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Combined Application of Organic and Inorganic Amendments Improved the Yield and Nutritional Quality of Forage Sorghum

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Abstract: The use of organic amendments is seen to be a promising method for enhancing crop productivity and soil health. Therefore, this study was performed for two consecutive years (2019 and 2020) to determine the effects of organic biochar (BC), sugar industry press mud (MUD), and poultry manure (PM) combined with inorganic amendments on the yield and nutritional quality of forage sorghum at the College of Agriculture, Bahauddin Zakariya University, Bahadur sub-campus, Layyah, Pakistan. The treatments were comprised of the following: control (no inorganic or organic amendments added); recommended dose of NPK (59:72:30 kg ha^{-1}); half dose of NPK (29.5:36:15 kg ha^{-1}); recommended dose of poultry manure (PM) at 5 t ha^{-1}; recommended dose of press mud (MUD) at 40 t ha^{-1}; recommended dose of biochar (BC) at 11 t ha^{-1}; BC + half NPK; MUD + half NPK; PM + half NPK; PM + BC + half NPK; PM + MUD + half NPK; BC + MUD + half NPK; PM + BC + MUD + half NPK. The treatments were carried out in a triplicate randomized complete block design. Results revealed that combined application of PM + BC + MUD + 1/2 NPK significantly enhanced the plant height (201 cm), number of leaves (17), stem diameter (18 mm), stem dry weight (201.7 g), leaf dry weight (30.4 g), leaf area (184.3 cm^2), green forage yield (31.8 Mg ha^{-1}), and dry biomass yield (12.7 Mg ha^{-1}) compared with the control treatment. Forage quality traits, including crude protein (CP), brix percentage, acid detergent fiber (ADF), and acid detergent lignin (ADL), showed maximum value with the combined application of PM + BC + MUD + 1/2 NPK. ADF and ADL are linked with lower digestibility; therefore, it was concluded that the combined application of PM + BC + MUD + 1/2 NPK can improve the productivity, dry biomass yield, and CP of sorghum, but reduces the digestibility under semi-arid conditions, such as those in Central Pakistan.

Keywords: organic amendments; NPK; dry biomass yield; nutritional quality; forage sorghum

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1. Introduction

Fertilizer application plays an important role in improving crop productivity [1]. Fertilizer application improves yield through boosting nutrient availability and strengthening the soil's resilience to climatic change [1]. Long-term application of unbalanced fertilizers causes nutrient depletion and soil acidification and poses a serious threat to environmental quality [2]. Moreover, poor fertilizer application also intensifies the impacts of climate change on crop productivity [3]. Although the application of chemical fertilizers is considered to be important for obtaining higher productivity, over-dependence on chemical fertilizers can deteriorate soil quality and crop productivity over time [4]. As a result, in this context, the use of organic fertilizers can provide numerous advantages, including significant improvements in soil health and crop output [5–7].

Biochar (BC) is a carbon-rich byproduct of lignocellulosic biomass pyrolysis [8,9]. The usage of BC has been identified as an essential strategy for reducing greenhouse gas emissions by enhancing carbon sequestration [9,10]. The use of BC also improves soil fertility, soil aggregation stability, soil cation exchange (CEC) capacity, soil nutrients, and water retention capacity, and hence significantly improves crop growth and production [11]. Press mud (MUD) is another major organic fertilizer source that is obtained as a byproduct of the sugar industry. Its color is dark brown, and it is high in organic matter (OM), carbon, calcium, nitrogen, phosphorus, potassium, and sulfur [12,13]. The application of MUD significantly improved the growth and biomass productivity by improving the physiochemical properties and nutrient availability of soil [12–15].

Poultry manure (PM) is another valuable source of organic fertilizer. It is a low-cost, environmentally friendly source that promotes soil fertility, soil structure, and the availability of important nutrients (NPK) [16]. Although the amount of nutrients released by PM varies depending on the rate of application, PM application improves N availability by 53% [17,18]. Organic manure treatment considerably boosted plant development by increasing nutrient availability and minimizing nutrient losses [18]. Organic additions have been shown to boost crop yield and quality, as well as tolerance to various stressful conditions [19–21]. Ancient farmers used organic manures for crop productivity that proved to be good for soil health. However, they were slow in their response to improving crop yield. Modern agriculture has led farmers to use inorganic fertilizers for crop production as they are affordable, economical, and quick in their response. Soil health problems and nutrient leaching into underground water are posing serious threats to humans and animals [22]. Therefore, there is a dire need to find a midpoint between inorganic and organic fertilizers that may sustain the crop yield without affecting soil fertility. In this context, combined application of organic and inorganic fertilizers can improve crop productivity on a sustainable basis without affecting soil health. Sorghum (*sorghum bicolor* L.) is an important crop, which is cultivated globally for food and feed purposes. Ruminants such as sorghum, due to their sweet taste, are mostly used as green forage. Other uses include applications as a grain and syrup for human food, fodder for animals, and it is also used to make biofuels and alcoholic beverages. It is an important crop in Pakistan, where it is mostly grown for forage purposes. One of the major causes of the lower yield of sorghum is poor nutrient management [20,21]. Moreover, no information is available on the interactive effect of organic and inorganic fertilizers on the growth and yield of sorghum fodder grown in semi-arid regions of Pakistan. Therefore, this study was planned to assess the impact of different organic manures in combination with NPK on the productivity, forage yield, and nutritional quality (ADF, aNDF, CP) of forage sorghum grown in the semi-arid region of Punjab, Pakistan.

2. Materials and Methods

2.1. Study Site

A field experiment was conducted for two consecutive years (2019 and 2020), at the College of Agriculture, BZU, Bahadur Campus, Layyah, Pakistan. The mean rainfall and average temperatures are shown in Table 1. Soil samples from different parts of the experimental field were collected with a soil auger, homogenized, and stored in the lab. After that, the soil samples were analyzed by standard procedures to determine soil physiochemical properties. The soil particle size distribution was determined following the hydrometric method. The particle size distribution was sand 40.70%, silt 37.30%, clay 22%. According to the USDA, the soil texture was classified as sandy loam. Soil pH (pH) was determined potentiometrically in a water–soil solution in the ratio of 1:2.5 (*w*/*v*) using METTLER TOLEDO, Jenway, UK. Soil organic matter was determined using the Walkley–Black method; total nitrogen was determined using the Kjeldahl distillation method (Model MA 036/Plus from Marconi Company) [23]; available phosphorus was determined using UV-Vis spectrophotometry (BMS-1602, Biotechnology Medical Services K. Group, Calle Castelló, Madrid, Spain) [24]; potassium was determined using flame photometry (FP 6410, Shanghal Jingke, China). Soil pH was 8.2, organic matter comprised 0.62%, total nitrogen comprised 456 mg kg^{-1}, and available phosphorus and potassium comprised 6.2 and 163 mg kg^{-1}, respectively. Treatments were repeated in the same plots in both years. In both years, wheat was grown before sorghum.

