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RESPONSE OF WHEAT PRODUCTIVITY AND SOIL FERTILITY TO THE RESIDUAL EFFECT OF ORGANIC NUTRIENTS SOURCES

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Abstract

Effective nutrient management is the only way to boost crop growth, yield, soil fertility and mitigate climate change effects. To evaluate the effect of organic and inorganic nutrient sources on wheat productivity, an experiment was conducted at the Agriculture University Peshawar-Pakistan during the winter of 2018-2020. A randomized complete block design was used for the experiment with a split-plot arrangement. Wheat crops were grown in main plots while previously applied nutrient was kept in subplots. Experimental treatments consist of half (H) NPK, full NPK, legume residues (LR) @ 10 tons ha^{-1}, humic acid (HA) @ 5 kg ha^{-1}, biochar (BC) @ 10 tons ha^{-1}, LR + HNPK, HA + HNPK, BC + HNPK, HLR +HHA+ HNPK, HLR + HBC + HNPK, HBC + HHA + HNPK. The residual effect of treatments on wheat crops was statistically significant in terms of wheat yield and yield components. The residual effect of biochar and HNPK improved wheat grain $spike^{-1}$ by 60%, stover yield by 97%, grain protein content by 74% while improved soil AB-DTPA K by 27% as compared to sole application of HNPK. Furthermore, combined application of HNPK improved SOM 80%, plant height 15%, soil total N by 92%, AB-DTPA P (61%) were found in BC 10-ton ha^{-1} treatment. Plots that were previously sown with maize varieties (POMV) resulted in better wheat yield as compared to plots sown with CS 220 hybrid plots. Overall, the application of biochar in combination with NPK resulted in higher yield and yield components of wheat along with enhancing soil fertility over the sole application of inorganic source of these nutrients.

Key words: Residual effect, Biochar, Humic acid, Legumes residues, Wheat, Soil Properties.

Introduction

Wheat, a major staple food crop in Pakistan, is grown in irrigated and rainfed areas under arid and semi-arid climates to meet the growing population's demand. Pakistan's agricultural sector is vital to the country's economy, contributing 22.7% to GDP in 2023 and employing 37.4% of the labor force. Wheat, a vital crop for maintaining a healthy diet, accounts for 7.8% of value addition and 1.8% of GDP (Cherif *et al*., 2023). However, wheat production has declined over the last decade, except in 2021 when yield was slightly high. Pakistan is the 7th-largest individual wheat producer and the maize-wheat cropping system is crucial for food security. Intensive cropping requires high input energy, leading to environmental degradation and increased cultivation costs (Al-Muaini, 2019). The energy crisis, high fertilizer costs, and low purchasing power in farming communities necessitate the use of alternative methods like organic manure and bio-fertilizer. Sustainable agriculture promotes organic supplements and biofertilizers, while crop rotation systems provide soil, environmental, and human health benefits (Bahrulolum *et al*., 2021). Organic farming is a sustainable agricultural practice that avoids synthetic fertilizers, pesticides, and genetically modified organisms. Consumers perceive organic products as healthier and safer, leading to increased demand and price. However, debates exist on environmental impact, nutritional quality, safety, and health effects. (Giampieri *et al*., 2022).

Soil fertility can be enhanced by incorporating cover crops that add organic matter, using green manure or legumes for biological nitrogen fixation, and using micro-dose fertilizers to improve soil structure and promote healthy, fertile soil (Sunori *et al*., 2023). Biochar, a carbonized biomass, is a soil amendment with potential limitations due to nutrient deficiencies. Biochar-based fertilizers improve nitrogen, phosphorus, and potassium fertility, but lack information on methods. Biochar-based fertilizers are more effective in improving soil properties and crop yields (Ali *et al.,* 2019). The post-pyrolysis method is the most used technique for enriching biochar. Future research should focus on understanding the mechanisms of long-term application of BCFs. (Ndoung *et al*., 2021). pH is crucial for measuring acidity and alkalinity in biochar, which is generally alkaline. It increases with pyrolysis temperature, while low-temperature biochar is acidic. The pH is also dependent on the feedstock used. (Shetty & Prakash, 2020). Biochar are carbon-rich solid materials obtained by the thermochemical decomposition of organic biomass in an oxygen-limited environment (Yadav & Jagadevan, 2019). Biochar application affects plant height, grain spike, straw yield, soil responses, agricultural systems, crop types, climatic conditions, and fertilization status. It reduces inorganic N leaching, increases nutrient retention, and prevents nitrification and denitrification losses. (Bista *et al*., 2019). Biochar amendments improve fertilizer efficiency in fertilized systems, but interactions between biochar and fertilizer on plant production and soil health remain unclear (Han *et al*., 2022). Some authors suggest that treatments receiving both biochar and fertilizer increase fertilizer use efficiency by enhancing plant growth and soil N mineralization.

Chemical and molecular structures, sources, and application rates are crucial for determining HA's effects on crops and soil. HA application can result in inconsistent yield results due to different biological origins (Rashad *et al*., 2022). HA's functional group composition reflects its degree of humification, and hydrophobicity during the evolution of soil organic matter and also regulate pH in soil also suitable for alkaline soil (Meng *et al.*, 2023). Humic acid are the decomposed residues of plant and animal materials such as lignin, tannin, and cellulose. A large amount of HA is present in the soil after the absorption of crop residues (Wei *et al.*, 2022). The HA fraction contains approximately 60% organic carbon (C) and plays an important role in the growth of soil microorganisms (Ren *et al.*, 2023). HA contains nitrogen, phosphorus, potassium, oxygen, hydrogen, and sulfur, promoting plant growth (Plant height, Grain spike and yield) also promoting hormones like auxin and cytokinin, aiding stress resistance, nutrient metabolism, and photosynthesis (Ampong *et al.*, 2022). HA application doesn't affect crop growth or soil health; high doses improve physical characteristics, but chemical effects and crops remain uncertain (Furtado e Silva *et al.*, 2022). Legumes are natural nitrogen production by solubilizing insoluble P, improving soil's environment, increasing microbial activity, restoring organic matter, and smothering weeds, enhancing soil health and reducing weed growth (Jalal *et al.*, 2022). Green gram showed better direct and residual effects of partially acidulated material and rock phosphate/single superphosphate mixture compared to rice during winter due to legume effect (Kushwaha & Mehta, 2023). Mineral fertilizers have been crucial in wheat-based cropping systems for three decades. Plant residues can replace them by altering soil environment, improving physical properties, and affecting microbial populations (Biswas *et al.*, 2017). Combined farming systems are increasingly used due to rising labor costs and decreasing numbers. Proper management, like soil absorption, ensures long-term soil health benefits (Goswami *et al.*, 2020).

