00^{de}	410.55±4.49^{f}	119.37±0.82^{f}
WCNPK	1.70±0.01^{bc}	426.46±3.37^{d}	124.91±2.83^{c}
WGNPK	1.44±0.01^{ef}	384.64±4.52^{h}	111.16±1.97^{h}
FMNPK	1.70±0.02^{bc}	477.24±5.29^{b}	138.42±3.41^{b}
C	0.98±0.01^{l}	160.51±3.10^{s}	45.79±2.76^{s}
LSD	0.049	0.333	0.234

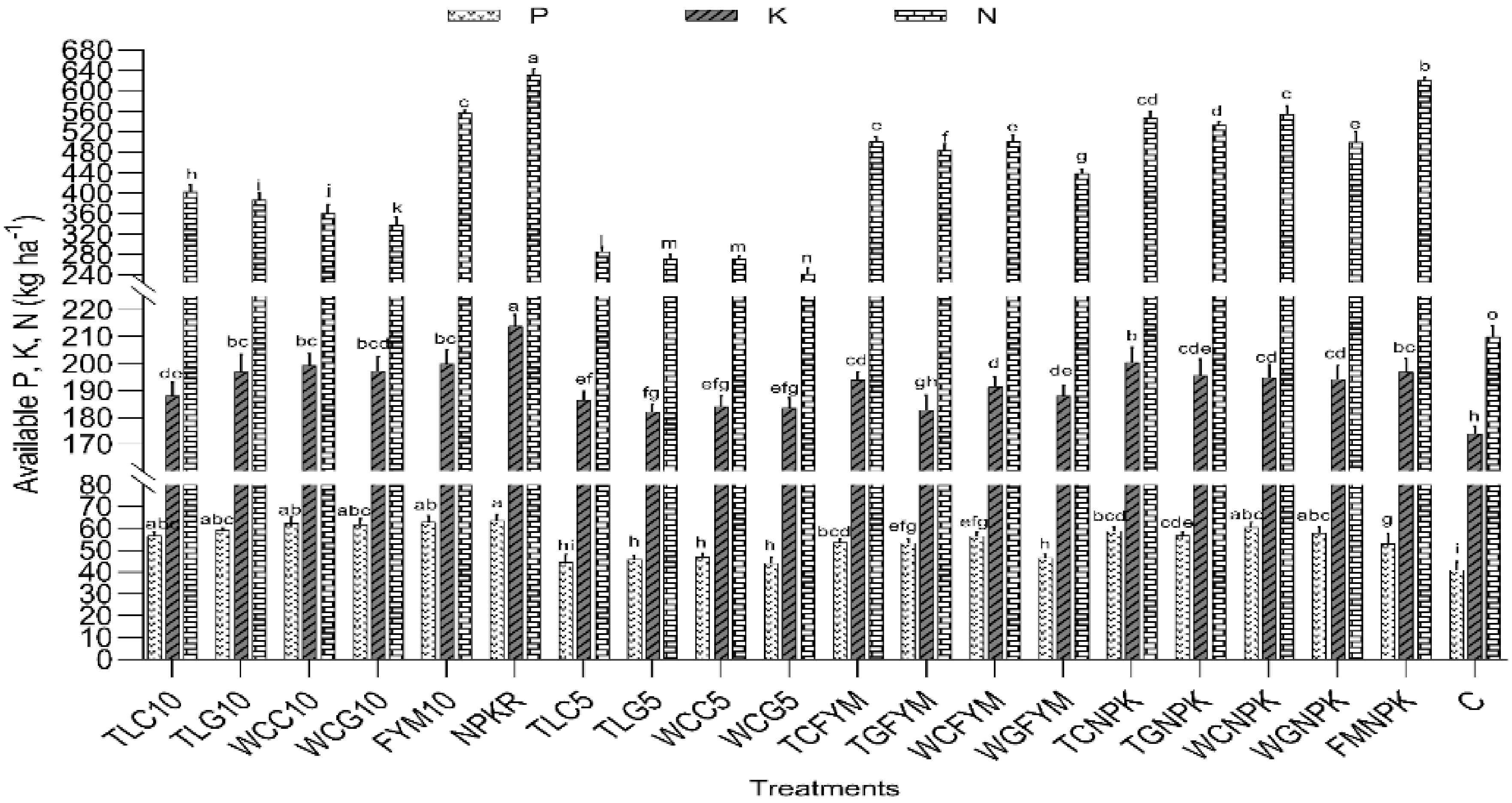
Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Figure 4.10. Available soil N, P, K in mustard field as influenced by applied treatments



Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at *p<0.05*

Figure 4.11. Available N, P, K in french bean field as influenced by applied treatments



Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.17. Elemental content of soil in the mustard field as influenced by applied treatments

Treatments	Na (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	K (mg kg^{-1})	P (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Cu (mg kg^{-1})	Cr (mg kg^{-1})
TLC10	280.34±2.4^{b}	294.18±3.8^{b}	260.82±2.7^{b}	171.44±4.7^{c}	326.28±3.4^{a}	205.97±1.7^{c}	442.67±2.2^{a}	93.18±1.7^{a}	12.564±0.16^{a}	2.667±0.03^{b}	6.974±0.02^{a}	9.718±0.03^{b}
TLG10	286.74±3.6^{a}	363.38±4.5^{a}	275.64±5.1^{a}	195.21±1.3^{a}	332.64±2.8^{b}	220.69±2.3^{b}	435.72±2.1^{b}	75.33±1.1^{c}	10.590±0.25^{b}	3.154±0.04^{a}	6.257±0.02^{b}	10.103±0.03^{ab}
WCC10	178.80±2.3^{d}	241.82±2.4g	229.49±3.8^{c}	144.77±2.1^{d}	297.97±2.5^{k}	205.97±3.4^{c}	326.15±2.5^{h}	59.69±1.5^{f}	7.256±0.17^{f}	1.257±0.03^{ef}	5.923±0.01^{b}	9.000±0.02^{c}
WCG10	197.31±2.1^{c}	176.31±2.1^{i}	183.85±3.5^{h}	188.95±3.2^{b}	302.33±2.1^{f}	224.15±2.9^{a}	333.54±2.8^{g}	80.31±1.9b	8.897±0.15^{d}	1.000±0.03^{fg}	5.743±0.03^{b}	10.385±0.04^{a}
FYM10	201.74±3.3^{c}	255.66±3.1^{f}	193.93±1.9^{g}	137.34±2.9^{f}	370.26±3.2^{e}	155.27±2.1^{f}	376.90±3.2^{e}	65.56±2.1^{e}	8.610±0.13^{d}	2.219±0.04^{c}	4.907±0.04^{c}	8.441±0.04^{cd}
NPKR	97.86±4.6^{hi}	119.93±3.3^{o}	113.81±1.5^{n}	95.31±2.5^{i}	252.61±3.6^{i}	111.17±1.7^{l}	167.09±1.7^{p}	39.83±1.3^{k}	4.413±0.09^{hi}	0.496±0.05^{hi}	3.849±0.03^{de}	4.484±0.04^{h}
TLC5	162.92±4.2^{e}	100.18±3.4^{q}	148.19±2.2^{k}	97.41±1.8^{i}	245.82±4.1^{j}	125.39±1.9^{i}	251.52±3.7^{j}	42.80±2.3^{j}	7.850±0.08^{e}	1.515±0.02^{de}	3.365±0.04^{ef}	5.521±0.02^{efg}
TLG5	158.96±3.2^{e}	206.47±1.1^{h}	130.39±2.0^{l}	110.91±1.8^{g}	299.02±1.8^{g}	117.03±2.4^{j}	304.39±2.3^{i}	52.94±2.5^{g}	9.601±0.12^{c}	1.792±0.01^{d}	3.963±0.05^{d}	5.740±0.02^{ef}
WCC5	101.59±3.7^{gh}	167.15±1.8^{j}	104.46±2.9^{o}	82.26±2.3^{j}	112.49±1.1^{o}	117.03±2.5^{j}	185.31±3.1^{m}	33.92±1.0^{m}	4.123±0.10^{hi}	0.714±0.01^{gh}	3.555±0.02^{def}	5.900±0.01^{e}
WCG5	112.11±5.2^{fg}	137.40±2.8^{m}	156.61±3.6^{j}	107.53±1.8^{h}	171.78±2.1^{m}	127.36±1.4^{h}	189.51±3.9^{l}	45.63±3.4^{i}	5.055±0.06^{g}	0.568±0.03^{hi}	3.264±0.02^{f}	5.114±0.03^{g}
TCFYM	204.20±1.6^{c}	258.78±4.1^{d}	198.68±3.1^{d}	139.15±4.5^{ef}	374.79±3.5^{d}	159.07±3.9^{d}	381.51±3.6^{d}	66.36±2.7^{de}	8.715±0.13^{d}	2.273±0.02^{c}	4.967±0.05^{c}	8.544±0.02^{cd}
TGFYM	206.68±2.3^{c}	261.92±3.6^{c}	196.29±3.2^{e}	140.70±3.2^{e}	379.34±3.7^{c}	157.16±3.3^{e}	386.14±2.4^{c}	66.02±2.2^{e}	8.821±0.18^{d}	2.246±0.02^{c}	5.027±0.03^{c}	8.648±0.02^{cd}
WCFYM	203.17±1.7^{c}	257.79±2.8^{de}	195.31±1.5^{f}	138.31±3.7^{f}	379.59±2.5^{c}	156.37±2.2^{ef}	372.90±2.7^{f}	67.16±2.1^{d}	8.671±0.24^{d}	2.235±0.04^{c}	4.942±0.04^{c}	8.501±0.01^{cd}
WGFYM	203.60±2.1^{c}	257.48±3.1^{e}	195.54±2.2^{ef}	138.48±3.2^{ef}	380.05±2.8^{c}	156.56±2.1^{ef}	374.84±3.1^{ef}	67.24±1.7^{d}	8.682±0.08^{d}	2.237±0.01^{c}	4.948±0.03^{c}	8.512±0.02^{cd}
TCNPK	163.12±1.9^{e}	100.30±1.9^{q}	148.37±1.9^{k}	97.52±2.8^{i}	246.12±2.9^{j}	125.55±1.8^{i}	251.82±3.6^{j}	42.86±1.5^{j}	9.613±0.08^{c}	1.517±0.01d^{e}	3.369±0.02^{ef}	5.528±0.01^{efg}
TGNPK	159.15±2.5^{e}	206.72±2.4^{h}	130.55±2.9^{l}	111.05±2.9^{g}	299.39±3.2f^{g}	117.17±1.4^{j}	304.76±4.3^{i}	53.01±1.4^{g}	7.860±0.09^{e}	1.794±0.02^{d}	3.968±0.05^{d}	5.747±0.04^{ef}
WCNPK	98.67±2.8^{hi}	162.34±2.4^{k}	101.45±4.1^{q}	79.89±2.8^{k}	109.25±3.5^{p}	113.66±1.1^{k}	179.98±2.9^{n}	32.94±2.1^{n}	4.004±0.26^{hi}	0.694±0.01^{gh}	3.452±0.05^{def}	5.731±0.04^{ef}
WGNPK	115.59±2.1^{f}	141.67±2.1^{l}	161.49±2.7^{i}	110.88±3.1^{g}	177.12±3.1^{l}	131.32±1.9^{g}	195.41±3.7^{k}	47.05±2.6^{h}	5.213±0.25^{g}	0.586±0.01^{hi}	3.365±0.04^{ef}	5.273±0.03^{fg}
FMNPK	99.70±2.8^{hi}	122.20±2.7^{n}	115.97±2.5^{m}	97.11±3.1^{i}	257.38±2.9^{h}	113.27±2.4^{k}	170.24±1.3^{o}	40.58±2.8^{k}	4.496±0.27^{h}	0.505±0.02^{hi}	3.921±0.03^{de}	4.568±0.01^{h}
C	88.73±1.9^{i}	109.93±2.6^{p}	103.42±3.2^{p}	83.47±1.5^{j}	134.93±2.3^{n}	99.04±2.6^{m}	148.86±3.9^{q}	35.51±1.8^{l}	3.971±0.07^{i}	0.278±0.01^{i}	2.397±0.02^{g}	3.668±0.02^{i}
LSD	5.52	0.55	0.43	1.05	1.53	0.64	1.27	0.46	0.22	0.14	0.24	0.23

Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$

Table 4.18. Elemental content of soil in the french bean field as influenced by applied treatments

Treatments	Na (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	K (mg kg^{-1})	P (mg kg^{-1})	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Cu (mg kg^{-1})	Cr (mg kg^{-1})
TLC10	273.65±2.4^{a}	287.50±4.8^{b}	253.90±6.2^{b}	167.55±2.2^{c}	422.61±4.2^{a}	201.30±3.1^{c}	432.62±6.2^{a}	91.26±2.4^{a}	12.279±0.4a	2.606±0.0^{a}	6.816±0.2^{a}	9.397±0.2^{c}
TLG10	280.24±2.1^{a}	355.14±4.7^{a}	269.39±2.4^{a}	190.78±3.4^{a}	416.82±3.9^{b}	215.68±3.5^{b}	425.83±5.4^{b}	72.96±2.1^{c}	10.349±0.3b	3.082±0.0^{b}	6.111±0.4^{b}	9.873±0.9^{b}
WCC10	174.74±1.6^{e}	236.33±3.2^{g}	224.28±3.5^{c}	138.15±2.5^{e}	193.48±3.6^{o}	201.30±2.8^{c}	318.42±4.7^{h}	58.34±2.8^{g}	7.092±0.3j	1.228±0.1^{i}	5.789±0.5^{c}	8.796±0.7^{d}
WCG10	192.50±3.2^{d}	172.31±3.4^{j}	179.67±3.1^{g}	184.66±2.9^{b}	295.14±2.5^{j}	219.07±3.1^{a}	325.97±3.2^{g}	78.49±2.9^{b}	8.629±0.2g	2.358±0.0^{c}	5.613±0.2^{c}	10.149±1.1^{a}
FYM10	214.39±4.2^{b}	271.69±5.2^{c}	206.09±4.5^{d}	145.95±3.1^{d}	393.48±3.6^{c}	165.00±4.5^{d}	403.87±3.9^{c}	69.67±3.1^{d}	9.150±0.4e	0.97±0.0^{j}	5.214±0.2^{d}	8.870±0.9^{d}
NPKR	117.32±2.9^{gh}	127.45±4.8^{p}	120.95±4.3^{o}	101.28±1.6^{k}	268.45±1.8^{l}	118.14±2.3^{n}	177.56±3.6^{p}	42.33±2.9^{m}	4.689±0.2n	0.550±0.0^{o}	4.090±0.4^{fg}	4.765±0.4^{k}
TLC5	166.04±1.6^{f}	102.09±2.9^{r}	151.03±6.2^{j}	99.27±1.2^{k}	250.52±5.3^{m}	127.79±3.7^{j}	256.32±5.3^{k}	43.29±2.7^{l}	8.000±0.1h	1.544±0.0^{g}	3.430±0.3^{hi}	5.627±0.6^{hi}
TLG5	162.00±1.3^{f}	211.08±2.5^{h}	132.88±3.5^{l}	113.03±1.7^{h}	304.74±4.6^{h}	119.27±2.6^{m}	311.21±6.8^{i}	53.96±3.5^{h}	9.784±0.4c	1.826±0.2^{f}	4.038±0.9^{fg}	5.850±1.7^{fg}
WCC5	103.20±2.4^{j}	170.34±3.5^{k}	106.46±5.4^{p}	83.16±2.7^{m}	114.64±3.8^{s}	119.27±2.1^{m}	188.86±6.8^{o}	34.56±3.7^{o}	4.202±0.8o	0.727±0.0^{k}	3.623±0.7^{h}	6.013±0.2^{f}
WCG5	114.58±3.0^{hi}	140.03±3.6^{n}	160.61±2.2^{i}	109.59±2.6^{i}	175.06±2.7^{q}	129.80±2.2^{i}	194.47±6.3^{n}	46.50±2.7^{k}	5.152±0.5l	0.579±0.2^{n}	3.326±0.5^{i}	5.211±0.2^{j}
TCFYM	203.54±2.1^{c}	257.52±3.2^{e}	197.72±3.1^{e}	138.48±2.1^{e}	372.97±2.9^{g}	158.30±3.2^{e}	379.65±4.6^{e}	66.37±2.9^{e}	8.673±0.3g	2.262±0.0^{d}	4.943±0.1^{e}	8.503±0.8^{e}
TGFYM	206.01±4.2^{bc}	260.65±2.1^{d}	195.34±3.4^{f}	140.02±1.8^{e}	377.50±3.7^{f}	156.40±3.7^{f}	384.27±3.5^{d}	65.70±2.1^{f}	8.778±0.3f	2.235±0.0^{e}	5.336±0.8^{d}	8.606±0.9^{e}
WCFYM	202.19±1.6^{c}	256.54±2.6^{f}	194.36±5.8^{f}	137.64±4.6^{f}	377.74±3.9^{e}	155.95±4.7^{g}	371.09±2.2^{f}	66.84±2.4^{e}	8.629±0.7g	2.224±0.0^{e}	4.918±0.3^{e}	8.460±1.0^{e}
WGFYM	202.95±2.1^{c}	256.23±3.5^{f}	194.59±3.9^{f}	137.81±3.5^{f}	378.20±5.1^{d}	155.80±3.9^{g}	372.69±3.0^{f}	66.92±4.6^{e}	8.639±0.2g	2.226±0.0^{e}	4.890±0.5^{e}	8.470±1.5^{e}
TCNPK	162.33±3.5^{f}	99.81±4.2^{s}	147.65±3.7^{k}	97.05±3.7^{l}	244.92±3.7^{n}	124.94±2.5^{k}	250.60±3.9^{l}	42.31±2.1^{m}	9.566±0.3d	1.510±0.1^{h}	3.353±0.2^{i}	5.501±0.6^{i}
TGNPK	159.38±.4.7^{f}	205.72±3.8^{i}	129.92±2.7^{m}	111.18±3.6^{hi}	297.94±2.7^{i}	116.61±2.8^{o}	304.28±4.3^{j}	52.75±1.8^{i}	7.822±0.3i	1.785±0.1^{g}	3.948±0.7^{g}	5.919±0.8^{f}
WCNPK	98.52±2.2^{j}	161.55±3.5^{l}	101.63±4.8^{q}	79.50±2.3^{n}	108.72±3.2^{t}	113.45±2.6^{p}	179.11±3.7^{p}	32.78±2.5^{p}	3.975±0.1p	0.690±0.2^{l}	3.469±0.7^{i}	5.703±0.5^{gh}
WGNPK	123.69±2.8^{g}	151.59±3.1^{m}	173.46±5.1^{h}	118.64±3.2^{g}	189.53±4.7^{p}	140.52±3.7^{h}	209.09±2.7^{m}	50.34±2.4^{j}	5.481±0.7k	0.627±0.0^{m}	3.604±0.3^{h}	5.642±1.3^{hi}
FMNPK	106.69±3.2^{ij}	131.09±2.5^{o}	124.09±2.6^{n}	103.91±3.7^{j}	275.41±3.8^{k}	121.20±3.9^{l}	182.16±6.4^{p}	43.42±3.1^{l}	4.811±0.2m	0.540±0.0^{o}	4.196±0.1^{hi}	4.888±0.9^{k}
C	88.73±±3.4^{k}	109.93±3.6^{q}	100.42±2.6^{r}	83.47±2.9^{m}	134.93±4.1^{r}	99.04±2.3^{q}	148.86±5.2^{q}	39.51±1.7^{n}	3.971±0.3p	0.078±0.0^{p}	2.397±0.1^{j}	3.668±0.4^{l}
LSD	4.23	0.23	0.53	1.09	0.10	0.10	0.14	1.22	0.280	0.0300.0	0.000	0.100

Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.19. Organic carbon Fractions and bacterial colony count of soil as influenced by applied treatment in mustard field