Table 1. Meteorological data of the experimental site during 2019 and 2020 as observed in Layyah, Pakistan.

Months	Rainfall (mm)			Temperature °C		
	2019	2020	Last 10 Years Average	2019	2020	Last 10 Years Average
July	70.2	58.6	72	32.1	33.7	33.1
August	93	86.5	92	32.7	33.4	33.2
September	trace	28	24	32.6	30.8	31.0
October	33	trace	25	25.3	25.4	25.1

Source: Adaptive Research Farm, Karor Lal Esan, Punjab, Pakistan, which is 30 km from the research site at Layyah, Pakistan.

2.2. Experimental Materials

Seed of forage sorghum cv. JS-2002 was obtained from Fodder Research Institute Sargodha, Pakistan. An organic amendment PM (N-64 P-71, K, 122 mg kg^{-1}) was obtained from Hamza protein farm, MUD (N-120 P-116, K, 148 mg kg^{-1}) was obtained from Thal Sugar mill, and BC (N-254 P-110, K, 152 mg kg^{-1}) was collected from the Agronomy Department, College of Agriculture, BZU, Bahadur sub-campus, all in Layyah, Pakistan. In the organic amendments, N contents were determined using Kjeldahl distillation method (Model MA 036/Plus from Marconi Company, Chelmsford, UK), available P was determined using UV-Vis spectrophotometry (BMS-1602, Biotechnology Medical Services K. Group, USA), and potassium was determined using flame photometry (FP 6410, Shanghai Jingke, Shanghai, China).

2.3. Treatments and Experimental Design

The treatments were comprised of the following: control (no inorganic or organic amendments added); locally recommended dose of NPK (59:72:30 kg ha^{-1}); half dose of NPK (29.5:36:15 kg ha^{-1}); recommended dose of PM (5 t ha^{-1}); recommended dose of MUD (40 t ha^{-1}); recommended dose of BC (11 t ha^{-1}); BC + half NPK; MUD + half NPK; PM + half NPK; PM + BC + half NPK; PM + MUD + half NPK; BC + MUD + half NPK; PM + BC + MUD + half NPK. The experiment was arranged in randomized complete block design (RCBD) with three replications, with a net plot size of 1.8 m × 5 m (9 m^2).

2.4. Crop Husbandry

Soil was prepared by tractor plowing and rotavator application. The crop was sown on 28 June 2019 and 22 June 2020 with a hand drill, maintaining a row distance of 30 cm and a seed rate of 85 kg ha^{-1}. The irrigations (flooded surface irrigation) were applied according to crop requirements. In total, 6 irrigations (75 mm each) were applied from sowing to harvesting. Organic amendments were applied at the time of sowing by broadcasting and inorganic amendments were applied in the form of powder with second irrigation when the crop was at 4–6 leaf stage, followed by fortnightly irrigation. All fertilization treatments were applied in single doses except nitrogen (N), which was applied in two equal doses. The N was applied in the form of urea, P_2O_5 was applied in the form of Di-ammonium phosphate, and K was applied in the form of sulphate of potash. For weed control, manual hoeing and Atrazine + mesotrione herbicide (1000 mL ha^{-1}, 44.09% w/v) was used as a post-emergent weedicide to control the weeds. The crop was harvested at physiological maturity with a stubble height of 2.5 cm on 6 October 2019 and 2 October 2020.

2.5. Data Collected

2.5.1. Forage-Yield-Related Traits

The plots were hand-harvested and weighed to determine the forage yield. After that, the subsamples of plants were taken and kept in craft paper bag and then oven dried at 72 °C for 24 h to obtain the constant weight, weighed to determine the biomass yield, and converted into Mg ha^{-1}. Ten randomly selected plants in every plot were taken to measure the plant height, number of leaves per plant, stem diameter, and plant biomass traits (leaf and stem dry weight). Flag leaf area was measured with leaf area meter (CI-202 leaf area meter, Forestry Suppliers Inc, Jackson, MS, USA).

2.5.2. Qualitative Traits

Five randomly selected plants from each plot were used to measure stalk brix value with a handheld refractometer (Sino Technology, Fujian, China) using the procedures of Yun-long et al. [25]. Samples were ground, after which, a subsample of 10 g was passed through a 1 mm sieve. An ANKOM A220 fiber analyzer (ANKOM Technology, Fairport, NY, USA) with F-57 filter bags and amylase was used to determine neutral detergent fiber (aNDF) and acid detergent fiber (ADF) [26]. The formula N concentration × 6.25 was used to calculate the crude protein concentration, while the Kjeldahl procedure was used to determine the nitrogen concentrations [27].

2.6. Data Analysis

The recorded data were subjected to analysis of variance using the Statistix 8.1 software to find differences between years and among treatments, along with the year × treatment interaction. Year and replicates within the year were considered to be random, while treatment and the year × treatment interaction were considered to be fixed effects. Means were separated by Tukey's HSD at 5% of probability level [28].

3. Results

Analyses of the data showed that the year effects and the interaction of year and fertilizer treatments were significant, and the results were consistent across the years (Tables 1 and 2). Therefore, a mean comparison of two years' averages is presented in the tables and the figures, and the significant year–fertilizer treatment interaction will not be discussed. Otherwise, when the year effect was significant, 2020 had greater values than 2019. This was likely due to rainfall and lower temperatures in September 2020 than in September 2019 (Table 1).

3.1. Morphological Traits

The application of various organic and inorganic amendments significantly improved the growth traits of sorghum crop. The application of PM + BC + MUD + 1/2 NPK improved plant height (201 cm) number of leaves (17), stem diameter (18.0 mm), stem dry weight (201.7 g), leaf dry weight (30.4 g), and leaf area (184.3 cm) as compared with the control treatment. The year effect was also significant, as the significance difference for leaves, stem/leaves dry weight, and leaf area remained, but the results were nonsignificant for plant height. (Table 2).

Table 2. Performance for plant height, number of leaves, stem diameter, stem/leaves dry weight, and leaf area of forage sorghum at different organic amendments under field conditions of Layyah, Pakistan, during 2019 and 2020.