The application of organic manures not only increases crop yield but also significantly affects soil physical, chemical, and biological properties. This integrated nutrient management strategy has been reviewed in relation to wheat productivity and sustaining soil fertility. organic fertilizers, which are environmentally friendly and low-cost inputs, play a significant role in plant nutrition and growth regulation (Karthik & Maheswari, 2021). The judicious use of organic manure, and organic fertilizer helps sustain wheat production. Soil fertility can build up or deplete over time due to various factors, including cropping system, manures, and fertilizer application. Continuous appraisal of soils is essential in fixed cropping systems with continuous use of fertilizers (Tesfahunegn & Gebru, 2020). The study investigates the impact of inorganic and organic fertilizers on crop productivity and soil properties in rainfed maize-wheat cropping systems. It also evaluates the effect of biochar on wheat yield and soil properties. Results reveal that organic amendments enhance soil organic matter levels and microbial activities.

Material and Methods

Experimental site: Experiments were conducted at the Agriculture Research Farm of the University of Agriculture, Peshawar during Fall 2018-19 and 2019-20. The location had a semi-arid subtropical climate, 360mm annual rainfall, and a maximum temperature of 40°C. The soil was silt loam, deficient in nitrogen but with adequate K, P, pH, and organic matter content, Ec and its basic properties are given in (Table 1). The mean daily temperature and rainfall for both seasons were summarized in (Fig. 1).

Table 1. Experimental site's physical and chemical properties.

Properties	Unit	Values
Textural class		Silt loam
Sand	%	46
Silt	%	41
Clay	%	13
Electrical conductivity	dS m^{-1}	0.27
pH		7.51
Organic matter	%	1.11
"Soil Total N"	%	0.030
"AB-DTPA P"	mg kg 1	4.91
"AB-DTPA "K"	mg kg 1	77.4

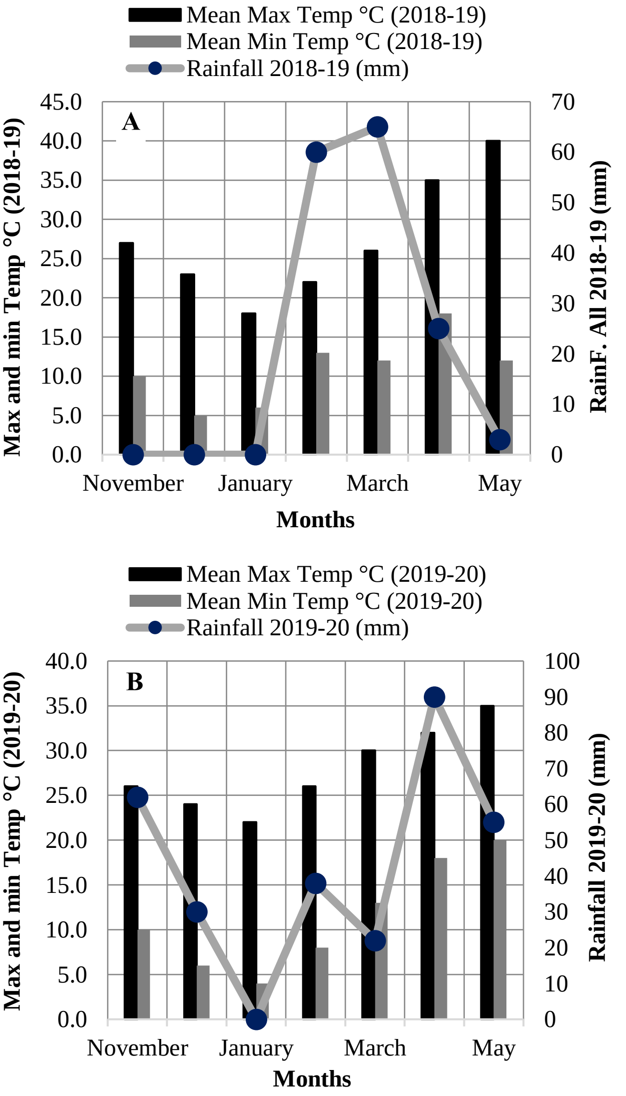

Fig. 1. Mean daily temperature and rainfall for 2018-19 (A) and 2019-20 (B) growing seasons in Pakistan Metrological Department Peshawar.

Materials and treatments: Seeds were obtained from the Agricultural Research farm and Irrigated field, ploughed, and seedbed prepared for wheat sowing using a cultivator. The research was consist of two Factors i.e., Factor "A" was wheat in the plot of (maize variety Azam and hybrid CS 220) and factor "B" was fertilizer Application (Control, HNPK, Full NPK, LR @ 10ton ha^{-1}, BC @ 10ton ha^{-1}, HA @ 5kg ha^{-1}, LR + HNPK, BC + HNPK, HA + HNPK, HLR + HHA HNPK, HLR + HBC + HNPK, HBC + HHA + HNPK) which was applied previously. The physio-chemical properties of the experiment site are displayed in Table 1. Planting was done during winter (wheat sowing date 24-11-2018-19 and harvesting date 5-4-2019-20) season in 2018-2020. Weeds were controlled using mechanical and chemical herbicides, using Affinity 400 DF. Uniform agronomic practices were used for each replication.

Experimental design: The experiment used a split-plot design with three replications per year, with wheat assigned to main plots and fertilizer application to subplots. In the experimental field, subplots sized 3.5 x 3 m2 with 10 rows spaced 30 cm apart and 5 meters long, 50 cm between two subplots, and main plots with 42m length, 16m width, 1m gap between main and replication plots were maintained.

Observation and measurement: Soil samples were randomly collected from 15 cm depth in subplots for soil mineral N determination before and after crop growth in all seasons (Maynard *et al*., 1993). Plant height data was collected at physiological maturity stage using measuring tape from treatments, with ten best plants selected. The number of grains per spike was recorded by counting grains in randomly selected five spikes. Strove yield was recorded after threshing separately and expressed in kg ha^{-1}. The pH meter is used for pH with ratio of 1:5 soil water suspensions. Ten g of soil was added to a shaking bottle, and 50 ml distilled water was added and shaken for 30 minutes (McLean, 1983). Soil organic matter was determined using the Walkley-Black procedure, (Nelson & Sommers, 1996). while soil P, K content was determination of P, K using AB-DTPA procedure. (Soltanpour & Schwab, 1977) Soil P was measured using a spectrophotometer at 880 nm wavelengths, and K was determined using a flame photometer. Kjeldhal is used for total N in soil was used as suggested by (Bremner, 1996). Protein content in grain was determined by multiplying total grain nitrogen by 6.25 to convert nitrogen into protein.

Statistical analysis

ANOVA was used to detect treatment effects for variables, while testing for the mean and standard error of the means were used to separate means in significant differences (Astorino *et al*., 2012). Special mean comparisons were made to achieve research goals using GenStat 8.1 for data analysis was used for analysis of all data.