Treatment	SOC (%)	HAC (%)	FAC (%)	HAC:FAC	MBC mg/kg	B. count (log cfu g^{-1} soil)	SCS
TLC10	0.970±0.02^{ab}	0.501±0.01^{d}	0.337±0.00^{n}	1.48	523.20±1.1^{c}	4.11±0.92^{i}	2.91
TLG10	0.99±0.01^{a}	0.514±0.01^{b}	0.363±0.01^{g}	1.41	529.33±1.4^{ab}	4.27±0.64^{e}	2.97
WCC10	0.976±0.02^{ab}	0.507±0.00^{c}	0.371±0.02^{d}	1.36	526.03±1.8^{c}	4.26±1.23^{f}	1.98
WCG10	0.977±0.02^{ab}	0.521±0.00^{a}	0.358±0.00^{h}	1.45	518.83±0.8^{d}	3.89±0.81^{p}	0.85
FYM10	0.976±0.02^{ab}	0.450±0.01^{h}	0.348±0.00^{k}	1.29	532.90±1.6^{a}	4.54±0.75^{a}	2.40
NPKR	0.787±0.01^{e}	0.376±0.01^{o}	0.366±0.01^{g}	1.02	510.57±1.3^{e}	3.94±0.18^{n}	0.21
TLC5	0.837±0.01^{cde}	0.408±0.00^{l}	0.337±0.02^{o}	1.20	393.23±1.7^{n}	3.99±0.83^{l}	1.27
TLG5	0.893±0.03^{bcd}	0.421±0.00^{k}	0.342±0.00^{l}	1.22	384.13±1.2^{p}	4.09±0.35^{j}	1.53
WCC5	0.830±0.00^{de}	0.450±0.02^{hi}	0.348±0.01^{j}	1.29	388.30±1.1^{o}	4.02±0.56^{k}	2.41
WCG5	0.893±0.02^{bcd}	0.446±0.01^{ij}	0.365±0.02^{f}	1.22	383.07±1.6^{p}	4.19±0.67^{g}	1.39
TCFYM	0.920±0.01^{abc}	0.456±0.00^{g}	0.407±0.01^{b}	1.11	477.13±1.2^{h}	4.43±0.54^{c}	2.81
TGFYM	0.947±0.03^{ab}	0.471±0.01^{f}	0.456±0.01^{a}	1.03	482.33±1.2^{g}	4.51±0.61^{b}	2.73
WCFYM	0.850±0.02^{cde}	0.444±0.01^{j}	0.351±0.00^{i}	1.26	463.03±1.6^{i}	4.31±0.83^{d}	0.97
WGFYM	0.947±0.00^{ab}	0.485±0.01^{e}	0.397±0.03^{c}	1.22	445.63±1.9^{j}	4.16±0.92^{h}	1.68
TCNPK	0.820±0.01^{de}	0.377±0.02^{o}	0.366±0.01^{e}	1.03	438.73±1.8^{k}	3.80±1.37^{r}	0.82
TGNPK	0.837±0.02^{cde}	0.400±0.01^{m}	0.315±0.02^{n}	1.26	423.47±1.2^{l}	3.90±0.84^{o}	0.41
WCNPK	0.813±0.00^{de}	0.388±0.01^{n}	0.332±0.02^{q}	1.16	443.20±1.5^{j}	3.94±0.48^{m}	1.36
WGNPK	0.837±0.03^{cde}	0.401±0.00^{m}	0.331±0.01^{r}	1.24	411.20±1.9^{m}	3.80±0.82^{r}	0.28
FMNPK	0.810±0.04^{de}	0.379±0.02^{o}	0.340±0.01^{m}	1.11	488.20±1.5^{f}	3.86±0.74^{q}	1.85
C	0.787±0.02^{e}	0.376±0.00^{o}	0.334±0.00^{p}	1.12	374.20±1.3^{q}	3.70±0.61^{s}	0.20
LSD	0.037	0.002	0.00		1.83	0.021	

Where, SOC = soil organic carbon, HAC = humic acid carbon, FAC = fulvic acid carbon, SCS = soil carbon sequestration after two years of experimentation. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$

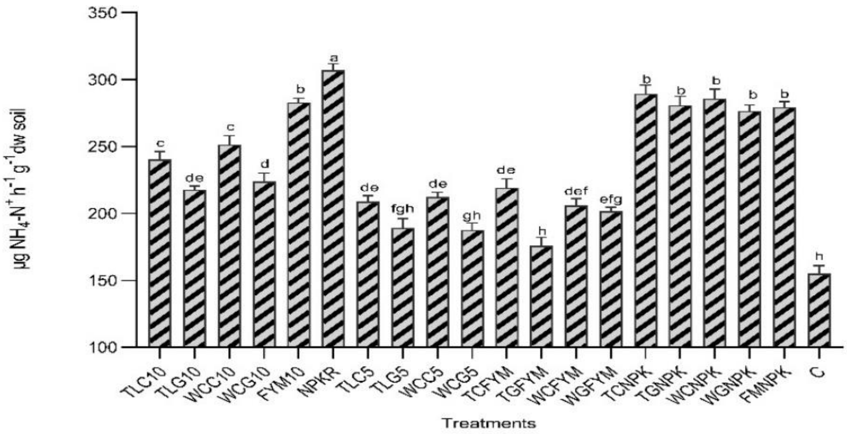
Table 4.20. Organic carbon fractions and bacterial colony count of soil as influenced by applied treatments in french bean field

Treatment	SOC (%)	HAC (%)	FAC (%)	HAC:FAC	MBC (mg kg^{-1})	B. count (log cfu g^{-1} soil)	SCS
TLC10	0.971±0.03^{ad}	0.502±0.00^{e}	0.359±0.00^{h}	1.39	502.83±1.5^{a}	4.18±0.07^{cde}	2.95
TLG10	0.993±0.02^{a}	0.526±0.01^{b}	0.371±0.01^{f}	1.41	472.20±1.3^{d}	4.12±0.10^{de}	3.73
WCC10	0.980±0.01^{ab}	0.518±0.02^{c}	0.383±0.02^{b}	1.35	450.23±0.9^{f}	4.10±0.09^{e}	2.39
WCG10	0.990±0.02^{a}	0.538±0.01^{a}	0.379±0.01^{d}	1.41	494.93±1.5^{b}	4.24±0.06^{bcd}	1.97
FYM10	0.983±0.00^{ab}	0.432±0.01^{i}	0.377±0.01^{e}	1.14	503.33±1.1^{a}	4.49±0.16^{a}	3.06
NPKR	0.793±0.02^{e}	0.364±0.02^{r}	0.341±0.02^{o}	1.06	420.40±1.6^{g}	3.77±0.66^{h}	0.60
TLC5	0.853±0.02^{cde}	0.401±0.01^{l}	0.331±0.00^{p}	1.22	386.60±1.3^{l}	3.94±0.85^{fg}	0.42
TLG5	0.897±0.02^{be}	0.423±0.01^{j}	0.355±0.01^{i}	1.19	395.40±1.9^{k}	4.06±0.58^{ef}	0.50
WCC5	0.833±0.01^{de}	0.450±0.02^{g}	0.347±0.01^{n}	1.29	382.10±2.1^{m}	3.78±0.48^{h}	1.42
WCG5	0.897±0.02^{be}	0.431±0.02^{i}	0.348±0.01^{l}	1.23	388.53±1.9^{l}	3.85±0.08^{gh}	1.29
TCFYM	0.900±0.03^{be}	0.447±0.01^{h}	0.351±0.02^{k}	1.27	453.80±1.4^{f}	4.26±0.04^{bc}	1.91
TGFYM	0.960±0.01^{abc}	0.454±0.00f	0.381±0.02c	1.19	461.90±1.6e	4.36±0.69^{ab}	1.84
WCFYM	0.840±0.01^{abc}	0.418±0.01^{k}	0.325±0.01^{s}	1.29	477.53±1.4^{c}	4.24±0.53^{bcd}	0.17
WGFYM	0.960±0.03^{de}	0.512±0.02^{d}	0.398±0.01^{a}	1.29	464.77±1.6^{e}	4.35±0.48^{b}	1.64
TCNPK	0.827±0.00^{e}	0.379±0.01^{p}	0.366±0.01^{g}	1.03	415.73±1.9^{h}	3.76±0.81^{h}	1.64
TGNPK	0.837±0.01^{de}	0.405±0.01^{m}	0.331±0.02^{p}	1.22	415.80±1.6^{h}	3.87±0.39^{gh}	0.45
WCNPK	0.808±0.02^{e}	0.398±0.02^{o}	0.329±0.00^{q}	1.20	402.17±1.2^{j}	3.85±0.09^{gh}	0.85
WGNPK	0.843±0.01^{cde}	0.401±0.00^{n}	0.353±0.01^{j}	1.13	396.57±1.1^{k}	3.72±0.46^{h}	0.51
FMNPK	0.803±0.01^{e}	0.374±0.01^{q}	0.326±0.00^{r}	1.14	409.37±1.3^{i}	3.85±0.37^{gh}	0.20
C	0.787±0.02^{e}	0.362±0.02^{s}	0.348±0.01^{m}	1.04	374.20±1.6^{j}	3.70±0.16^{hi}	0.07
LSD	0.050	0.00	0.00		1.93	0.063	

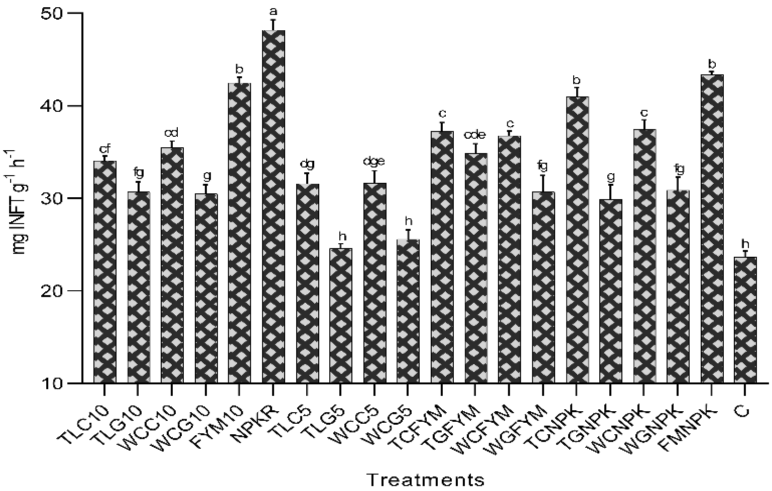
Where, SOC = soil organic carbon, HAC = humic acid carbon, FAC = fulvic acid carbon, SCS = soil carbon sequestration. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Figure 4.12. Soil enzyme activities (A = urease B = dehydrogenase, C = phosphatase) as influenced by applied treatments in the mustard field