Treatments (Trt)	Plant Height (cm)	Number of Leaves per Plant	Stem Diameter (mm)	Stem Dry Weight (g)	Leaves Dry Weight (g)	Leaf Area (cm)
Control (no inorganic or organic ammendments added)	169.2 ± 1.57 I	9 ± 0.70 G	12.2 ± 0.18 J	158.4 ± 4.13 I	22.3 ± 0.87 H	94.2 ± 6.74 I
NPK, 59:72:30 kg ha^{-1}	173.2 ± 1.29 HI	9 ± 0.85 FG	12.6 ± 0.18 IJ	163.4 ± 4.80 HI	22.8 ± 1.07 H	99.6 ± 7.57 HI
1/2 NPK, 29.5:36:15 kg ha^{-1}	177 ± 0.63 GH	10 ± 0.67 FG	13.2 ± 0.22 HI	168.4 ± 5.33 GHI	23.2 ± 1.05 GH	105.3 ± 7.09 HI
Poultry manure (PM), 5 t ha^{-1}	178.7 ± 1.19 FG	10 ± 0.94 FG	13.7 ± 0.18 GH	171.6 ± 5.17 FGH	23.6 ± 0.87 GH	109.56.80 GHI
Press mud (MUD), 40 t ha^{-1}	181.7 ± 1.49 FG	10 ± 0.85 FG	14.2 ± 0.22 FG	174.8 ± 4.92 EFG	24.1 ± 1.02 FGH	114.9 ± 7.15 FGH
Biochar (BC), 11 t ha^{-1}	183.3 ± 1.70 EF	11 ± 0.79 EF	14.7 ± 0.28 EF	177.3 ± 6.13 EFG	24.8 ± 0.86 EFG	121.6 ± 8.12 EFG
BC + 1/2 NPK	187 ± 1.93 DE	13 ± 0.67 DE	15.1 ± 0.27 DE	180.4 ± 5.89 DEF	25.6 ± 0.77 DEF	128.0 ± 7.35 EF
MUD + 1/2 NPK	188.3 ± 0.79 D	14 ± 0.43 CD	15.6 ± 0.26 D	184.8 ± 5.41 CDE	26.6 ± 0.73 CDE	135.0 ± 7.44 DE
PM + 1/2 NPK	190.7 ± 1.19 CD	14 ± 0.37 CD	16.3 ± 0.43 C	188.5 ± 6.04 BCD	27.2 ± 0.67 BCD	147.8 ± 5.36 CD
PM + BC + 1/2 NPK	193.8 ± 1.18 BC	15 ± 0.24 BC	16.9 ± 0.61 BC	192.5 ± 5.99 ABC	27.6 ± 0.75 BC	159.8 ± 5.51 BC
PM + MUD + 1/2 NPK	196.8 ± 1.18 AB	15 ± 0.48 BC	17.4 ± 0.49 AB	196.5 ± 5.42 AB	28.7 ± 0.47 AB	171.6 ± 7.73 AB
BC + MUD + 1/2 NPK	198.7 ± 2.02 AB	16 ± 0.92 AB	17.8 ± 0.46 A	200.1 ± 5.76 A	29.9 ± 0.40 A	179.6 ± 10.16 A
PM + BC + MUD + 1/2 NPK	201 ± 2.37 A	17 ± 1.08 A	18.0 ± 0.59 A	201.7 ± 6.51 A	30.4 ± 0.59 A	184.3 ± 13.02 A
HSD ($p \leq 0.05$)	5.0	2	0.65	10.2	1.9	15.5
			Years (Y)			
2019	185.8 ± 6.04	12 ± 1.63 B	15.0 ± 1.00 B	175.8 ± 8.22 B	25.2 ± 1.95 B	132.1 ± 13.34 B
2020	186.4 ± 5.53	13 ± 1.88 A	15.4 ± 1.30 A	187.0 ± 9.34 A	26.6 ± 1.28 A	137.4 ± 23.17 A
HSD ($p \leq 0.05$)	ns	0.40	0.15	2.3	0.44	3.5
			Significance interactions			
Treatments	*<0.001 ** *	*<0.001 ** *	*<0.001 ** *	*<0.001 ** *	*<0.001 ** *	*<0.001 ** *
Years	*ns*	*<0.002 ** *	*<0.001 ** *	*<0.001 ** *	*<0.001 ** *	*<0.004 ** *
Trt × Y	*ns*	*ns*	*<0.001 ** *	*ns*	*<0.04 **	*<0.001 ** *

Means having similar letters did not differ significantly at $p < 0.05$. ns, *, and ** indicate nonsignificant, significant at $p \leq 0.05$, and at $p \leq 0.01$, respectively. Values represent mean ± SE.

3.2. Forage Yield Variables

Increase in organic amendments dosage resulted in an increase in green/dry biomass yield. Combined application of PM + BC + MUD + 1/2 NPK produced maximum green forage (31.8 Mg ha^{-1}) and biomass yield (12.7 Mg ha^{-1}), relative to the control treatment. The year effect also showed significant difference for green/dry biomass yield (Table 3).

3.3. Nutritional Quality

The application of various organic and inorganic amendments significantly improved the crude protein (CP), ADF, and acid detergent lignin of the sorghum crop and reduced the aNDF (Figures 1–4). Increase in the level of organic and inorganic amendments increased the CP, ADF, and lignin, but decreased the aNDF. Maximum CP, ADF, and lignin were recorded with the combined application of organic PM + BC + MUD + 1/2 NPK as compared with the control plot. Neutral detergent fiber was found to be maximum in the control plot as compared with the organic and inorganic treatments (Figure 2). The maximum brix value (132.9 g kg^{-1}) was observed under the application of PM + BC + MUD + 1/2 NPK, which was statistically on par with the application of BC + MUD + 1/2 NPK, relative to the control treatment (Table 3).

Table 3. Performance for green/dry biomass yield and brix value on fresh stalk of forage sorghum under different organic amendments under field conditions of Layyah, Pakistan, during 2019 and 2020.