Results

Plant height (cm): Plant height in grain crops is not a yield component but indicates nutrient influence on plant metabolism. Concentrate organic fertilizer and inorganic fertilizer increased plant height compared to inorganic sources and control when applied separately displays in the (Table 2). Statistical analysis reveals previous maize varieties and fertilizer treatments (organic and in-organic) sources significantly impacted of residual effects on plant height on the wheat crop. Year significantly influences wheat plant height, but non-significant interactions between PMV x YS and YS x PMV x FT, while PMV x FT and YS x FT are significant. Plots treated with BC at a @ of 10-ton per ha showed a statistically significant increase in plant height of 128.9 cm, followed by HA and LR application, which were statistically similar. Control plots without any fertilizers produced short-statured plants of 117.3 cm. Wheat in the previous maize significantly impact wheat plant height due to residual effects. Wheat in the plot of previous maize (Azam), that produce resulted in taller plants (127.5 cm) while wheat in the previous maize varieties (Hybrid) obtain short plants height (117.3 cm) of crops of wheat. In 2018-19, shorter plants were achieved in wheat crops compared to 2019-20.

Table 2. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts the plant height cm of wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	111.2	113.7	112.4f
HNPK (75:50:30)	115.9	123.2	119.6e
NPK (150: 100: 60)	117.6	125.0	121.3d
LR (10 ton/ha)	121.8	129.5	125.6b
HA (5kg/ha)	123.0	130.8	126.9b
BC (10ton/ha)	125.0	132.9	128.9a
LR + HNPK	119.8	127.4	123.6c
HA + HNPK	119.1	126.7	122.9cd
BC + HNPK	122.3	130.1	126.2b
HLR + HHA + HNPK	116.7	124.2	120.4de
HLR + HBC + HNPK	113.8	121.0	117.4ef
HBC + HHA + HNPK	118.2	125.7	122.0cd
LSD for FT	2.7	3.4	2.2
Wheat in the plot PMV			
Wheat in the plot of Azam	123.6	130.8	127.2a
Wheat in the plot Hybrid	113.8	120.9	117.3b
LSD for PMV	3.0	2.1	1.0
Years (YS)			
Y1: 2018-19			118.7b
Y2: 2019-20			125.8a
Significance Level (SL)			*
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	**
FT x PMV	**	YS x PMV x FT	**ns**

This means using various alphabets within the same category are significantly different at ($p \leq 0.05$) "ns" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties (PMV)

Grains per spike: Table 3. shows data on the Grains per spike as impacted by the residual effect of fertilizer treatments (organic and in-organic) and previous maize varieties. The statistical evaluation of the data indicated that the residual effect of different fertilizer treatments (organic and inorganic) sources together with varied ratios had significant effects on the grains per spike of the wheat crop. Wheat in the plot of previous maize varieties also indicated significant variations as a residual influence on the grains per spike of wheat crops that were statistically identical with each other. Year was determined to be non-significant as the source of variance. All possible combinations, with the exception of YS x FT and FT x PMV, were found to be non-significant. BC + HNPK fertilizer produced the highest grains per spike (44.5) following the treatments of HA + HNPK and LR + HNPK, which were statistically equal to one another with values of (43.5 and 43.2, respectively), In accordance statistically with other fertilizer treatments, such as NPK, HNPK, and control plots where no fertilizer was used, lower grains per spike were observed in control plots.

Stover yield (kg/ha): Wheat crops show stover yield as affected by the residual effect of fertilizers and crops of wheat on a plot of previous maize varieties. Stover yield is significantly impacted by fertilizer treatments (organic and in-organic) and previous maize varieties over two years in (Table 4). The year is a significant source of variation, but all interactions are non-significant except for YS x FT and FT x PMV. The maximum aggregate yield (7119.5 kg/ha) was achieved with BC with HNPK fertilizer, while HA + HNPK and LR + HNPK fertilizer produced similar results. Control plots showed a minimum aggregate yield (3605.7 kg/ha). Wheat in previous maize (Azam) had a higher stover yield (5315.7 kg/ha) compared to wheat previous maize "hybrid" (5105.0 kg/ha).

pH of soil: The residual effects of fertilizer treatments (organic and inorganic) and previous maize varieties have an impact on soil pH. Analysis of the data showed in (Table 5). The study found that the residual effects of different fertilizers from both organic and inorganic sources, combined with varying ratios, significantly impacted soil pH. Except for FT x PMV and YS x FT, which were determined to be significant, and remaining possible interactions were found to be non-significant. Also determined to be non-significant was the year as a source of variance. As for maize varieties, the residual effect of the previous hybrid produced the highest soil pH (7.67), whereas the previous Azam produced a lower pH (7.51) for wheat crops. Among different Fertilizer treatments (organic and inorganic), maximum soil pH (7.76) was observed by the treatments of HBC + HHA + HNPK, and the minimum soil pH (7.47) was observed on HA treatment applied at the rate of (5 kg/ha).

Table 3. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts of the grain spike^{-1} wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	27.0	28.7	27.8ef
HNPK (75:50:30)	27.5	28.3	27.9ef
NPK (150: 100: 60)	28.2	29.0	28.6f
LR (10 ton/ha)	41.0	43.0	42.0bcd
HA (5kg/ha)	41.0	42.3	41.7cd
BC (10ton/ha)	40.7	42.3	41.5cd
LR + HNPK	42.3	44.0	43.2abc
HA + HNPK	43.0	44.0	43.5ab
BC + HNPK	43.3	45.7	44.5a
HLR + HHA + HNPK	39.7	41.5	40.6de
HLR + HBC + HNPK	40.2	41.0	40.6de
HBC + HHA + HNPK	38.5	40.7	39.6e
LSD for FT	2.7	2.2	1.7
Wheat in the plot PMV			
Wheat in the plot of Azam	37.8	39.7	38.8a
Wheat in the plot Hybrid	37.6	38.7	38.1a
LSD for PMV	**ns**	1.2	**ns**
Years (YS)			
Y1: 2018-19			37.7b
Y2: 2019-20			39.2a
Significance Level (SL)			**ns**
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	*
FT x PMV	*	YS x PMV x FT	**ns**

This means using various alphabets within the same category are significantly different at ($p≤0.05$) "ns" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties PMV)

Table 4. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts the stover yield (kg/ha) Wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	3582.1	3629.3	3605.7g
HNPK (75:50:30)	3904.3	3939.4	3921.9fg
NPK (150: 100: 60)	4112.6	4149.6	4131.1ef
LR (10 ton/ha)	5223.7	5270.7	5247.2cd
HA (5kg/ha)	5300.7	5348.4	5324.6e
BC (10ton/ha)	5029.3	5074.5	5051.9d
LR + HNPK	6459.8	6518.0	6488.9b
HA + HNPK	6459.8	6518.0	6488.9b
BC + HNPK	7087.6	7151.4	7119.5a
HLR + HHA + HNPK	5276.5	5324.0	5300.2cd
HLR + HBC + HNPK	5029.3	5074.5	5051.9d
HBC + HHA + HNPK	5601.5	5651.9	5626.7c
LSD for FT	99.1	68.9	59.5
Wheat in the plot PMV			
Wheat in the plot of Azam	5283.0	5332.3	5307.7a
Wheat in the plot Hybrid	5228.2	5276.0	5252.1b
LSD for PMV	**ns**	43.5	32.5
Years (YS)			
Y1: 2018-19			5255.6b
Y2: 2019-20			5304.2a
Significance Level (SL)			*
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	**
FT x PMV	**	YS x PMV x FT	**ns**