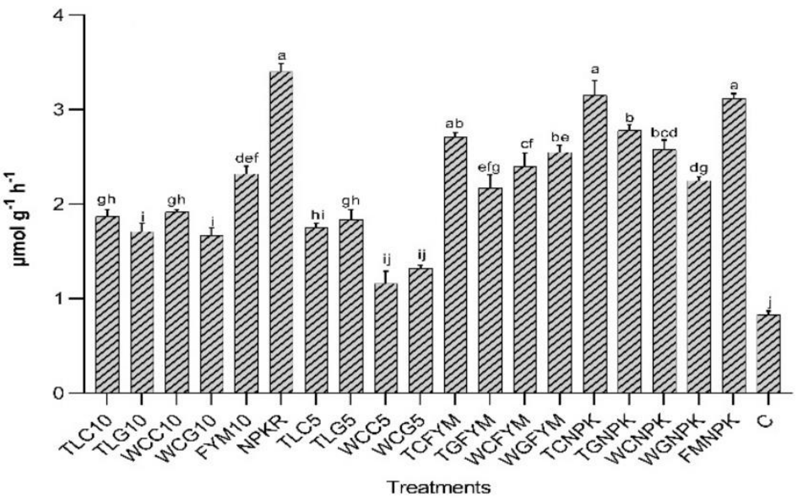
A



B



C



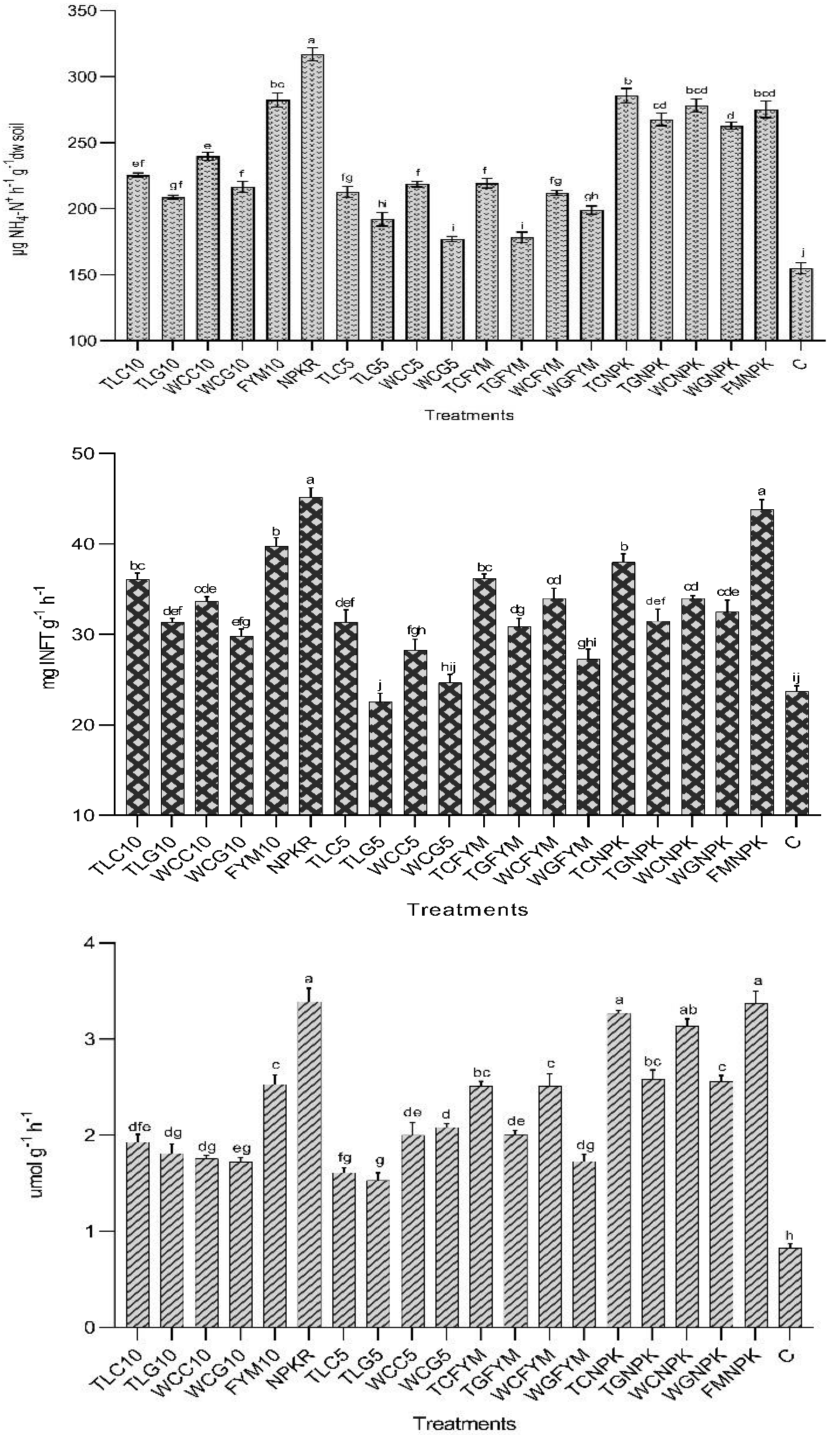
Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at *p<0.05*.

Figure 4.13. Soil enzyme activities (A = urease B = dehydrogenase, C = phosphatase) as influenced by applied treatments in french bean field

A

B

C



Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at *p<0.05.*

4.3. Objective 3: To investigate the impact of biochar application on emission of GHGs (N_2O, CO_2) from agroecosystems

4.3.1. Estimation of nitrous oxide flux, global warming potential (GWP) and carbon equivalent emission (CEE) from mustard (*Brassica juncea* L.,variety TS 38) and french bean (*Phaseolus vulgaris* L., variety Arka Anoop) field

4.3.1.1. Nitrous oxide flux (µg N_2O-N m^{-2} h^{-2}) and cumulative nitrous oxide emission (kg ha^{-1})

Applied treatments significantly influence N_2O emissions from mustard field Figure 4.14. Relatively lower emission of N_2O flux was observed during the early period of the mustard growth with the highest peak at flowering stage (50 DAS) and the emission declined steadily toward the maturation stage of the crop. Highest (235.12 µg $m^{-2}h^{-1}$) N_2O flux was recorded from inorganically fertilized plots (NPKR) at 50th DAS corresponding to flowering stage of the crop. Application of FYM at 10 t ha^{-1} (FYM10) reduced the emission peak to 167.23 µg $m^{-2}h^{-1}$. Moreover, co-addition of biochar (5 t ha^{-1} each) along with inorganic NPK fertilizer (50% of recommended) reduced (TCNPK = 159.63 µg $m^{-2}h^{-1}$, TGNPK = 161.14 µg $m^{-2}h^{-1}$, WCNPK =167.32 µg $m^{-2}h^{-1}$ and WGNPK =175.14 µg $m^{-2}h^{-1}$) the N_2O emission from mustard field. However, minimum (79.38 µg $m^{-2}h^{-1}$) N_2O flux were noted under addition of 10 t ha^{-1} of conventionally made tea litter biochar (TLC10).

Cumulative emission of N_2O from mustard field throughout the crop-growing season are displayed in the figure 4.15. Compared to control, lone application of inorganic fertilizers at recommended dose (NPKR) increased 21.31% of cumulative N_2O emission. While, 6.59% reduction of the same was documented under addition of FYM at 10 t ha^{-1} (FYM10). Similarly, addition of biochars at 10 t ha^{-1} significantly reduced (24.92 to 45.83%) N_2O emission from mustard field. Co-application of biochar and FYM equally (at 5 t ha^{-1} each) also revealed a distinguishable result by reducing the emission upto 10.48-20.29%. However, co-application of NPK fertilizer (50% of recommended dose) and biochar (5 t ha^{-1}) decreased the same upto 16.52%.

Similarly, the highest N_2O emission in french bean field were observed at flowering stage of the crop (50-60th DAS) (Figure 4.16). Treatment NPKR showed highest (227.12 µg $m^{-2}h^{-1}$) peak at 50th DAS and lowest (82.09 µg $m^{-2}h^{-1}$) was observed in treatment TLC10 at the same DAS. As compared to the control, addition of FYM at the rate of 10 t ha^{-1} (FYM10) reduced N_2O emission to 169.23 µg $m^{-2}h^{-1}$ at the equal DAS. Also, co-application of biochar (at 5 t ha^{-1} each) with inorganic NPK fertilizer (at 50% of recommended dose) showed reduction in N_2O emission as compared to sole application of inorganic NPK fertilizers (TCNPK = 161.25 µg $m^{-2}h^{-1}$, TGNPK= 168.14 µg $m^{-2}h^{-1}$, WCNPK = 149.23 µg $m^{-2}h^{-1}$ and WGNPK = 173.96 µg $m^{-2}h^{-1}$). Moreover, compared to treatment FYM10, co-application of biochar and FYM at 5 t ha^{-1} reduced the same (TCFYM = 143.85 µg $m^{-2}h^{-1}$, TGFYM = 148.24 µg $m^{-2}h^{-1}$, WCFYM = 132.56 µg $m^{-2}h^{-1}$and WGFYM = 162.24 µg $m^{-2}h^{-1}$).

Cumulative N_2O emission from french bean field throughout the crop-growing season are presented in the Figure 4.17. Compared to the control, treatment NPKR displayed an upsurge of 12.78% cumulative N_2O emission while, 13.60% reduction in N_2O flux was recorded from lone application of FYM at 10 t ha^{-1} (FYM10). Addition of biochars at 10 t ha^{-1} reduced the N_2O emission from 24.59 to 51.69% in french bean field. Co-application of biochar and FYM (at 5 t ha^{-1} each) also reduced the N_2O emission upto 24.45-36.08%. However, co-application of inorganic NPK fertilizers (50% of recommended dose) and biochar (5 t ha^{-1}) decreased the same upto 9.75-23.01%.

4.3.1.2. Global warming potential (GWP) (kg CO_2 eqiv. ha^{-1})

Calculated global warming potential for both mustard and french bean field was maximum in inorganically fertilized plots (44.75 kg CO_2 eqiv. ha^{-1} and 39.77 kg CO_2 eqiv. $ha^{-1, \text{ respectively}}$). While, lowest of the same was documented under addition of TLC biochar at 10 t ha^{-1} (TLC10) (15.08 kg CO_2 eqiv. ha^{-1} and 14.11 kg CO_2 eqiv. $ha^{-1, \text{ respectively}}$) (Table 4.21).

4.3.1.3. Carbon equivalent emission (CEE) (kg C ha^{-1})

Calculated carbon equivalent emission from mustard and freach bean fields were in the range of 4.11 kg C ha^{-1} to 12.20 kg C ha^{-1} and 3.85 kg C ha^{-1} to 10.85 kg C ha^{-1}, respectively. Irrespective of the crops, the highest CEE was recorded under treatment NPKR (12.20 kg C ha^{-1} from mustard and 10.85 kg C ha^{-1} in french bean). While treatment FYM10 showed lower CEE from mustard and french bean crops (8.71 kg C ha^{-1} and 8.31 kg C ha^{-1}, respectively). However, the lowest of the same from mustard and french bean crops were recorded from treatment TLC10 (4.11 kg C ha^{-1} and 3.85 kg C $ha^{-1, respectively}$) (Table 4.21).

4.3.1.4. Amendment effect index (AEI)

Effect of amendments on cumulative N_2O emission from both the experimental fields are presented on the Table 4.22. Application of TLC biochar at the rate of 10 t ha^{-1} (TLC10) made the highest positive impact on reduction of N_2O emission from both mustard and french bean fields. Whereas application of inorganic NPK fertilizers (NPKR) showed contradictory impact than that of the other treatments by increasing the N_2O emission from both the fields. Recorded AEI order amongst the treatments in mustard field were: TLC10 > TLG10 > WCC10 > TLC5 > TLG5 > WCG10 > WCC5 > WCC5 > TGFYM > WCFYM > TCFYM > WCNPK > TGNPK > TCNPK > WCG5 > WGYM > FYM10 > FMNPK > WGNPK. While the AEI order among the treatments of french bean field were: TLC10 > WCC10> TLG10 > WCFYM > TLC5 > TGFYM > WCC5 > TCFYM > TLG5 > WGFYM > WCG10 > WCNPK > WCG5 > TGNPK > TCNPK > FYM10 > WGNPK > FMNPK.