Treatments (Trt)	Green Biomass Yield (Mg ha^{-1})	Dry Biomass Yield (Mg ha^{-1})	Brix Value (g kg^{-1})
Control (no inorganic or organic ammendments added)	26.0 ± 0.93 H	9.7 ± 0.27 H	74.1 ± 3.07 H
NPK, 59:72:30 kg ha^{-1}	26.8 ± 0.47 GH	10.0 ± 0.36 GH	82.1 ± 5.14 GH
1/2 NPK, 29.5:36:15 kg ha^{-1}	27.8 ± 0.35 FG	10.2 ± 0.43 FGH	85.7 ± 4.48 GH
Poultry manure (PM), 5 t ha^{-1}	28.0 ± 0.39 EFG	10.5 ± 0.51 E–H	88.9 ± 4.43 FGH
Press mud (MUD), 40 t ha^{-1}	28.2 ± 0.43 DEF	10.9 ± 0.55 D–G	91.9 ± 4.47 EFG
Biochar (BC), 11 t ha^{-1}	28.6 ± 0.57 DEF	11.2 ± 0.48 C–F	95.7 ± 6.28 D–G
BC + 1/2 NPK	29.1 ± 0.50 CDE	11.4 ± 0.47 B–E	101.4 ± 6.77 C–F
MUD + 1/2 NPK	29.4 ± 0.51 CD	11.6 ± 0.55 BCD	104.6 ± 6.89 CDE
PM + 1/2 NPK	30.2 ± 0.69 BC	11.9 ± 0.46 ABC	109.2 ± 7.09 BCD
PM + BC + 1/2 NPK	31.0 ± 0.88 AB	12.3 ± 0.53 AB	113.8 ± 7.11 AB
PM + MUD + 1/2 NPK	31.3 ± 0.86 AB	12.3 ± 0.39 AB	124.2 ± 7.26 AB
BC + MUD + 1/2 NPK	31.8 ± 0.94 A	12.7 ± 0.50 A	130.5 ± 7.64 A
PM + BC + MUD + 1/2 NPK	31.8 ± 0.71 A	12.6 ± 0.17 A	132.9 ± 8.14 A
HSD ($p \leq 0.05$)	1.28	0.99	15.3
	Years (Y)		
2019	29.0 ± 0.81 B	10.8 ± 0.64 B	104.7 ± 12.42 A
2020	29.5 ± 1.53 A	11.8 ± 0.65 A	100.7 ± 11.42 B
HSD ($p \leq 0.05$)	0.29	0.22	3.5
	Significance interactions		
Treatments	*<0.001 ** *	*<0.001 ** *	*<0.001 ** *
Years	*<0.001 ** *	*<0.001 ** *	*<0.02 * *
Trt × Y	*<0.001 ** *	*ns*	*ns*

Means having similar letters did not differ significantly at $p < 0.05$. ns, *, and ** indicate nonsignificant, significant at $p \leq 0.05$, and at $p \leq 0.01$, respectively. Values represent mean ± SE.

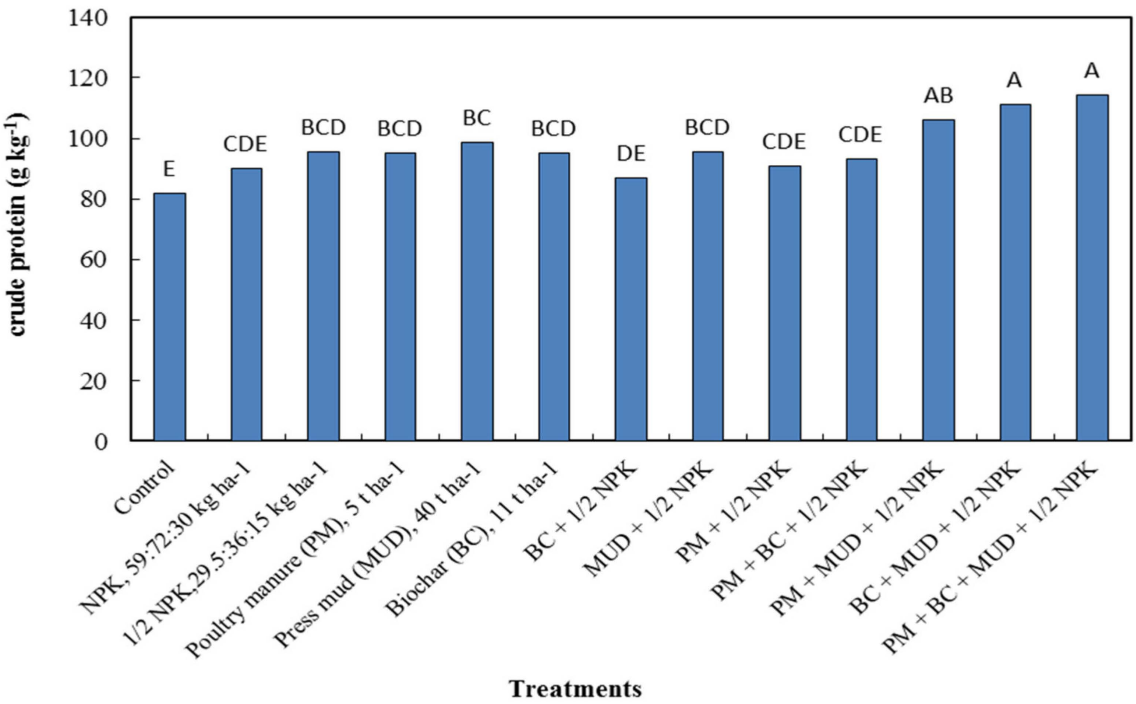

Figure 1. Effect of organic and inorganic amendments on crude protein of forage sorghum under the field conditions at Layyah, Pakistan. Values are the means of two years and three replicates. Means with similar letters at the top of the bar did not differ significantly at $p \leq 0.05$ (HSD = 11.7).