This means using various alphabets within the same category are significantly different at (p≤0.05) "ns" = Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties (PMV)

Table 5. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts the pH of soil Wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	7.65	7.55	7.60b
HNPK (75:50:30)	7.68	7.57	7.63b
NPK (150: 100: 60)	7.64	7.49	7.56bc
LR (10 ton/ha)	7.57	7.62	7.59b
HA (5kg/ha)	7.46	7.48	7.47d
BC (10ton/ha)	7.64	7.55	7.59b
LR + HNPK	7.65	7.59	7.62b
HA + HNPK	7.63	7.56	7.59b
BC + HNPK	7.62	7.57	7.59b
HLR + HHA + HNPK	7.66	7.70	7.68ab
HLR + HBC + HNPK	7.35	7.33	7.34c
HBC + HHA + HNPK	7.75	7.77	7.76a
LSD for FT	**ns**	0.15	0.12
Wheat in the plot PMV			
Wheat in the plot of Azam	7.53	7.49	7.51b
Wheat in the plot Hybrid	7.68	7.64	7.67a
LSD for PMV	0.16	0.05	0.04
Years (YS)			
Y1: 2018-19			7.61a
Y2: 2019-20			7.56a
Significance Level (SL)			**ns**
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	**
FT x PMV	**	YS x PMV x FT	**ns**

This means using various alphabets within the same category are significantly different at ($p \leq 0.05$) "ns" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties (PMV).

Table 6. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts on the soil organic matter (%) of Wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	1.22	1.01	1.11f
HNPK (75:50:30)	1.43	1.22	1.33de
NPK (150: 100: 60)	1.63	1.42	1.53cd
LR (10 ton/ha)	1.51	1.27	1.39de
HA (5kg/ha)	1.64	1.39	1.51cd
BC (10ton/ha)	1.41	1.20	1.30ef
LR + HNPK	1.79	1.59	1.69bc
HA + HNPK	1.48	1.24	1.36de
BC + HNPK	1.70	1.49	1.60bc
HLR + HHA + HNPK	1.86	1.61	1.74b
HLR + HBC + HNPK	2.14	1.88	2.01a
HBC + HHA + HNPK	1.78	1.57	1.67bc
LSD for FT	0.42	0.04	0.21
Wheat in the plot PMV			
Wheat in the plot of Azam	1.67	1.44	1.56a
Wheat in the plot Hybrid	1.59	1.37	1.48b
LSD for PMV	**ns**	0.04	0.05
Years (YS)			
Y1: 2018-19			1.63a
Y2: 2019-20			1.41a
Significance Level (SL)			**ns**
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	**
FT x PMV	**	YS x PMV x FT	**ns**

This means using various alphabets within the same category are significantly different at ($p \leq 0.05$) "ns" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties (PMV)

Soil organic matter (%): The data on SOM affected by the residual effect of different fertilizer treatments (organic and inorganic) and wheat in the plot of previous maize varieties are presented in (Table 6). Statistical study revealed that fertilizer treatments (organic and inorganic) sources, combined with various ratios, significantly impacted soil organic matter. wheat on the plot of previous maize varieties did not differ among themselves in SOM for the wheat crop. The interactions between FT x PMV and YS x FT were found to be significant except for PMV x YS and YS x PMV x FT. The source of variance among different years was determined to be non-significant. Plots of fertilizer application with HLR + HBC + HNPK with the subsequent residual effect of HLR + HHA + HNPK fertilizer application significantly increased soil SOM with values (2.01 and 1.74%) that were statistically at the same level. The minimum SOM was recorded in the control (1.11%) where no fertilizers were applied. Higher soil SOM was observed by the residual of wheat on the plot (PMV Azam) (1.56%) compared to wheat on the plot of (PMV hybrid) with value (1.48%).

Nitrogen concentration in soil (%): Data on nitrogen of soil as affected by the residuals impact of fertilizer treatments (organic and inorganic) and wheat in the plot of previous maize varieties are shown in (Table 7). Soil nitrogen is significantly impacted by remaining effects of fertilizer treatments (organic and inorganic) on plots. wheat on the plot of early Maize varieties also differed significantly for wheat soil N. The interaction between PMV x YS was produced to be nonsignificant, while YS x FT, FT x PMV and YS x PMV x FT were significant. The year did not significantly influence soil N content, but plots with the highest N content (0.057%) were fertilized with BC @ 10 t/ha, followed by BC + HNPK fertilizer. The soil's nitrogen concentration was lowest (0.030%) in control pots while no fertilizers were used. Among wheat in a plot of different previous maize varieties, maximum soil N (0.045%) was recorded by previous Azam compared to maize hybrid, which resulted in lower soil N content (0.040%). During the 1st year (2018-19) compared to the 2nd year (2019-20), a residual effect of different treatments was observed in the result of higher N content in the soil produced (0.043%).

Phosphorus content in soil (mg/kg): Data on soil P content for wheat crops affected by residual fertilizer treatments (organic and inorganic) and wheat in the plot of previous maize varieties are shown in (Table 8). A statistical investigation of the data revealed that the residuals treatments effects of various organic matter-based fertilizers applied to the soil had a significant effect on its P content and in organic treatments combined with various ratios of previous maize varieties. The year was not found to be a significant source of variation. All possible combination were found to be Significant, YS x FT, FT x PMV, YS x PMV x FT except PMV x YS which were found to be non-significant. Compared with different fertilizer applications on plots receiving BC 10 tom/ ha, there was a significant increase in maximum soil P content (7.93 mg/kg), followed by LR application at 10 ton/ ha and BC + HNPK, (7.37, 7.35 mg/kg), they showed statistically Same results, which were similar in terms of their P contents for wheat soil that was altered by fertilizer residue. In control plots where no fertilizers were used, the lowest P level in wheat soil was found (4.91 mg/kg). During the year of 2018-19, the lowest soil P content (6.15 mg/kg) was observed compared to 2019-20, resulting in higher soil P content (6.43 mg/kg). Among the wheat in the plot of previous maize, produced lower soil P content (6.00 mg/kg) compared to wheat in the plot of previous maize hybrid (6.58 mg/kg).

