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Phosphorus and Potassium Application Improves Fodder Yield and Quality of Sorghum in Aridisol under Diverse Climatic Conditions

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Abstract: Fodder yield and quality must be improved for sustainable livestock production. A lack of or low application of phosphorus (P) and potassium (P) are among the leading constraints of lower fodder yield and quality of sorghum [most cultivated fodder crop during kharif season (crop cultivation in summer and harvesting during winter] in Aridisol of Pakistan. Therefore, this two-year field study evaluated the role of different P and K levels on fodder yield and quality of sorghum cultivar '*Ijar-2002*' planted in Multan and Okara districts, Punjab, Pakistan. Seven P-K (kg ha^{-1}) levels, i.e., T_1 (40–0), T_2 (80–0), T_3 (0–40), T_4 (0–60), T_5 (40–40), T_6 (80–40), T_7 (60–80) and an untreated T_0 (control) were included in the study. Results indicated that individual effects of years, locations and P-K levels had a significant effect on fodder yield and quality. All treatments received an equal amount of nitrogen (i.e., 120 kg ha^{-1}). Application of P-K in Aridisols at both locations significantly improved fodder yield, dry matter yield, and ether contents during both years. The T_6 (80–40 kg ha^{-1}) significantly improved yield and quality traits of sorghum fodder except for crude fiber (CF) and acid and neutral detergent fiber (ADF and NDF) at both locations during both years of study. Moreover, fodder harvested from Multan observed significantly higher CF, ADF, NDF, cellulose and hemicellulose contents than Okara. However, sorghum grown in Okara harvested more fodder yield due to more plant height and ether contents. In conclusion, planting sorghum in Aridisols, fertilized with 80–40 kg ha^{-1} P-K seemed a viable option to harvest more fodder yield of better quality.

Keywords: sorghum; locations; P-K levels; fodder quality; yield traits; tropical conditions

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) is widely cultivated for forage purposes during summer season and has a significant role in livestock production [1]. Livestock share in agriculture and gross domestic product of Pakistan is 61% and 12%, respectively [2]. In Punjab, Pakistan, total production of summer fodder is 11,939 thousand tons from an area of 902 thousand hectares with an average fodder production of 55 t ha^{-1} [2]. Recently, sorghum fodder production has declined by 20% to 120 thousand tons [2]. About 60% of livestock depends on the feeds of wheat straw, maize stalks, sorghum, and millet [3]. In Pakistan, sorghum ranks fourth among cereals with respect to area under cultivation and produce fodder and grains, especially under harsh environmental conditions of the country. Availability of high yielding cultivars, imbalance and lower nutrients' application, low plant population, and poor weed management practices are among the leading constraints of low sorghum productivity [4].

Climate variability has significant impact on temperature, whereas the optimum temperature range for vegetative and reproductive growth of sorghum is 26–34 °C and 25–28 °C, respectively [5]. When temperature rises >36 °C it causes abortion of the entire inflorescence [6]. Predictable changes in climatic conditions, especially rising air mean maximum and minimum temperatures and fluctuations in rainfall pattern, had adversely affected fodder yield and quality traits in most parts of the world [7]. Climate change exerted multidimensional stresses on crop plants and changed rainfall patterns in the last few decades. The growth and yield are reduced when crops face these environmental fluctuations [8]. The ultimate solution to cope with these climate changes is timely adaptation of techniques that can mitigate these changes and boost plant production [9]. Failure in the adaptation of these novel techniques will create hurdles in the production of nutritious food and fodder for livestock in sufficient quantity [10]. Tropical and subtropical areas of the world are facing lower average fodder yield of sorghum than the potential of 50–100 tons per hectare. The main causes of severe fodder shortage during winter and summer seasons are low rainfall and high temperature during sowing.

Nutritional composition of fodder is highly sensitive to variation in balanced fertilizer application, drought/limited irrigation, genotypic characteristics, and higher population per unit area etc. [11,12]. Sorghum fodder contains higher digestible nutrients, consisting of 8% protein, 3% fat and 45% nitrogen-free extract [13]. Generally, fodder quality is dependent on the percentage of two main quality characteristics, i.e., crude protein (CP) and crude fiber (CF). The higher the percentage of CF, the lower the value of CP that leads towards lower fodder quality. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) are mostly applied for standard testing of fiber in any fodder. Fodder digestibility is assessed by determining ADF, while eating prospective is checked through NDF [14].