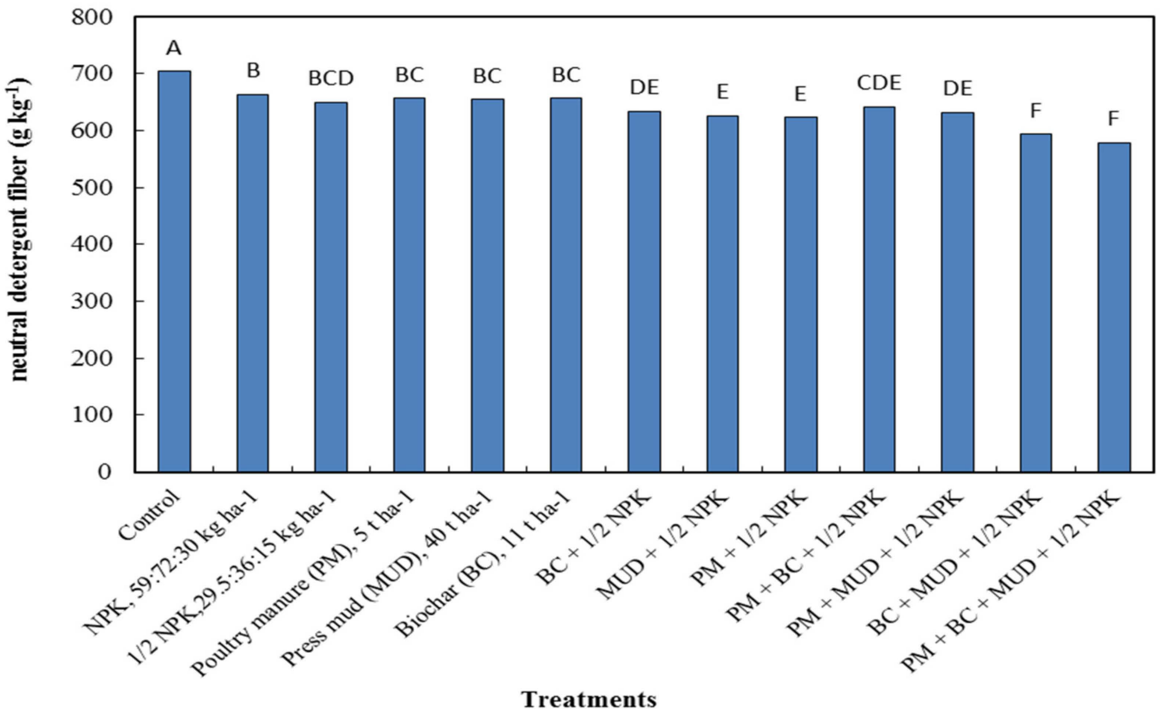

Figure 2. Effect of organic and inorganic amendments on neutral detergent fiber of forage sorghum under the field conditions of Layyah, Pakistan. Values are the means of two years and three replicates. Means with similar letters at the top of the bar did not differ significantly at $p \leq 0.05$ (HSD = 20.9).

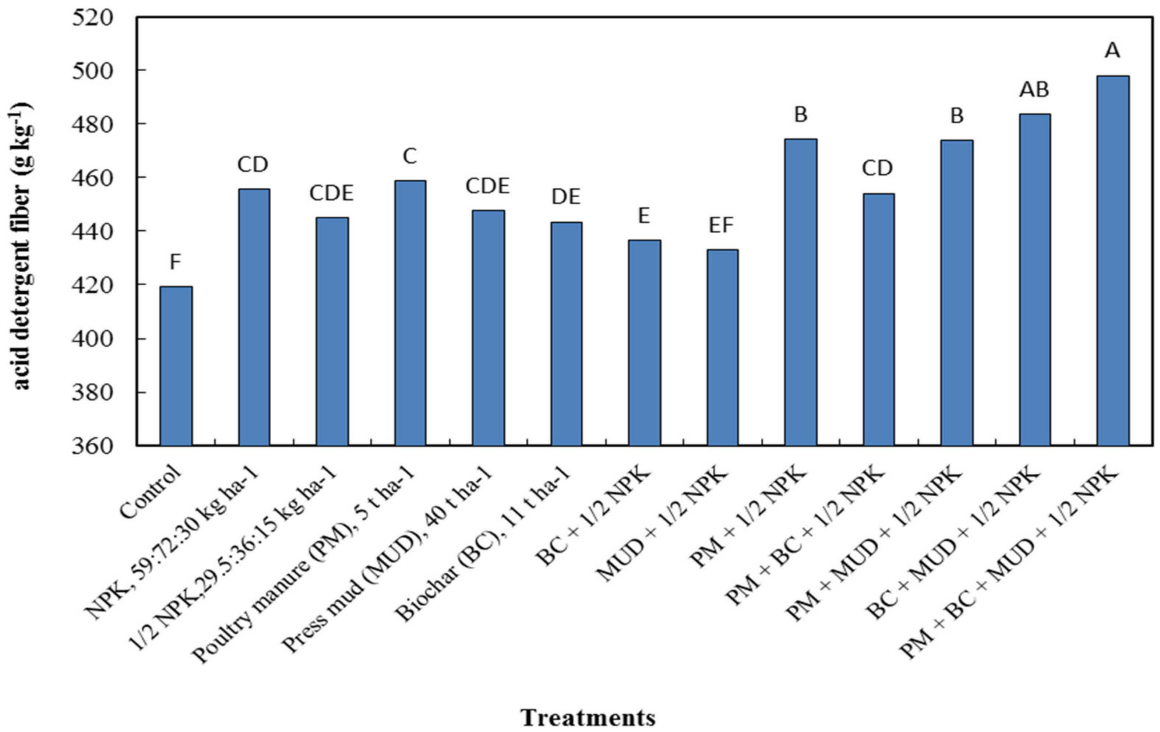

Figure 3. Effect of organic and inorganic amendments on acid detergent fiber of forage sorghum under the field conditions of Layyah, Pakistan. Values are the means of two years and three replicates. Means with similar letters at the top of the bar did not differ significantly at $p \leq 0.05$ (HSD = 14.8).

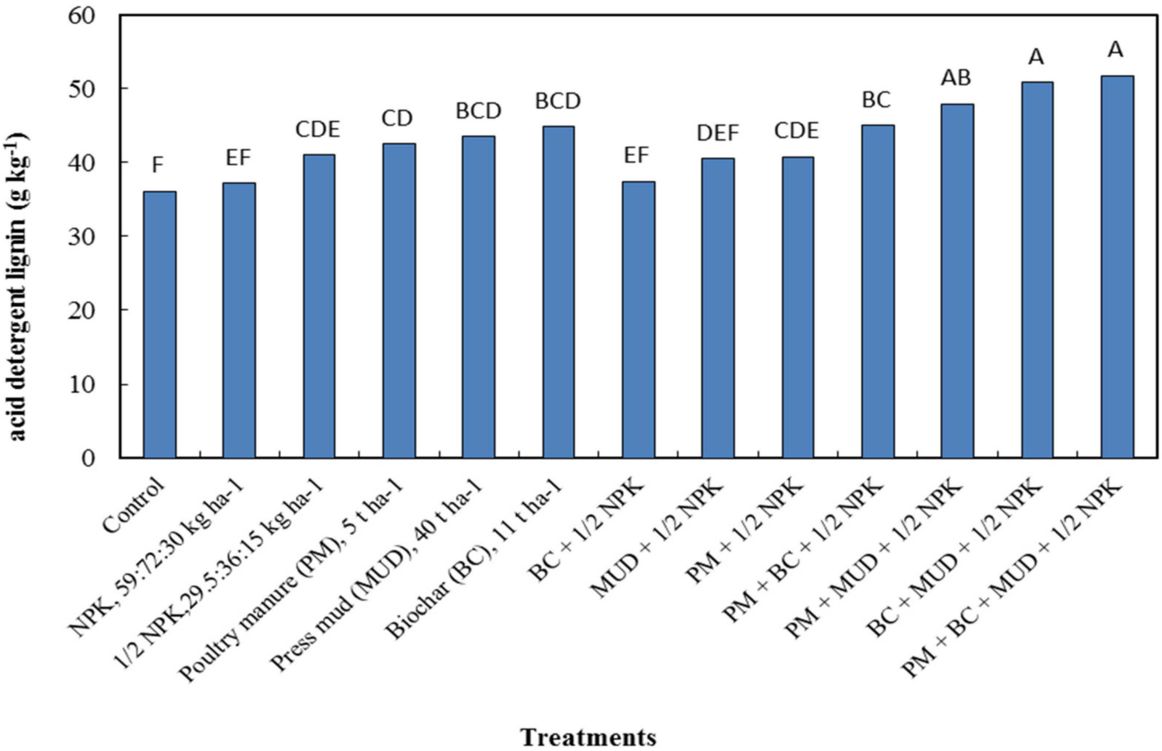

Figure 4. Effect of organic and inorganic amendments on acid detergent lignin of forage sorghum under the field conditions of Layyah, Pakistan. Values are the means of two years and three replicates. Means with similar letters at the top of the bar did not differ significantly at $p \leq 0.05$ (HSD = 4.5).