K content in soil (mg/kg): Data regarding soil K content affected by the residual effect of fertilizer treatments (organic and inorganic) and previous maize varieties in the wheat crops are shown in (Table 9). A statistical investigation of the data revealed that residual effects from varied fertilizer treatments (organic and inorganic) sources in combination with varying ratios for wheat crop has significant effects on soil K content. The K content of the soil varied significantly amongst previous varieties of maize as well in wheat crop. The year was not found to be a significant source of variation. All possible interactions were found to be nonsignificant. BC applied in combination with HNPK fertilizer resulted in the production of maximum soil K content (98.7 mg/kg). Minimum soil K content was obtained as a control. Regarding the residual effect of different maize varieties, the synthetic wheat in the plot of previous Azam resulted in higher soil K content of wheat (85.6 mg/kg) while wheat in the plot of previous hybrid produced lower soil K content (83.7 mg/kg).

Table 7. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts on the N content in soil (%) of wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	0.031	0.029	0.030g
HNPK (75:50:30)	0.033	0.033	0.033f
NPK (150: 100: 60)	0.031	0.031	0.031fg
LR (10 ton/ha)	0.047	0.057	0.052b
HA (5kg/ha)	0.039	0.039	0.039e
BC (10ton/ha)	0.052	0.063	0.057a
LR + HNPK	0.042	0.047	0.044c
HA + HNPK	0.042	0.042	0.042cd
BC + HNPK	0.050	0.054	0.052b
HLR + HHA + HNPK	0.039	0.041	0.040de
HLR + HBC + HNPK	0.042	0.042	0.042cd
HBC + HHA + HNPK	0.043	0.043	0.043cd
LSD for FT	0.004	0.004	0.003
Wheat in the plot PMV			
Wheat in the plot of Azam	0.044	0.046	0.045a
Wheat in the plot Hybrid	0.038	0.041	0.040b
LSD for PMV	0.004	0.003	0.001
Years (YS)			
Y1: 2018-19			0.041b
Y2: 2019-20			0.043a
Significance Level (SL)			*
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	**
FT x PMV	**	YS x PMV x FT	**

This means using various alphabets within the same category are significantly different at ($p \leq 0.05$) "ns" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties (PMV)

Table 8. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts on the P content in soil of Wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	5.02	4.81	4.91g
HNPK (75:50:30)	5.33	5.33	5.33f
NPK (150: 100: 60)	5.11	5.11	5.11fg
LR (10 ton/ha)	6.81	7.93	7.37b
HA (5kg/ha)	5.95	5.95	5.95e
BC (10ton/ha)	7.32	8.55	7.93a
LR + HNPK	6.22	6.78	6.50c
HA + HNPK	6.28	6.28	6.28cd
BC + HNPK	7.12	7.58	7.35b
HLR + HHA + HNPK	5.99	6.15	6.07de
HLR + HBC + HNPK	6.32	6.32	6.32cd
HBC + HHA + HNPK	6.34	6.34	6.34cd
LSD for FT	0.42	0.41	0.29
Wheat in the plot PMV			
Wheat in the plot of Azam	5.86	6.14	6.00b
Wheat in the plot Hybrid	6.44	6.71	6.58a
LSD for PMV	0.39	0.33	0.15
Years (YS)			
Y1: 2018-19			6.15b
Y2: 2019-20			6.43a
Significance Level (SL)			*
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	**
FT x PMV	**	YS x PMV x FT	**

This means using various alphabets within the same category are significantly different at ($p \leq 0.05$) "ns" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties (PMV).

Discussion

Chemical fertilizers have improved agricultural sustainability but have also disturbed agro-ecosystems and polluted soil and water quality. To enhance crop productivity without harming nature, judicious use of organic fertilizers with organic fertilizers can be adopted. A study found that combining organic and inorganic fertilizers improved growth and yield, nitrogen use efficiency, micro and macronutrient recovery, P solubilization, and K availability (Umar *et al.*, 2020). Organic fertilizers also increase organic matter, improving crop performance and soil characteristics. Combined application of organic and inorganic fertilizers is considered a good option for enhancing nutrient recovery, plant growth, and yield (Sher *et al.*, 2022). However, no statistical difference in wheat yield was found in all plots applied with organic, inorganic, or a combination of both fertilizers.

Table 9. The residual influence of previous crop fertilizer treatments (organic and inorganic) impacts on the K content in soil (mg/kg) of Wheat crops.

Fertilizer treatments (FT)	Years (Ys)		
	Y1: 2018-19	Y2: 2019-20	Average
Control (C)	76.6	78.2	77.4e
HNPK (75:50:30)	80.0	80.2	80.1ef
NPK (150: 100: 60)	86.6	83.6	85.1cd
LR (10 ton/ha)	83.0	82.0	82.5de
HA (5kg/ha)	86.6	88.4	87.5bc
BC (10ton/ha)	89.6	91.1	90.3b
LR + HNPK	87.4	87.6	87.5bc
HA + HNPK	79.5	78.4	78.9ed
BC + HNPK	96.8	100.5	98.7a
HLR + HHA + HNPK	79.2	81.1	80.1ef
HLR + HBC + HNPK	80.7	83.8	82.2de
HBC + HHA + HNPK	83.8	86.4	85.1cd
LSD for FT	7.3	5.7	4.6
Wheat in the plot PMV			
Wheat in the plot of Azam	85.3	85.9	85.6a
Wheat in the plot Hybrid	83.0	84.3	83.7b
LSD for PMV	**ns**	**ns**	1.8
Years (YS)			
Y1: 2018-19			84.1a
Y2: 2019-20			85.1a
Significance Level (SL)			NS
Interactions (IR)	SL	IR	SL
PMV x YS	**ns**	YS x FT	**ns**
FT x PMV	**ns**	YS x PMV x FT	**ns**

This means using various alphabets within the same category are significantly different at ($p≤0.05$) "ns" =Non-significant, while "*", "**" and "***" indicate significance at levels of probability of 5, 1, and 0.1%. *Previous maize varieties (PMV)