4.3.2. Estimation of soil CO_2 efflux from mustard (*Brassica juncea L.*, variety TS 38) and french bean (*Phaseolus vulgaris* L., variety Arka Anoop) field

4.3.2.1 Soil CO_2 efflux (μmol m^{-2} s^{-1})

Soil CO_2 efflux at different growth stages of mustard and french bean are presented on figures 4.18 and 4.19, respectively. Addition of FYM at 10 t ha^{-1} (FYM10) hiked (upto 4.12% in mustard and 5.36% in french bean field) the CO_2 efflux while biochar application at the same rate significantly reduced (upto 30.28% in mustard and 33.26% in french bean field) the same compared to control. Maximum soil CO_2 flux was recorded during the seedling stage of mustard and french bean crops, which was in the range of 5.80 μmol m^{-2} s^{-1} to 8.26 μmol m^{-2} s^{-1} and 5.73 μmol m^{-2} s^{-1} to 8.4 μmol m^{-2} s^{-1} from treatment TLC10 and FYM10, respectively. The second highest CO_2 efflux was documented at the active vegetative stage of the crops. The recorded soil CO_2 emission was 5.11 μmol m^{-2} s^{-1} (WGNPK) to 6.88 μmol m^{-2} s^{-1} (FYM10) from mustard field and 5.05 µmol m^{-2} s^{-1} (WCG10) to 6.49 µmol m^{-2} s^{-1} (FMNPK) from french bean field. During flowering stage of both the crops, the CO_2 efflux was ranged between 2.34 µmol m^{-2} s^{-1} to 4.91 µmol m^{-2} s^{-1} and 2.44 µmol m^{-2} s^{-1} to 4.81 µmol m^{-2} s^{-1} in treatment WCG10 and control. While, at the maturation stage of the crops, soil CO_2 efflux was noted in the range of 2.81 µmol m^{-2} s^{-1} (WCG10) to 4.93 µmol m^{-2} s^{-1} (FMNPK) from mustard field and 2.92 µmol m^{-2} s^{-1} (WCG10) to 5.38 µmol m^{-2} s^{-1} (C) from french bean field.

Nevertheless, recorded cumulative soil CO_2 efflux were maximum (23.97 µmol m^{-2} s^{-1} and 24.40 µmol m^{-2} s^{-1}) in treatment FYM10 of mustard and french bean plots, respectively. Treatment NPKR recorded 22.11 µmol m^{-2} s^{-1} and 22.62 µmol m^{-2} s^{-1} of CO_2 efflux from mustard and french bean fields, respectively. Co-application of biochar and FYM equally at the rate of 5 t ha^{-1} showed the CO_2 efflux upto 21.58 µmol m^{-2} s^{-1} (WCFYM) from mustard and 21.70 µmol m^{-2} s^{-1} (TCFYM) from french bean field. Moreover, co-application of NPK fertilizer (50% of recommended dose) and biochar (5 t ha^{-1}) exhibited the same upto 19.64 µmol m^{-2} s^{-1} and 19.67 µmol m^{-2} s^{-1} in treatment WCNPK from mustard and french bean fields, respectively. Whereas, minimum (15.36 µmol m^{-2} s^{-1} and 16.15 µmol m^{-2} s^{-1}) of the same were recorded in treatment WCG10 from mustard and french bean field, respectively.

4.3.2.2. Amendment effect index (AEI)

Amendment effects on soil CO_2 efflux are presented on the Table 4.22. Compared to control, notable reduction (30.28% and 33.26%) of CO_2 efflux were observed under biochar application (at 10 t ha^{-1}) mainly WCG biochar (WCG10) in mustard and french bean fields, respectively. Greater (4.12% in mustard and 5.36% in french bean field) CO_2 efflux was noted from treatment FYM10 than control. Co-addition of biochar and FYM equally at the rate of 5 t ha^{-1} reduced the same upto 13.86% and 14.93% from mustard and french bean fields, respectively. Moreover, co-application of NPK fertilizer (50% of recommended dose) and biochar (5 t ha^{-1}) reduced it upto 21% from mustard field and upto 20% from french bean field.

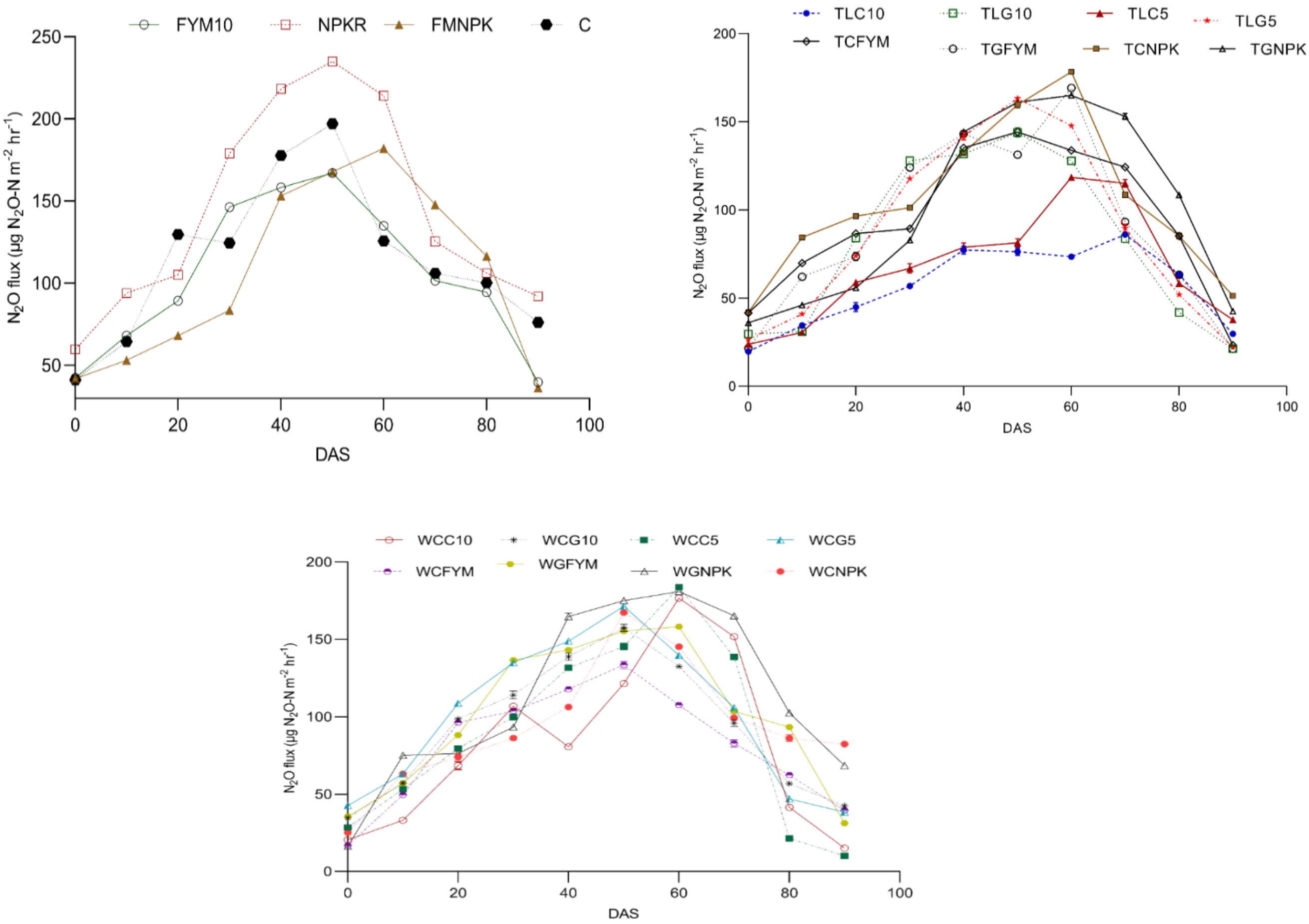
4.3.2.3. Correlation analysis between plant, soil and GHGs emission of mustard field

Cumulative N_2O emission and transpiration rate of mustard crop showed significant positive correlation (r = 0.674) at $p < 0.01$. Whereas, negative correlation (r = -0.551) was observed between N_2O emission and SOC at $p < 0.05$. Cumulative N_2O emission and soil CO_2 efflux showed significant negative correlation with soil pH (r = -0.677 and -0.660, respectively) at $p<0.01$. Substantial negative correlation of cumulative N_2O emission and soil CO_2 flux was documented with soil EC (r = -0.447 at $p<0.05$ and -0.568 at $p<0.01$, *respectively*). Moreover, cumulative N_2O emission and soil CO_2 efflux was found to be negatively related with soil water holding capacity (r = -0.617 and -0.757, respectively at $p<0.01$) and cation exchange capacity (r = -0.733 at $p<0.01$ and -0.559 at $p<0.05$, *respectively*). Additionally, positive correlation (r = 427) was noted between soil available nitrogen and N_2O emission (Image 4.4).

4.3.4.4. Correlation analysis between plant, soil and GHGs emission of french bean field

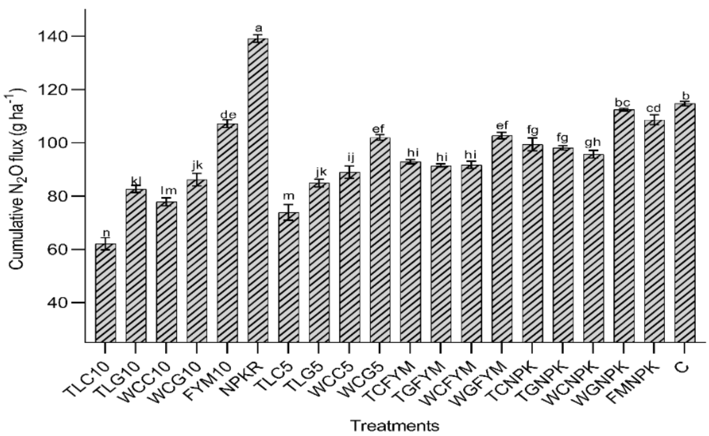
Cumulative N_2O emission and soil CO_2 efflux exhibited significant positive correlation with transpiration rate of the french bean plant (r = 0.663 at $p< 0.01$ and 0.474 at $p< 0.05$, *respectively*). Significant negative (r = -0.577) correlation was noted between cumulative N_2O emission and soil SOC at $p< 0.05$. Moreover, cumulative N_2O emission and soil CO_2 efflux displayed significant negative correlation with soil pH (r = -0.649 and -0.729, respectively) at $p<0.01$. Cumulative N_2O emission and soil CO_2 efflux exhibited significant negative correlation with soil EC (r = -0.538 and -0.556, respectively) at $p<0.05$. Cumulative N_2O emission showed noteworthy negative correlation with soil CEC (r = -0.736) at $p<0.01$. Additionally, the positive correlation (r = 336) was observed between cumulative N_2O emission with soil available nitrogen (Image 4.5).