4. Discussion

Modern agriculture, with intensive use of inorganic fertilizers, has substantially increased crop production; however, it also disturbed the natural agroecosystem and polluted soil and water resources. Thus, the best practice is to use inorganic fertilizers with organic manures to improve crop productivity and the natural ecosystem. Here, in this study, we determined the impact of NPK fertilizers alone and NPK fertilizers in combination with different organic manures on the growth and the biomass production traits of forage sorghum, including the plant height, the number of leaves, the stem and leaf weights, and the leaf area and quality (ADF, aNDF, CP, and brix values of forage sorghum). Application of both organic manures and combinations of NPK and organic manures significantly improved the growth and biomass during both years of study (Tables 2 and 3). Although not measured in the present study, combined application of organic manures and fertilizers has been shown to improve the nitrogen use efficiency (NUE), the recovery of macro- and micronutrients, and the P and K availability, thus resulting in substantial improvement in growth and biomass production traits [22].

Dineshkumar et al. [29] reported that the application of organic fertilizers even at low rates facilitates the uptake of NPK and Mg, which in turn improve chlorophyll synthesis. The increase in chlorophyll contents following organic amendments is also reported as having plant photosynthetic efficiency [29–32], and leads to improved growth and biomass production (Tables 2 and 3). The application of organic manures also improved the soil microbial population and soil organic matter (SOM) and structural stability, according to Sutrino and Yusnawan [30], which contribute towards improvement in growth and biomass production, as reported by Asghari et al. [33] and Hosseinzadeh et al. [34]. Combined use of organic and inorganic fertilizers is a good option for improving crop growth and biomass (Tables 2 and 3), and is better compared with higher applications of NPK fertilizers [35]. All three organic amendments (MUD, PM, and biochar) significantly improved the biomass production traits of sorghum, such as plant height, number of leaves, stem and leaf weights, leaf areas, and the biomass quality. Hao et al. [36] reported that the application of organic manures with reduced NPK content might improve the microbial activities and nutrients availability, which leads to significant improvement in growth and biomass production traits. Organic amendments have beneficial impacts on soil quality and improve the nutrient release and nutrient availability to the plants [37]. The soil nutrient status is directly related to grain yield, and it also affects the final quality [38]. Moreover, reduction in soil bulk density—owing to an increase in soil biopores, soil aeration, SOM, and aggregate stability—following organic manures improves soil's water-holding capacity and soil porosity, which results in significant improvement in growth and biomass production [39,40].

The increase in biomass yield and the improvement in biomass quality traits, such as aNDF and crude protein, can be attributed to improved nutrient-use efficiency following organic manures and NPK application [41]. Ul-Allah et al. [42] reported that organic manure, if applied in equal amounts with respect to NPK, improves forage quality traits, such as NDF, crude protein, and metabolizable energy, compared with NPK alone, due to the presence of micronutrients and the improvement in soil physical properties. The addition of N in combination with organic manures (MUD, PM, and BC) increased the mineralization of nutrients from organic manures and enhanced nutrient supply, leading to significant improvement in growth, biomass production, and nutritional quality parameters, such as aNDF, CP, and brix values. Higher values of ADF and ADL are linked with lower digestibility [42]; thus, these reduce the forage quality. Here, further national quality tests (in vivo digestibility and metabolizable energy) are suggested to check whether these higher values are acceptable for forage or not. The application of organic manures prevented nutrient leaching by improving the soil structure and the binding of mineral nutrients [43], which in turn improved the yield and quality of the crops [44,45]. The integrative use of organic and inorganic fertilizers builds up soil quality and productivity on a long-term basis, and they also maintain a high rate of applied N in ammonium ions for a longer time, which improves NUE and, consequently, the final productivity [46,47]. Additionally, organic materials help to increase NUE, owing to their simple, controlled release [18,48], which also results in significant improvement in growth and biomass production.

The results indicated that the combined application of the poultry manure + biochar + press mud + half of recommended NPK treatment significantly improved the crude protein, brix percentage, ADF, and acid detergent lignin. This increase in quality can be attributed to improved availability of nutrients, SOM, soil structure, and increased NUE [8,9]. Organic manures contain appreciable amounts of NPK, and their field application improved the N uptake and resulted in significant increase in the protein contents of the plant parts [40,49].

5. Conclusions

The use of organic fertilizers is an essential strategy for improving crop development while reducing the negative environmental effects of synthetic fertilizers. According to the findings given here, the use of organic amendments in conjunction with inorganic fertilizers considerably improved the growth, biomass production, and crude protein of the forage sorghum crop, but simultaneously increased the ADL and ADF contents, indicating reduced digestibility. Surprisingly, all the organic additions increased the biomass productivity and forage quality. However, when compared with other amendment combinations across both years, the combined application of the poultry manure + biochar + press mud + half of NPK treatment remained the top performer. ADF and ADL also increased along with the productivity; therefore, more nutritional quality tests (in vivo digestibility, metabolizable energy, etc.) are required for final recommendations to be made.