The use of organic and inorganic manures in wheat can enhance plant height by providing macro and micronutrients. The increased organic manure dose is due to the rapid conversion of carbohydrates into protein, thereby increasing the number and size of growing cell (Meena *et al*., 2013) also reported this effect. Experiments show residuals significantly produce long wheat crop plants height and grain spike compared to control plots (Agarwal *et al*., 2022). The effects of the fertilizer application were to increase the height of the wheat plants, and the same phenomenon was repeated. Similar outcomes are also consistent with (Brar *et al*., 2015) that, according to their findings, also came to the conclusion that residual impacts of Organic fertilizers on the soil significantly improved the grain spike and yield of wheat crops. (Mahmood *et al*., 2017 ; Ali *et al*., 2015) also found similar findings, claiming that applying BC and NPK together enhanced grain spike and raised the yield-related aspects of the wheat crops. Organic fertilizer application significantly increased wheat and maize straw yield, with a 169-236% increase in the current season and 19-128% in the following season. This increase was also observed in rice and wheat straw due to the combined application of 12 and 24 t compost ha−1. (Farooq *et al.,* 2022). The increased straw yield positively impacts livestock feed availability and productivity by ensuring a higher feed supply, which can be used for soil application or sold for income generation (Dhaliwal *et al*., 2019) reported that using organic fertilizers in a maize-wheat cropping system improved plant stove yield, soil properties, and nutrient build-up. Biochar, combined with 75% RDN, showed superior crop yield and macronutrient uptake, with results comparable to those of NPK treatment. (Wu *et al*., 2013) the study found that combining biochar with organic manures significantly improved wheat strove yield, possibly due to the remaining impact of organic nutrients and minerals from previous crops in the soil. Similar findings were observed (Ding *et al*., 2020), Research reveals residual effects of organic substances Increase stover, and crop yields. The soil pH in wheat trial sites ranges between 5.26 and 6.15, and 5.05 and 5.55 for tef trial sites, which is moderately acidic and sub-optimal for crop production. Total nitrogen and available phosphorus are above critical levels in wheat fields, with values in the range of 0.160.18% for nitrogen and 9.40-15.57 ppm for phosphorus, 0.17-0.19% for nitrogen, and 7.75-11.85 ppm for phosphorus in tef fields (Agegnehu *et al*., 2014) Both nutrient values fall in medium ranges. Biochar, a high-ash content soil amendment, increases soil pH, while HA may decrease it. The high CaCO3 concentration of BC is a key factor in causing pH increases. (Thakuria *et al*., 2016). The BC treatment temporarily increased the pH of the calcareous soil (pH 8.2) up to a maximum of 8.57 (Cardelli *et al*., 2017). (Ferrarezi *et al*., 2022) Soil pH is crucial for determining the solubility and bioavailability of macro and micronutrients. Pakistani soil, being alkaline and high pH, has a narrow range of 5.5-6.5 pH, while micronutrients are available at low pH except Mo.

Organic fertilizers significantly improve soil quality, enhancing nutrient release and availability for plants. They directly increase and enhance the cycling of nutrients, resulting in improved grain yield. Crop residue also enhances soil organic matter content, Physico-chemical properties, and biological properties, preserving fertility. (Ali et al., 2018). Additionally, biochar can be used as a soil amendment, promoting nutrient supply, and reducing greenhouse gas emissions (Dong *et al*., 2021; de Melo *et al*., 2020). Reports show similar results (Wanniarachchi *et al*., 2019) Study suggests organic fertilizers enhance soil organic matter (SOM) compared to inorganic commercial fertilizers, promoting agricultural production and retaining soil fertility. Fertilizers improve crop yields and organic matter returns by increasing SOM content and biological activity. They increase water stability, porosity, infiltration capability, and hydraulic conductivity while lowering bulk density. (Li *et al*., 2019). Carbon sequestration in soil, macro-aggregate formation, reduces GHG emissions (Yang *et al*., 2017), Crop growth is improved by soil cation exchange capability (Agegnehu *et al*., 2016), Biochar is stable, aromatic, and has long residence times due to its high specific surface area (Leng & Huang, 2018), Biochar's resistance to microbial decomposition makes it beneficial for soil fertility, HA stability, and C sequestration in black soil, enhancing stability and enhancing stability.

Nitrogen, a crucial chlorophyll molecule, is vital for plants to absorb sunlight energy through photosynthesis, promoting growth and grain yield, and optimizing energy availability (Qi *et al*., 2017). The findings correspond to Cui *et al*., (2017) Organic additions significantly increased the nitrogen content in wheat compared to chemical fertilizer treatments. This increase may be due to the decomposition of organic matter, which incorporates macronutrients into the soil matrix, acting as a reservoir. (El-Ghamry *et al*., 2009). That found that nutrients are released and available for plant uptake, while humus accumulates in the environment, increasing soil moisture retention and nutrient supply potentials, as confirmed by the results (Khater *et al*., 2019), who mentioned that farmyard manure plays an important role in supplying important nutrients required by plants. (Agegnehu *et al*., 2016) stated that the Biochar, when we used in conjunction with chemical NPK fertilizer (CEC), significantly increased soil K content, soil water content, total SOC, total N, accessible P, nitrate-nitrogen, ammonium-nitrogen, exchangeable cations, and cation exchange capacity. The statement is based on (Naeem *et al*., 2018), Soil characteristics, including SOC and NPK, were significantly elevated, and phosphatic fertilizers significantly impacted crops and soil P availability due to their low solubility and use efficiency. Phosphate fixation improved P status. Phosphate application increases soil P content, highlighting the residual effect of phosphatic fertilizers on subsequent crops (Arif *et al*., 2017) for these soils. Biochar enhances soil P fixation, possibly due to organic molecules blocking P fixation sites from decomposing manure, as observed in biochar-treated plots. (Ayaga *et al*., 2006) reported that the study found that biochar significantly increases soil P content due to better decomposition of BC and slow nutrient release for plant growth and development. This effect may be due to improved soil decomposition and nutrient release. (Demelash *et al*., 2014; Mahmood *et al*., 2017) The study found that applying organic amendments improves soil structure, porosity, and minerals and nutrients. The increase in soil NPK content and mineral nutrients may be attributed to the residual effect of BC and organic amendments.

Conclusion

Soil fertility was enhanced with full doses of organic fertilizers or with half inorganic fertilizers, with organic fertilizers showing higher residual effects. A half dose of NPK fertilizers with BC or HA produced higher wheat yields. Organic fertilizers had better residual effects on wheat yield and soil health.

Therefore, the Farmer(s) of our country may apply organic amendments and along with 50% NPKS for enhancing the production of wheat in our country which may reduce 50% NPKS. Thus, the farmers of our country can be economically benefited by the 50% reduced of chemical fertilizer.

References

Agarwal, A.H., V.H. Kashyap, A. Mishra, S. Bordoloi, P.K. Singh and N.C. Joshi. 2022. Biochar-based fertilizers and their applications in plant growth promotion and protection: 3 *Biotech*., 12(6): 136.

Agegnehu, G., C. Vanbeek and M.I. Bird. 2014. Influence of integrated soil fertility management in wheat and tef productivity and soil chemical properties in the highland tropical environment. *J. Soil Sci. Plant Nutr.*, 14(3): 532-545.

Agegnehu, G., P.N. Nelson and M.I. Bird. 2016. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. *Soil Tillage Res.*, 160: 1-13.

Ali, K., M. Arif, B. Islam, Z. Hayat, A. Ali, K. Naveed and F. Shah. 2018. Formulation of biochar based fertilizer for improving maize productivity and soil fertility: *Pak. J. Bot.*, v. 50, no. 1, p. 135-141.

Ali, K., M. Arif, M. Jan, T. Yaseen, M. Waqas, and F. Munsif. 2015. Biochar: a novel tool to enhance wheat productivity and soil fertility on sustainable basis under wheatmaize-wheat cropping pattern: *Pak. J. Bot*., v. 47, no. 3, p. 1023-1031.