Figure 4.14. N_2O fluxes from the mustard field



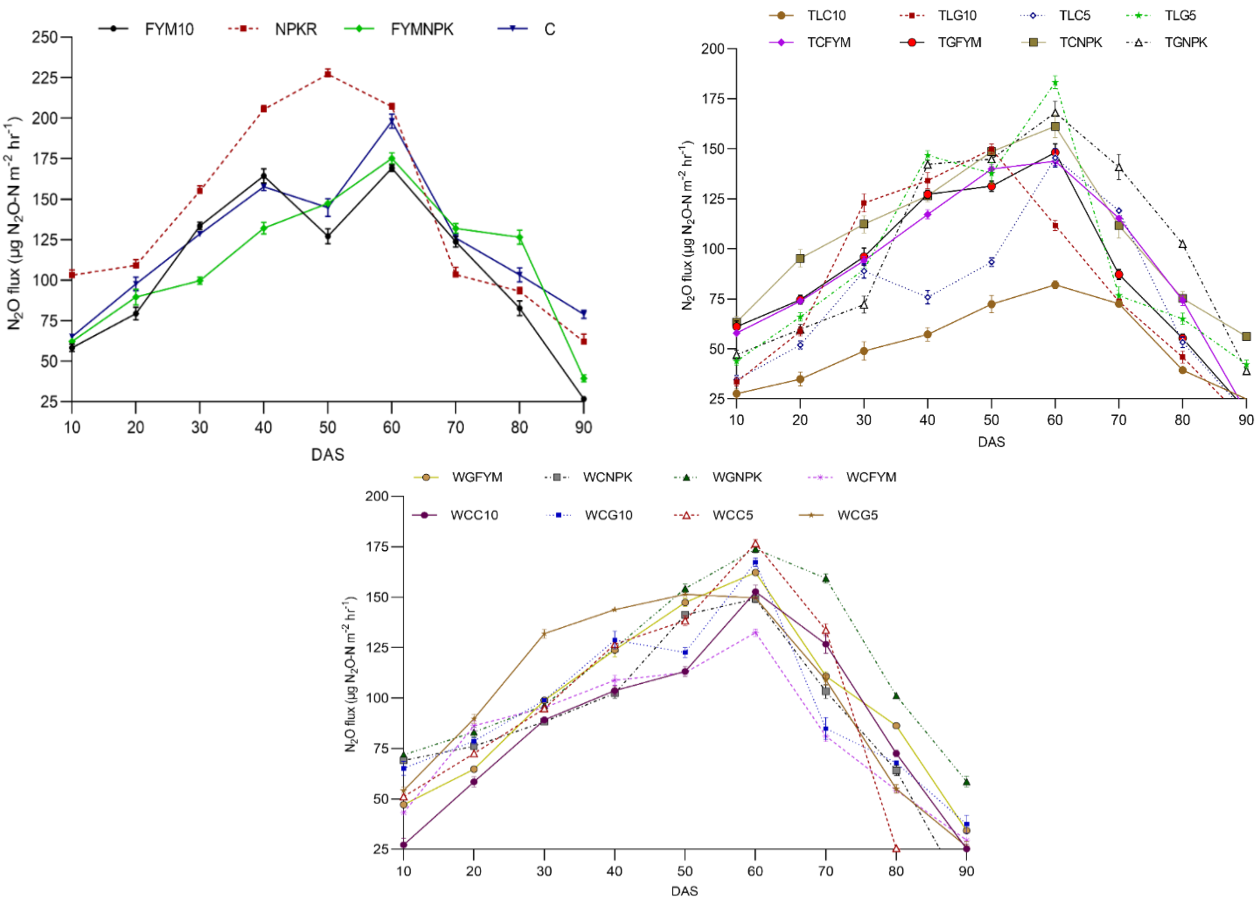
Where, DAS = days after sowing. Data are the means of 3 replicates.

Figure 4.15. Cumulative N_2O fluxes from the mustard field



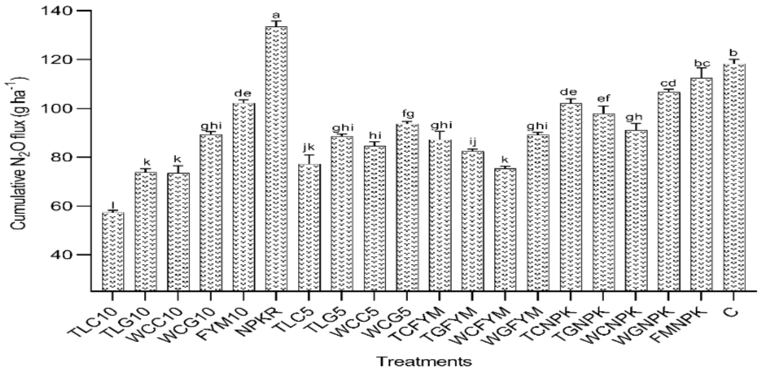
Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Figures 4.16. N_2O fluxes from the french bean field



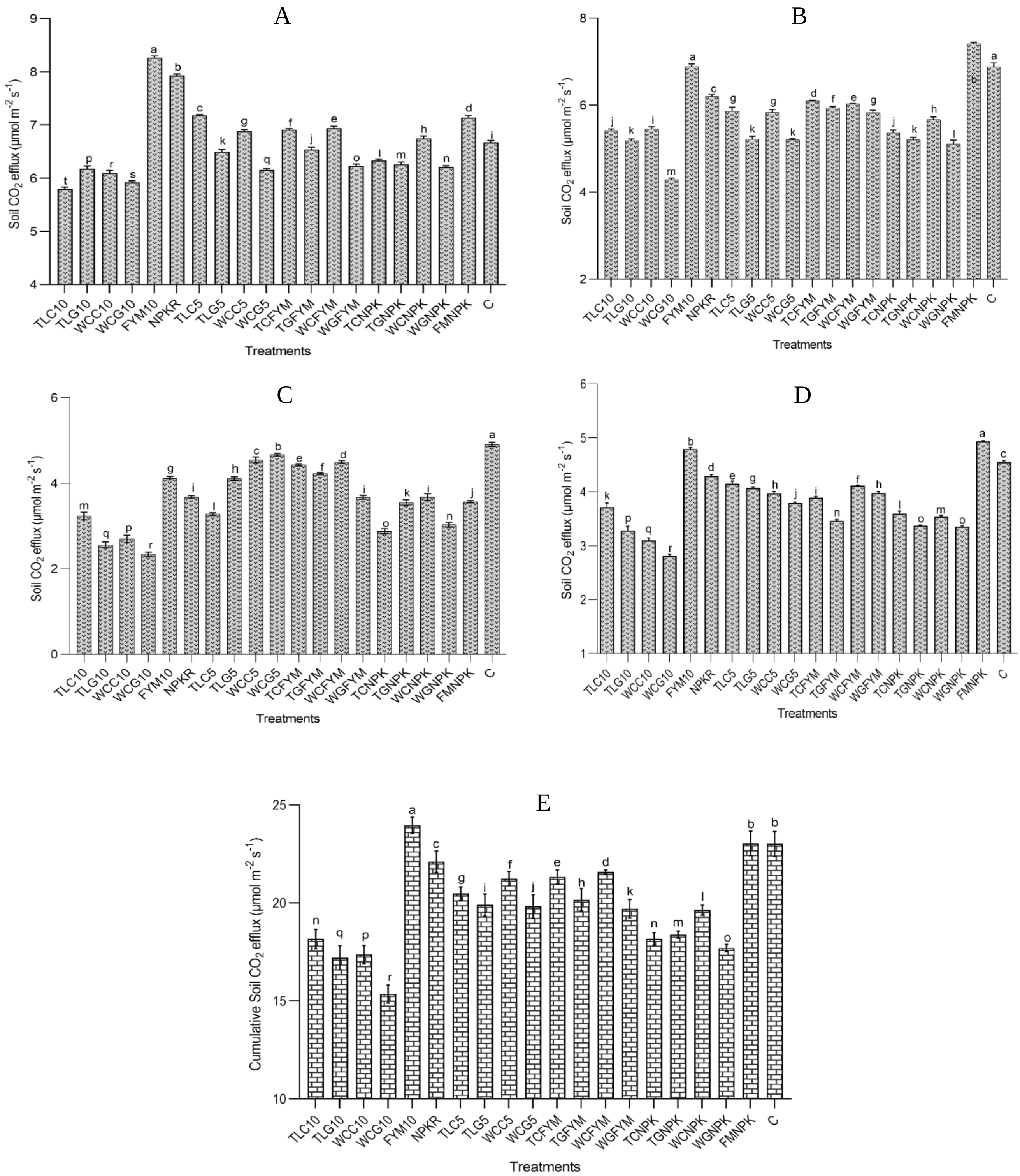
Where, DAS = days after sowing. Data are the means of 3 replicates.