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References

1. Liu, Q.; Xu, H.; Yi, H. Impact of fertilizer on crop yield and C: N: P stoichiometry in arid and semi-arid soil. *Int. J. Environ. Res. Public Health* **2021**, *18*, 4341. [CrossRef]
2. Guo, J.H.; Liu, X.J.; Zhang, Y.; Shen, J.L.; Han, W.X.; Zhang, W.F.; Christie, P.; Goulding, K.W.T.; Vitousek, P.M.; Zhang, F.S. Significant acidification in major Chinese croplands. *Science* **2010**, *327*, 1008–1010. [CrossRef]
3. Shisanya, C.A.; Mucheru, M.W.; Mugendi, D.N.; Kung'u, J.B. Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central highlands of Kenya. *Soil Tillage Res.* **2009**, *103*, 239–246. [CrossRef]
4. Hepperly, Y.P.; Lotter, D.; Ulsh, C.Z.; Siedel, R.; Reider, C. Compost, manure and synthetic fertilizer influences crop yields, soil properties, nitrate leaching and crop nutrient content. *Compost Sci. Util.* **2009**, *17*, 117–126. [CrossRef]
5. Huang, S.; Zhang, W.; Yu, X.; Huang, Q. Effects of long-term fertilization on corn productivity and its sustainability in an Ultisol of southern China. *Agric. Ecosyst. Environ.* **2010**, *138*, 44–50. [CrossRef]
6. Song, Z.; Gao, H.; Zhu, P.; Peng, C.; Deng, A.; Zheng, C.; Mannaf, M.A.; Islam, M.N.; Zhang, W. Organic amendments increase corn yield by enhancing soil resilience to climate change. *Crop J.* **2015**, *3*, 110–117. [CrossRef]
7. Bidabadi, S.S.; Dehghanipoodeh, S.; Wright, G.C. Vermicompost leachate reduces some negative effects of salt stress in pomegranate. *Int. J. Recycl. Org. Waste Agric.* **2017**, *6*, 255–263. [CrossRef]
8. Faloye, O.T.; Alatise, M.O.; Ajayi, A.E.; Ewulo, B.S. Synergistic effects of biochar and inorganic fertiliser on maize (*Zea mays*) yield in an alfisol under drip irrigation. *Soil Tillage Res.* **2017**, *174*, 214–220. [CrossRef]
9. Calamai, A.; Chiaramonti, D.; Casini, D.; Masoni, A.; Palchetti, E. Short-term effects of organic amendments on soil properties and maize (*Zea maize* L.) growth. *Agriculture* **2020**, *10*, 158. [CrossRef]
10. Zhang, M.; Ok, Y.S. Biochar soil amendment for sustainable agriculture with carbon and contaminant sequestration. *Carbon Manag.* **2014**, *5*, 255–257. [CrossRef]
11. Roy, P.; Dias, G. Prospects for pyrolysis technologies in the bioenergy sector: A review. *Renew. Sustain. Energy Rev.* **2017**, *77*, 59–69.
12. Khan, S.; Qureshi, I.; Shifa, M.S.; Waziri, A.H. An efficient calixarene-based functional material for the sorption and recovery of Cr (VI) from water. *Int. J. Environ. Anal. Chem.* **2019**, *99*, 1123–1134. [CrossRef]
13. Bashir, S.; Bashir, S.; Gulshan, A.B.; Khan, M.J.; Iqbal, J.; Sherani, J.; Husain, A.; Ahmed, N.; Shah, A.N.; Bukhari, M.A.; et al. The role of different organic amendments to improve maize growth in wastewater irrigated soil. *J. King Saud Univ. Sci.* **2021**, *33*, 101583. [CrossRef]
14. Chiu, C.C.; Cheng, C.J.; Lin, T.H.; Juang, K.W.; Lee, D.Y. The effectiveness of four organic matter amendments for decreasing resin-extractable Cr (VI) in Cr (VI)-contaminated soils. *J. Hazard. Mater.* **2009**, *161*, 1239–1244. [CrossRef]
15. Sabir, M.; Hanafi, M.M.; Aziz, T.; Ahmad, H.R.; Zia-Ur-Rehman, M.; Saifullah, G.M.; Hakeem, K.R. Comparative effect of activated carbon, press mud and poultry manure on immobilization and concentration of metals in maize (*Zea mays*) grown on contaminated soil. *Int. J. Agric. Biol.* **2013**, *15*, 559–564.
16. Farhad, W.; Saleem, M.F.; Cheema, M.A.; Hammad, H.M. Effect of poultry manure levels on the productivity of spring maize (*Zea mays* L.). *J. Ani. Plant Sci.* **2009**, *19*, 122–125.
17. Adekiya, A.O.; Aboyeji, C.M.; Dunsin, O.; Festus, A.; Ayotunde, O.; Aremu, C.O.; Oyetunji, D.A.; Oloye, A.D.; Owolabi, I.O. Poultry manure addition affects production, plant nutritional status and heavy metals accumulation in green Amaranth (*Amaranthus hybridus*). *Int. J. Agric. Biol.* **2019**, *22*, 993–1000.
18. Ul-Allah, S.; Khan, A.A.; Fricke, T.; Buerkert, A.; Wachendorf, M. Effect of fertiliser and irrigation on forage yield and irrigation water use efficiency in semi-arid regions of Pakistan. *Exp. Agric.* **2015**, *51*, 485–500. [CrossRef]
19. Aina, O.E.; Amoo, S.O.; Mugivhisa, L.L.; Olowoyo, J.O. Effect of organic and inorganic sources of nutrients on the bioactive compounds and antioxidant activity of tomato. *Appl. Ecol. Environ. Res.* **2019**, *17*, 3681–3694. [CrossRef]