Ali, K., X. Wang, M. Riaz, B. Islam, Z.H. Khan, F. Shah, F. Munsif and S.I.U. Haq. 2019. Biochar: An eco-friendly approach to improve wheat yield and associated soil properties on sustainable basis: *Pak. J. Bot*., v. 54, p. 1255-1261.

Al-Muaini, A.H. 2019. Coupled effects of irrigation management and water salinity on date palm cultivars in the hyper-arid environment of the United Arab Emirates: a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy (Ph.D.) in Soil and Environment Sciences, School of Agriculture and Environment, Massey University, Palmerston North, New Zealand.

Ampong, K., M.S. Thilakaranthna and L.Y. Gorim. 2022. Understanding the role of humic acids on crop performance and soil health. *Front. Agron*., 4: 10.

Arif, M., M. Ilyas, M. Riaz, K. Ali, K. Shah, I.U. Haq and S. Fahad. 2017. Biochar improves phosphorus use efficiency of organic-inorganic fertilizers, maize-wheat productivity and soil quality in a low fertility alkaline soil. *Field Crops Res.*, 214: 25-37.

Astorino, T.A., A.J. Matera, J. Basinger, M. Evans, T. Schurman and R. Marquez. 2012. Effects of red bull energy drink on repeated sprint performance in women athletes. *Amino Acids*, 42: 1803-1808.

Ayaga, G., A. Todd and P.C. Brookes. 2006. Enhanced biological cycling of phosphorus increases its availability to crops in low-input sub-Saharan farming systems. *Soil Biol. Biochem.*, 38(1): 81-90.

Bahrulolum, H., S. Nooraei, N. Javanshir, H. Tarrahimofrad, V.S. Mirbagheri, A.J. Easton and G. Ahmadian. 2021. Green synthesis of metal nanoparticles using microorganisms and their application in the agrifood sector. *J. Nanobiotech.*, 19(1): 1-26.

Bista, P., R. Ghimire, S. Machado and L. Pritchett. 2019. Biochar effects on soil properties and wheat biomass vary with fertility management. *Agronomy*, 9(10): 623.

Biswas, B., N. Pandey, Y. Bisht, R. Singh, J. Kumar and T. Bhaskar. 2017. Pyrolysis of agricultural biomass residues: Comparative study of corn cob, wheat straw, rice straw and rice husk. *Biores. Technol.*, 237: 57-63.

Brar, B.S., J. Singh, G. Singh and G. Kaur. 2015. Effects of long-term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize–wheat rotation. *Agronomy*, 5(2): 220-238.

Bremner, J.M. 1996. Nitrogen-total: Methods of soil analysis. *Chem. Methods*, 5: 1085-1121.

Cardelli, R., M. Becagli, F. Marchini and A. Saviozzi. 2017. Effect of biochar, green compost, and vermicompost on the quality of a calcareous soil: A 1-Year laboratory experiment. *Soil Sci.*, 182(7): 248-255.

Cherif, M., J. Díaz-Cassou and C. Megevand. 2023. Climate change and development in Morocco: Morocco's Quest for Stronger and Inclusive Growth, p. 121.

Cui, T., Z. Li and S. Wang. 2017. Effects of in-situ straw decomposition on composition of humus and structure of humic acid at different soil depths. *J. Soils Sedim.*, 17: 2391-2399.

de Melo, M.L., D.N. Kothawala, S. Bertilsson, J.H. Amaral, B. Forsberg and H. Sarmento. 2020. Linking dissolved organic matter composition and bacterioplankton communities in an Amazon floodplain system. *Limnol. Oceanograp.*, 65(1): 63-76.

Demelash, N., W. Bayu, S. Tesfaye, F. Ziadat and R. Sommer. 2014. Current and residual effects of compost and inorganic fertilizer on wheat and soil chemical properties: *Nutr. Cycl. Agroecosys*., 100: 357-367.

Dhaliwal, S., R. Naresh, A. Mandal, R. Singh and M. Dhaliwal. 2019. Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. *Environ. Sustain. Ind.*, 1: 100007.

Ding, Z., A. Kheir, M.G. Ali, O.A. Ali, A.I. Abdelaal, X. Lin, Z. Zhou, B. Wang, B. Liu and Z. He. 2020. The integrated effect of salinity, organic amendments, phosphorus fertilizers, and deficit irrigation on soil properties, phosphorus fractionation and wheat productivity. *Sci. Rep.*, 10(1): 1-13.

Dong, F., Q. Lin, C. Li, G. He and Y. Deng. 2021. Impacts of pre-oxidation on the formation of disinfection byproducts from algal organic matter in subsequent chlor (am) ination: A review. *Sci. Total Environ.*, 754: 141955.

El-Ghamry, A.M., K.M. Abd El-Hai and K.M. Ghoneem. 2009. Amino and humic acids promote growth, yield and disease resistance of faba bean cultivated in clayey soil. *Aust. J. Basic Appl. Sci*., 3(2): 731-739.

Farooq, S., T. Yasmeen, A. Niaz, M. Rizwan and S. Ali. 2022. Rice straw biochar in combination with farmyard manure mitigates bromoxynil toxicity in wheat (*Triticum aestivum* L.): Chemosphere, v. 295, p. 133854.

Ferrarezi, R.S., X. Lin, A. C. Gonzalez Neira, F. Tabay Zambon, H. Hu, X. Wang, J.H. Huang and G. Fan. 2022. Substrate pH influences the nutrient absorption and rhizosphere microbiome of Huanglongbing-affected grapefruit plants. *Front. Plant Sci.*, 13: 1243.

Furtado e Silva, J.A., A.C. García, E.S. Lima, C.C. Souza and N.M. Amaral Sobrinho. 2022. Effect of short-term pig slurry amendment of soil on humified organic matter and its relationship with the dynamics of heavy metals and metals uptake by plants. *J. Environ. Sci. Health*, 57(11): 958-969.

Giampieri, F., L. Mazzoni, D. Cianciosi, J.M. Alvarez-Suarez, L. Regolo, C. Sánchez-González, F. Capocasa, J. Xiao, B. Mezzetti and M. Battino. 2022. Organic vs conventional plant-based foods: A review: *Food Chem.*, 383: 132352.

Goswami, S.B., R. Mondal and S.K. Mandi. 2020. Crop residue management options in rice–rice system: A review. *Arch. Agron. Soil Sci.*, 66(9): 1218-1234. doi:10.1080/03650340.2019.1661994.

Han, Z., H. Lin, P. Xu, Z. Li, J. Wang and J. Zou. 2022. Impact of organic fertilizer substitution and biochar amendment on net greenhouse gas budget in a tea plantation. *Agri. Ecosys. Environ.*, 326: 107779.