Figure 4.17. Cumulative N_2O fluxes from the french bean field



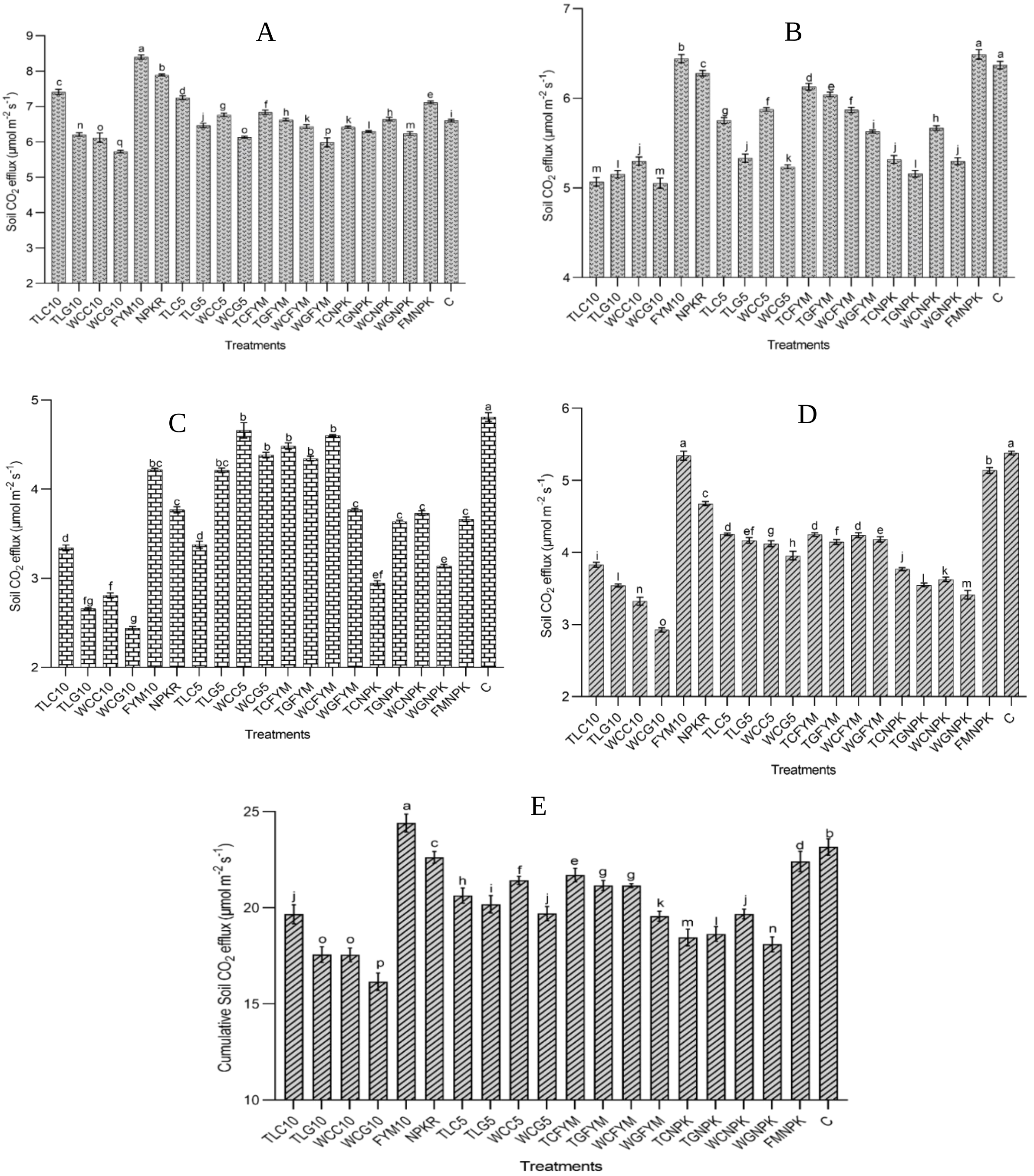
Data are the means of 3 replicate. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at *$p<0.05$*.

Figure 4.18. Soil CO_2 efflux from the mustard field as influenced by the treatments



Where, A = seedling, B = vegetative, C = flowering, D = maturation stages of the crop and E = cumulative CO_2 flux for whole crop growing season. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Figure 4.19. Soil CO_2 efflux from the french bean field as influenced by the treatments



Where, A = seedling, B = vegetative, C = flowering, D = maturation stages of the crop and E = cumulative CO_2 flux for whole crop growing season. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at *$p<0.05$*.

Table 4.21. Global warming potential (GWP) and carbon equivalent emission (CEE) as influenced by the applied treatments

Treatments	GWPM	GWPB	CEEM	CEEB
	($kg\ CO_2$ eqiv. ha^{-1})		(kg C ha^{-1})	
TLC10	15.0 ± 0.3^{m}	14.1 ± 0.2^{l}	4.1	3.8
TLG10	22.0 ± 0.4^{l}	21.9 ± 0.4^{k}	6.1	5.9
WCC10	23.1 ± 0.4^{l}	21.9 ± 0.8^{k}	6.3	5.9
WCG10	25.6 ± 0.6^{jk}	26.5 ± 0.3^{ghi}	7.0	7.2
FYM10	31.9 ± 0.4^{de}	30.4 ± 0.3^{de}	8.7	8.3
NPKR	44.7 ± 0.4^{a}	39.7 ± 0.6^{a}	12.2	10.8
TLC5	24.6 ± 1.1^{lk}	23.0 ± 1.0^{jk}	6.5	6.2
TLG5	25.3 ± 0.4^{jk}	26.3 ± 0.2^{ghi}	6.9	7.2
WCC5	26.4 ± 0.7^{ij}	25.2 ± 0.5^{hi}	7.2	6.8
WCG5	30.4 ± 0.3^{f}	27.9 ± 0.3^{fg}	8.2	7.6
TCFYM	27.6 ± 0.2^{hi}	25.98 ± 1.02^{ghi}	7.5	7.0
TGFYM	27.2 ± 0.2^{hi}	24.5 ± 0.2^{ij}	7.4	6.7
WCFYM	27.3 ± 0.4^{hi}	22.4 ± 0.2^{k}	7.4	6.1
WGFYM	30.6 ± 0.3^{ef}	26.5 ± 0.3^{ghi}	8.3	7.2
TCNPK	29.6 ± 0.7^{fg}	30.4 ± 0.5^{de}	8.0	8.3
TGNPK	29.2 ± 0.2^{fg}	29.1 ± 0.9^{ef}	7.9	7.9
WCNPK	30.5 ± 0.4^{gh}	27.1 ± 0.7^{gh}	8.3	7.4
WGNPK	33.4 ± 0.1^{bc}	31.8 ± 0.3^{cd}	9.1	8.6
FMNPK	32.3 ± 0.5^{cd}	33.5 ± 1.2^{bc}	8.8	9.1
C	34.1 ± 0.2^{b}	35.2 ± 0.5^{b}	9.3	9.6
LSD	0.70	0.905		

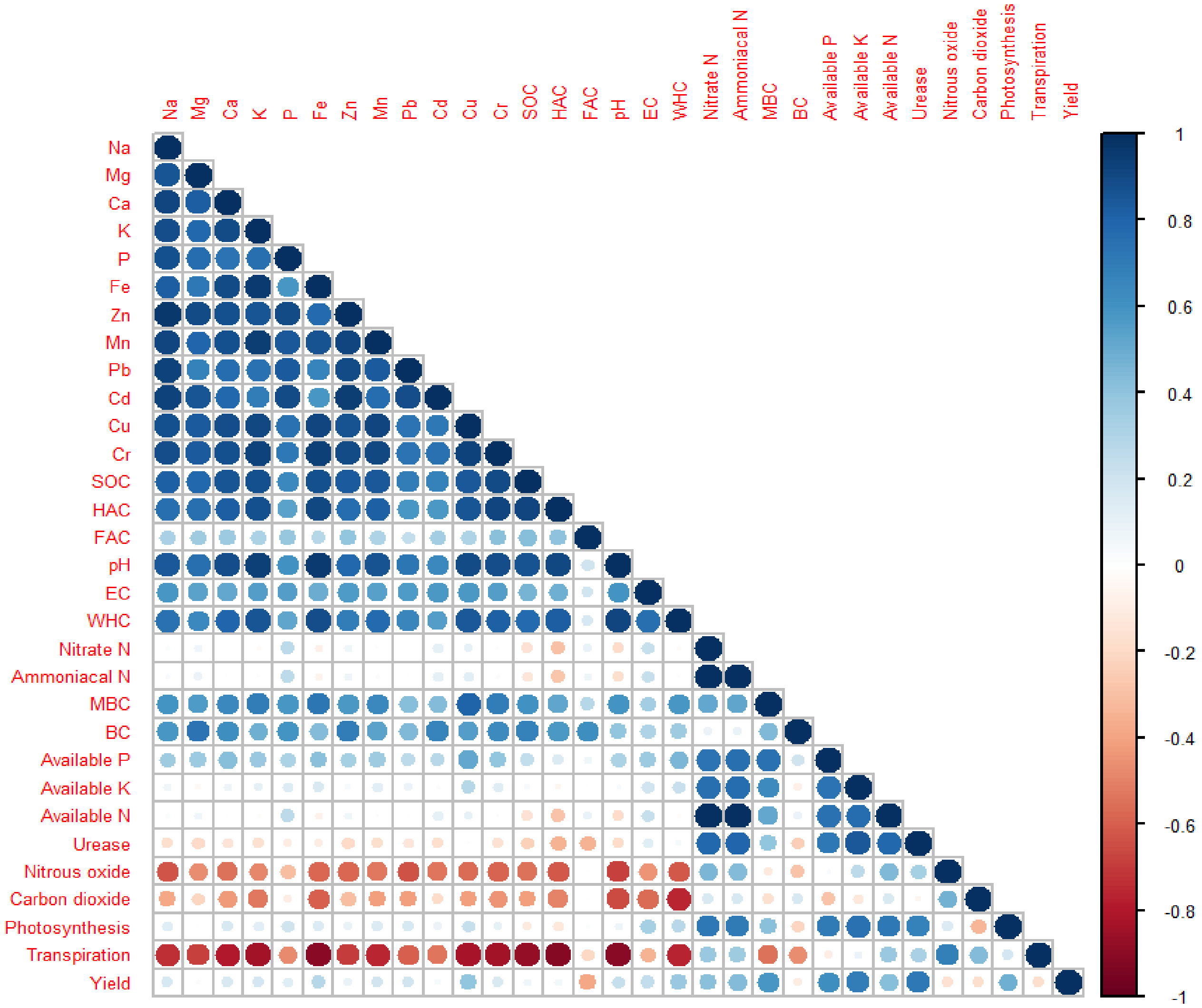
Where, GWPM = GWP of N_2O flux from mustard field, GWPB = GWP of N_2O flux from french bean field, CEEM = CEE of N_2O from mustard field, CEEB = CEE of N_2O from french bean field. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Table 4.22. Amendment effect index on GWP of N_2O and CO_2 flux

Treatments	AEIGWPM	AEIGWPB	AEICM	AEICB
TLC10	-55.88	-59.97	-21.10	-15.11
TLG10	-33.78	-37.71	-25.24	-24.16
WCC10	-32.14	-37.71	-24.5	-24.21
WCG10	-24.92	-24.58	-30.28	-33.26
FYM10	-6.57	-13.59	4.12	5.36
NPKR	30.91	12.79	-3.96	-2.33
TLC5	-29.77	-34.71	-11.04	-10.90
TLG5	-25.96	-25.15	-13.56	-12.87
WCC5	-22.50	-28.50	-7.74	-7.49
WCG5	-11.05	-20.82	-13.86	-14.93
TCFYM	-19.04	-26.31	-7.35	-6.30
TGFYM	-20.28	-30.27	-12.39	-8.63
WCFYM	-20.07	-36.25	-6.23	-8.69
WGFYM	-10.47	-24.65	-14.37	-15.54
TCNPK	-13.32	-13.67	-21.07	-20.31
TGNPK	-14.44	-17.26	-20.13	-19.51
WCNPK	-16.53	-23.00	-14.69	-15.05
WGNPK	-2.00	-9.74	-23.12	-21.85
FMNPK	-5.31	-4.91	0.10	-3.25