20. Stamenković, O.S.; Siliveru, K.; Veljković, V.B.; Banković-Ilić, I.B.; Tasić, M.B.; Ciampitti, I.A.; Đalović, I.G.; Mitrović, P.M.; Sikora, V.Š.; Prasad, P.V. Production of biofuels from sorghum. *Renew. Sustain. Energ. Rev.* **2020**, *124*, 109769. [CrossRef]
21. Kusvuran, A.; Bilgici, M.; Kusvuran, S.; Nazli, R.I. The effect of different organic matters on plant growth regulation and nutritional components under salt stress in sweet sorghum [*Sorghum bicolor* (L.) Moench.]. *Maydica* **2021**, *66*, 9.
22. Mahmood, F.; Khan, I.; Ashraf, U.; Shahzad, T.; Hussain, S.; Shahid, M.; Abid, M.; Ullah, S. Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *J. Soil Sci. Plant Nutr.* **2017**, *17*, 22–32. [CrossRef]
23. Bremner, J.M.; Mulvaney, C.S. Nitrogen-Total. In *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; American Society of Agronomy, Soil Science Society of America: Madison, WI, USA, 1982; pp. 595–624.
24. Olsen, S.R. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*; The United States Department of Agriculture: Washington, DC, USA, 1954; Volume 939, pp. 1–19.
25. Yun-long, B.; Seiji, Y.; Maiko, I.; Hong-Wei, C. QTLs for sugar contents of stalks in sweet sorghum (*Sorghum bicolor* L. Moench). *Agric. Sci. China* **2016**, *5*, 736–744.
26. Van Soest, P.J.; Robertson, J.D.; Lewis, B.A. Methods for dietary fiber, neutral detergent fiber non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* **1991**, *74*, 3583–3597. [CrossRef]
27. AOAC. *Official Method of Analysis*, 17th ed.; Association of Official Analytical Chemists: Arlington, VA, USA, 2002.
28. Steel, R.G.D.; Torrie, J.H.; Dickey, D.A. *Principles and Procedures of Statistics: A Biometrical Approach*, 3rd ed.; McGraw Hill Book Co. Inc.: New York, NY, USA, 1997; pp. 400–428.
29. Dineshkumar, R.; Subramanian, J.; Arumugam, A.; Rasheeq, A.A.; Sampath Kumar, P. Exploring the microalgae biofertilizer effect on onion cultivation by field experiment. *Waste Biomass Val.* **2018**, *11*, 77–87. [CrossRef]
30. Darini, M.T. Studies of chemıcal sandy soil and physiological properties of *Aloe vera* L. plant on nutrient stress condition. *Int. J. Curr. Res.* **2017**, *7*, 208–212.
31. Zameer, R.; Sadaqat, M.; Fatima, K.; Fiaz, S.; Zafar, H.; Qayyum, A.; Nashat, N.; Raza, A.; Shah, A.N.; Batool, R.; et al. Two-component system genes in Sorghum bicolor: Genome-wide identification and expression profiling in response to environmental stresses. *Front. Genet.* **2021**, *12*, 794305. [CrossRef]
32. Sutrisno, S.; Yusnawan, E. Effect of manure and inorganic fertilizers on vegetative, generative characteristics, nutrient, and secondary metabolite contents of mungbean. *Biosaintifika* **2018**, *10*, 56–65. [CrossRef]
33. Asghari, R.; Dadashi, M.; Razavi, A.; Feizi, H.; Bakhtiari, S. The study of some physiological responses of saffron to salinity stress and humic acid treatment. *J. Med. Spice Plants* **2018**, *23*, 162–167.
34. Hosseinzadeh, S.R.; Amiri, H.; Ismaili, A. Evaluation of photosynthesis, physiological, and biochemical responses of chickpea (*Cicer arietinum* L. cv. Pirouz) under water deficit stress and use of vermi compost fertilizer. *J. Integr. Agric.* **2018**, *17*, 2426–2437. [CrossRef]
35. Mubeen, K.; Iqbal, A.; Hussain, M.; Zahoor, F.; Siddiqui, M.H.; Mohsin, A.U.; Bakht, H.F.S.G.; Hanif, M. Impact of nitrogen and phosphorus on the growth, yield and quality of maize (*Zea mays* L.) fodder in Pakistan. *Philipp. J. Crop Sci.* **2013**, *38*, 43–46.
36. Hao, X.; Liu, S.; Wu, J.; Hu, R.; Tong, C.; Su, Y. Effect of long-term application of inorganic fertilizer and organic amendments on soil organic matter and microbial biomass in three subtropical paddy soils. *Nutr. Cycl. Agroecosys.* **2008**, *81*, 17–24. [CrossRef]
37. Birkhofer, K.; Bezemer, T.M.; Bloem, J.; Bonkowski, M.; Christensen, S.; Dubois, D.; Ekelund, F.; Fließach, A.; Gunst, L.; Hedlund, K.; et al. Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. *Soil Biol. Biochem.* **2008**, *40*, 2297–2308. [CrossRef]
38. Lima, D.L.D.; Santos, S.M.; Scherer, H.W.; Schneider, R.J.; Duarte, A.C.; Santos, E.B.H.; Esteves, V.I. Effects of organic and inorganic amendments on soil organic matter properties. *Geoderma* **2009**, *150*, 38–45. [CrossRef]
39. Gangwar, K.S.; Singh, K.K.; Sharma, S.K.; Tomar, O.K. Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo- Gengetic plains. *Soil Till. Res.* **2006**, *88*, 242–252. [CrossRef]
40. Papini, R.; Valboa, G.; Favilli, F.; L'abate, G. Influence of land use on organic carbon pool and chemical properties of Vertic Cambisols in central and southern Italy. *Agric. Ecosyst. Environ.* **2011**, *140*, 68–79. [CrossRef]
41. Souri, M.K.; Rashidi, M.; Kianmehr, M.H. Effects of manure-based urea pellets on growth, yield, and nitrate content in coriander, garden cress, and parsley plants. *J. Plant Nutr.* **2018**, *41*, 1405–1413. [CrossRef]
42. Ul-Allah, S.; Khan, A.A.; Fricke, T.; Buerkert, A.; Wachendorf, M. Fertilizer and irrigation effects on forage protein and energy production under semi-arid conditions of Pakistan. *Field Crops Res.* **2014**, *159*, 62–69. [CrossRef]
43. El-Aal, A.; Shiref, A.E.A.; Awadalla, H.A. Assessment of the organic and inorganic fertilizers application on maize/wheat production in calcareous soil. *Fayoum J. Agric. Res. Dev.* **2012**, *26*, 112–129. [CrossRef]
44. Dinka, T.B.; Goshu, T.A.; Haile, E.H. Effect of integrated nutrient management on growth and yield of food barley (*Hordeum vulgare*) variety in toke kutaye district, west showa zone, Ethiopia. *Adv. Crop Sci. Tech.* **2018**, *6*, 1–8. [CrossRef]
45. Naiji, M.; Souri, M.K. Nutritional value and mineral concentrations of sweet basil under organic compared to chemical fertilization. *Acta Sci. Pol. Hortorum Cultus* **2018**, *17*, 167–175. [CrossRef]
46. Souri, M.K. Effectiveness of chloride compared to 3, 4-dimethylpyrazole phosphate on nitrification inhibition in soil. *Commun Soil Sci. Plant Anal.* **2010**, *41*, 1769–1778. [CrossRef]
47. Souri, M.K.; Naiji, M.; Kianmehr, M.H. Nitrogen release dynamics of a slow release urea pellet and its effect on growth, yield, and nutrient uptake of sweet basil (*Ocimum basilicum* L.). *J. Plant Nutr.* **2019**, *42*, 604–614. [CrossRef]

48. Souri, M.K.; Neumann, G. Indications for passive rather than active release of natural nitrification inhibitors in Brachiariahumidicola root exudates. *J. Plant Nutr.* **2018**, *41*, 477–486. [CrossRef]
49. Adekiya, A.O.; Ejue, W.S.; Olayanju, A.; Dunsin, O.; Aboyeji, C.M.; Aremu, C.; Adegbite, K.; Akinpelu, O. Different organic manure sources and NPK fertilizer on soil chemical properties, growth, yield and quality of okra. *Sci. Rep.* **2020**, *10*, 16083. [CrossRef]