Jalal, A., M.C.M. Teixeira Filho, C.E. da Silva Oliveira, A. Khan, E.H.M. Boleta, A.L.M. da Silva and T. Shah. 2022. Legumes effect on nitrogen mineralization and microbial biomass potential in organic farming: Advances in Legumes for Sustainable Intensification, p. 281-306.

Karthik, A., and M. U. Maheswari. 2021. Smart fertilizer strategy for better crop production: Agricultural Reviews, v. 42, no. 1, p. 12-21.

Khater, H., M. Ragab, S. Youssef and A.H. Ali. 2019. Effect of different nitrogen fertilizer rates and sources on leaf chemical compositions and yield of quinoa plant as a new leafy vegetable crop. *Arab Uni. J. Agri. Sci.*, 27(1): 673-689.

Kushwaha, A. and C.M. Mehta. 2023. Pigeon Pea (*Cajanus cajan* L.) Based Intercropping System: A Review: *International Journal of Plant & Soil Science*, v. 35, no. 18, p. 1674-1689.

Leng, L. and H. Huang. 2018. An overview of the effect of pyrolysis process parameters on biochar stability. *Biores. Technol.*, 270: 627-642.

Li, Y., F. Fang, J. Wei, X. Wu, R. Cui, G. Li, F. Zheng and D. Tan. 2019. Humic acid fertilizer improved soil properties and soil microbial diversity of continuous cropping peanut: a three-year experiment. *Sci. Rep.*, 9(1): 1-9.

Mahmood, F., I. Khan, U. Ashraf, T. Shahzad, S. Hussain, M. Shahid, M. Abid and S. Ullah. 2017. Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties: *J. Soil Sci. Plant Nutr.*, 17(1): 22-32.

Maynard, D., Y. Kalra and J. Crumbaugh. 1993. Nitrate and exchangeable ammonium nitrogen. *Soil Samp. Methods Anal.*, 1: 25-38.

McLean, E. 1983. Soil pH and lime requirement: Methods of soil analysis. *Chem. Microbiol. Prop.*, 9: 199-224.

Meena, V., B. Maurya, R. Verma, R Meena, RS Meena, G. Jatav and D. Singh. 2013. Influence of growth and yield attributes of wheat (*Triticum aestivum* L.) by organic and inorganic sources of nutrients with residual effect under different fertility levels. *The Bioscan*, 8(3): 811-815.

Meng, W., F. Zhu, X. Wang, S. Guan, S. Dou and B.S. Ndzelu. 2023. Contrasting effects of straw and straw-derived biochar application on soil organic matter and corn yield in a Chinese Mollisol. *J. Soils Sedim.*, p. 1-14.

Naeem, M.A., M. Khalid, M. Aon, G. Abbas, M. Amjad, B. Murtaza, W.D. Khan and N. Ahmad. 2018. Combined application of biochar with compost and fertilizer improves soil properties and grain yield of maize. *J. Plant Nutr.*, 41(1): 112-122.

Ndoung, O.C.N., C.C.D. Figueiredo and M.L.G. Ramos. 2021. A scoping review on biochar-based fertilizers: Enrichment techniques and agro-environmental application. *Heliyon*, 7(12): e08473. doi:10.1016/j.heliyon.2021.e08473.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter: Methods of soil analysis. *Chem. Methods*, 5: 961-1010.

Qi, Y., J. Zhu, Q. Fu, H. Hu and Q. Huang. 2017. Sorption of Cu by humic acid from the decomposition of rice straw in the absence and presence of clay minerals. *J. Environ. Manag.*, 200: 304-311.

Rashad, M., M. Hafez and A.I. Popov. 2022. Humic substances composition and properties as an environmentally sustainable system: A review and way forward to soil conservation. *J. Plant Nutr.*, 45(7): 1072-1122.

Ren, G., X. Zhang, X. Xin, W. Yang, A. Zhu, J. Yang and M. Li. 2023. Soil organic carbon and nitrogen fractions as affected by straw and nitrogen management on the North China Plain. *Agri. Ecosys. Environ.*, 342: 108248.

Sher, A., M. Adnan, A. Sattar, S. Ul-Allah, M. Ijaz, M.U. Hassan, A. Manaf, A. Qayyum, B.H. Elesawy and K.A. Ismail. 2022. Combined application of organic and inorganic amendments improved the yield and nutritional quality of forage sorghum. *Agronomy*, 12(4): 896.

Shetty, R. and N.B. Prakash. 2020. Effect of different biochars on acid soil and growth parameters of rice plants under aluminium toxicity: *Sci. Rep.*, 10(1): 12249.

Soltanpour, P. and A. Schwab. 1977. A new soil test for simultaneous extraction of macro-and micro-nutrients in alkaline soils. *Comm. Soil Sci. Plant Anal.*, 8(3): 195-207.

Sunori, S.K., L. Mohan, M. Pant and P. Juneja. 2023. Classification of soil fertility using LVQ and PNN techniques: *8th International Conference on Communication and Electronics Systems (ICCES)* (pp. 1441-1446). IEEE.

Tesfahunegn, G.B. and T.A. Gebru. 2020. Variation in soil properties under different cropping and other land-use systems in Dura catchment, Northern Ethiopia. *PloS One*, 15(2): e0222476.

Thakuria, D., S. Hazarika and R. Krishnappa. 2016. Soil acidity and management options. *Ind. J. Fert.*, 12(12): 40-56.

Umar, W., M.A. Ayub, M.Z. ur Rehman, H.R. Ahmad, Z.U.R. Farooqi, A. Shahzad, U. Rehman, A. Mustafa and M. Nadeem. 2020. Nitrogen and phosphorus use efficiency in agroecosystems. *Resources Use Efficiency in Agriculture*, p. 213-257.

Wanniarachchi, D., M. Cheema, R. Thomas and L. Galagedara. 2019. Effect of biochar on TDR-based volumetric soil moisture measurements in a loamy sand podzolic soil. *Soil Syst.*, 3(3): 49.

Wei, S., Z. Li, Y. Sun, J. Zhang, Y. Ge and Z. Li. 2022. A comprehensive review on biomass humification: Recent advances in pathways, challenges, new applications, and perspectives. *Renew. Sustain. Energy Rev.*, 170: 112984.

Wu, F., Z. Jia, S. Wang, S.X. Chang and A. Startsev. 2013. Contrasting effects of wheat straw and its biochar on greenhouse gas emissions and enzyme activities in a Chernozemic soil. *Biol. Fert. Soils*, 49: 555-565.

Yadav, K. and S. Jagadevan. 2019. Influence of process parameters on synthesis of biochar by pyrolysis of biomass: An alternative source of energy, *in* Recent advances in pyrolysis: IntechOpen.

Yang, X., J. Meng, Y. Lan, W. Chen, T. Yang, J. Yuan, S. Liu and J. Han. 2017. Effects of maize stover and its biochar on soil CO_2 emissions and labile organic carbon fractions in Northeast China. *Agri. Ecosys. Environ.*, 240: 24-31.

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