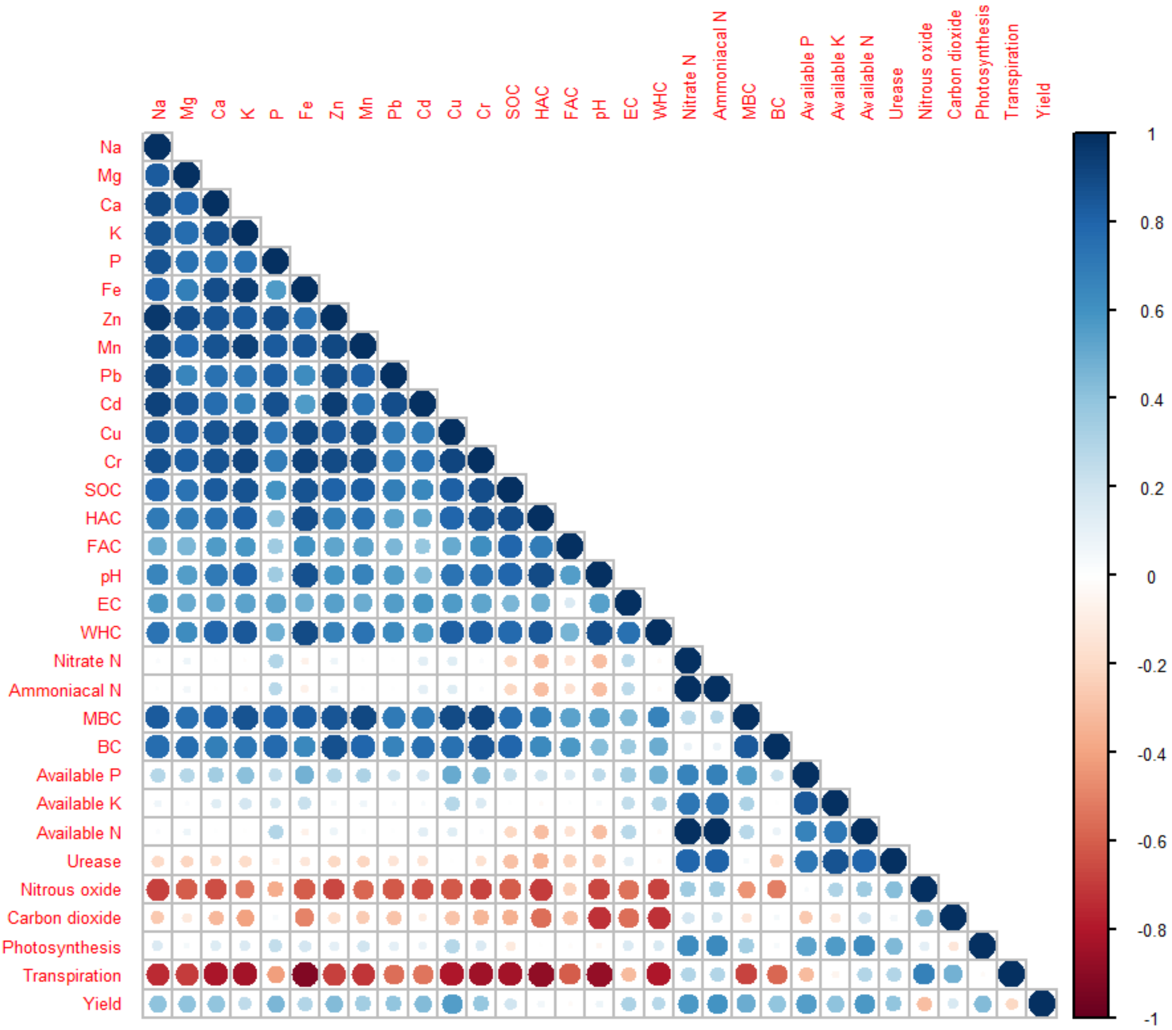
Where, AEIGWPM = amendment effect index on GWP of N_2O flux from mustard field, AEIGWPB = amendment effect index on GWP of N_2O flux from french bean field, AEICM = AEI on soil CO_2 efflux of mustard field, AEICB = AEI on soil CO_2 efflux of french bean field. Data are the means of 3 replicates. Mean values followed by the different letter are significantly different according to Duncan's multiple range test at $p<0.05$.

Image 4.4. Pearson correlation matrix of plant and soil parameters and GHGs emission from mustard field



Where, SOC = soil organic carbon, HAC = humic acid carbon, FAC = fulvic acid carbon, EC = electrical conductivity, WHC = water holding capacity, MBC = microbial biomass carbon, BC = bacterial count.

Image 4.5. Pearson correlation matrix of plant and soil parameters and GHGs emission from french bean field



Where, SOC = soil organic carbon, HAC = humic acid carbon, FAC = fulvic acid carbon, EC = electrical conductivity, WHC = water holding capacity, MBC = microbial biomass carbon, BC = bacterial count.

4.3.5 PCA for biochar influenced mustard and french bean seed germination performance and seedling growth:

PCA was carried out with 23 selected variables to observe the influence of biochar properties on germination performance and seedling growth of mustard. The variables identified to two components (DIM1 and (DIM2) that accounted for maximum variance for the observed germination performance of the seeds under application of biochar (Figure 4.20, A). Biochar properties like alkalinity, adsorption capacity, EC, pH, SA, total carbon, CEC, R50, CSP, WHC, and CN ratio along with germination parameters like percent germination, vigor index, seedling biomass are the components of DIM1 with 74.7% variation. Whereas, biochar properties like acidity, O/C, H/C, ash content, VM, and MC as well as germination parameters like seedling biomass, germination percentage and vigor index at 20 t ha^{-1} are the components of DIM2 with 11.9% variation.

Similarly, for french bean, PCA was carried out with 23 selected variables to observe the influence of biochar properties on germination performance and seedling growth (Figure 4.20, B). We found the same group of biochar properties and germination parameters in DIM1 and DIM2 for french bean seeds as well. Slightly higher (75.7%) weightage for DIM1 and lower (11.2%) for DIM2 were noted compared to mustard seeds.

4.3.6 PCA of the studied plant and soil parameters on N_2O and CO_2 emission from both the crop fields:

PCA was carried out with 31 selected (Figure 4.20, C). Soil pH, EC, SOC, HAC, FAC, MBC, soil elemental contents, ammoniacal N, available NPK, photosynthesis activity, yield are the components of DIM1 with 52.2% variation whereas, CO_2, N_2O, transpiration rate and urease activity are the components of DIM2 with 22% variation.

Likewise, for variables of french bean (Figure 4.20, D), we found the same group of soil and plant parameters in DIM1 and DIM2 for french bean field as well. Slightly higher (53.6%) weightage for DIM1 and lower (20.6%) for DIM2 were noted compared to mustard field.

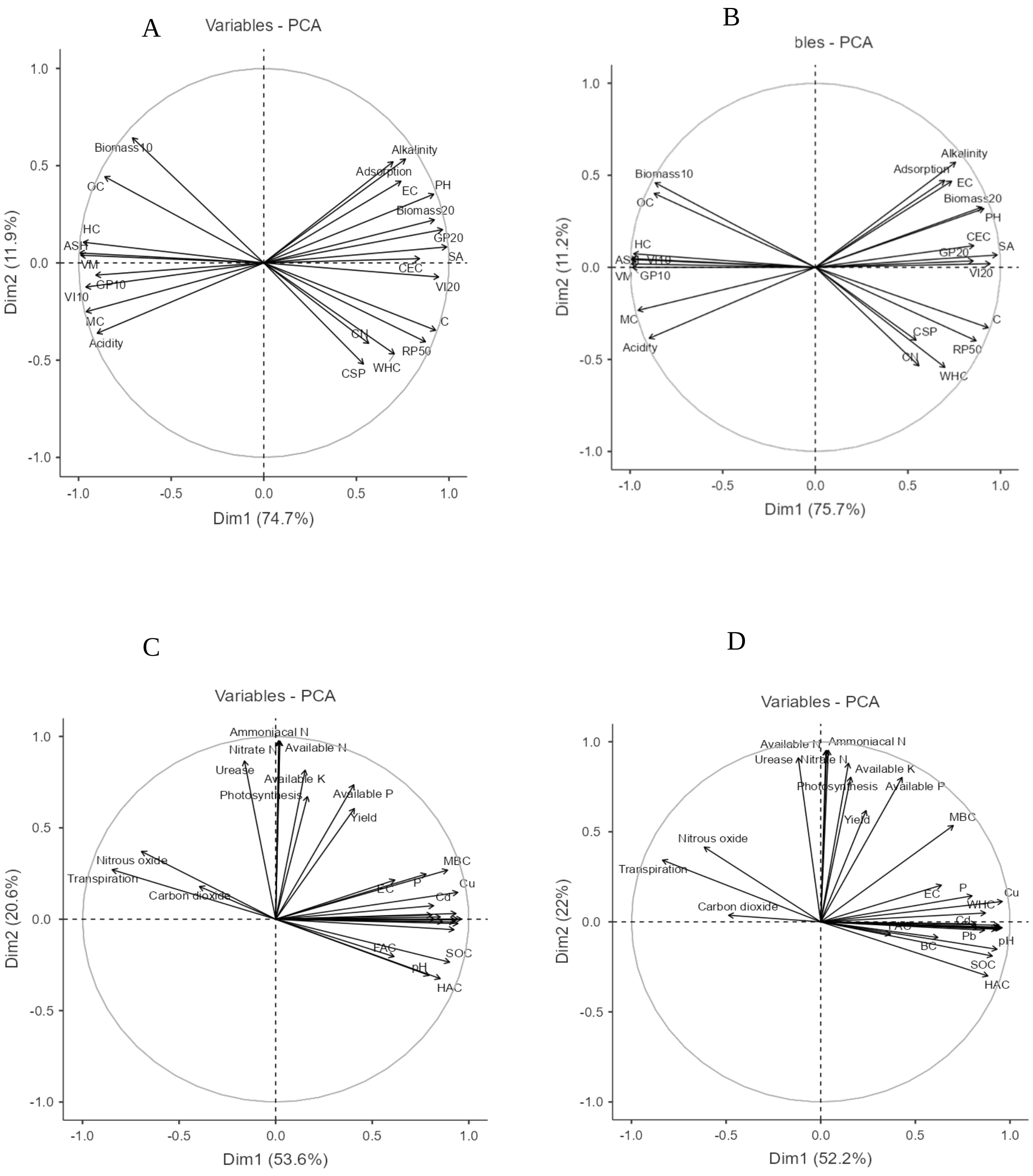


Figure 4.20. PCA analysis in the A = mustard germination-biochars, B = french bean germination-biochar, C = Soil-mustard-GHGs emission, D = Soil-french bean-GHGs emission.

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