An appropriate nutrients application is a key constituent for enriching fodder production and quality [15,16]. Balanced application of fertilizers has a vital role in enhancing fodder production. However, lower application of phosphorus (P) than nitrogen (N) in calcareous soils is the main constraint. Calcareous Aridisol is deficient in many essential nutrients and tend to adsorb most of the applied P at exchange sites and limited portion goes to soil solution which is taken by plants [17]. Balanced placement/incorporation of fertilizers into the soil during sowing can play a key role in improving root growth that would lead towards healthy plant growth [18]. Unfortunately, soils remain deficient to P and K due to the negligence of growers for the application of these nutrients, which reduces fodder production in calcareous soils [19].

Fodder growers in Pakistan also apply lower P and K without focusing soil fertility status and mainly focus on N application. Moreover, P contents in Pakistan soils are in the range of 0.02 to 0.5% at surface layer due to alkalinity. There are two main reasons of low P application for fodder production. The first is higher price of P fertilizers [20] and the second is the lack of awareness/unavailability of these fertilizers during the peak demand period [21]. Unfortunately, no or low application of P is a major yield-limiting factor since it is an essential constituent of nucleic acid and plays an important role in cellular respiration and plant metabolism [22]. Involvement of P in enzymatic reactions, atmospheric CO_2 fixation, sugar digestion, and energy storage and transfer have direct contribution in fodder quantity and quality [23]. The second neglected nutrient in Pakistan is K, which reduces crop yield [24,25]. Potassium plays several significant roles in osmoregulation, plant water relations, cell expansion, stomatal conductance, membrane stability, cation–anion balancing, solute transport, protein synthesis, initiating and stimulation enzymes, modifying protein and starch and production of adenosine triphosphate (ATP) [26].

Owing to their roles in plant growth and development, fodder production and quality of sorghum can be improved by P and K application [27]. The information regarding combined application of P and K on fodder production and quality of sorghum is rarely studied or reported [28]. Therefore, this 2-years field study was conducted at two locations with the hypothesis that fodder yield and quality of sorghum can be improved by combined application of P and K on Hyperthermic, Sodic Haplocambids, Haplic Aridisols in Pakistan. The major objective of the study was to determine the P-K level which would improve yield and quality of fodder sorghum on Aridisol.

2. Materials and Methods

2.1. Description of Experimental Sites

This two-year field study was conducted at two distinct locations, i.e., [Agronomy Research Farm, Bahauddin Zakariya University, Multan (30.10° N, 71.25° E and 128.3 m altitude above sea level) and Farmer's field, Okara (30.81° N, 73.45° E and 105 m altitude above sea level)], Punjab, Pakistan during sorghum-fodder seasons (i.e., August-December) in 2015 and 2016. Weather data of both experimental locations are given in Table 1. August was the hottest month during both years with mean daily temperature ranging from 33.2 °C (Multan) to 31.3 (Okara) during 2015 and 36.7 °C (Multan) to 34.1 °C (Okara) during 2016, whereas December was the coolest month with mean daily temperature ranging from 17.7 °C (Multan) to 15.8 °C (Okara) during 2015 and 28.5 °C (Multan) to 23.9 °C (Okara) (Table 1). The growing season of 2015 received 55 mm (Multan) and 45 mm (Okara) rainfall, while 13- and 42-mm rainfall was received during 2016 at Multan and Okara, respectively (Table 1). Before sowing, physico-chemical analysis of soil was conducted to judge initial soil fertility status at both locations. Soil texture of Multan and Okara was determined using Hydrometer method. Multan soil was silty-clay-loam and belonged to Sindhalianwali textural class, was Hyperthermic, Sodic Haplocambids/Haplic Aridisol, whereas Okara soil was silt-loam and belonged to Kasur soil series and was Typic Camborthids according to USDA and FAO classifications, respectively. Soils of Multan and Okara had pH 8.3 and 7.8 and EC 12 and 11 dS m^{-1}, respectively, that were determined through pH meter (Beckman 45 Modal, Gurnee, IL, USA) and EC meter (VWR Conductivity Meter DIG2052, Radnor, PA, USA). Moreover, Multan and Okara soils had 0.78% and 0.85% organic matter, 0.04% and 0.09% total N, 7.6 and 5.9 mg kg^{-1} available-P ($NaHCO_3$-DTPA), and 165 and 285 mg kg^{-1} extractable-K, respectively.

Table 1. Weather data of both study years (2015 and 2016) at Multan and Okara locations.

Months	Multan				Okara			
	2015		2016		2015		2016	
	Rainfall	Temperature	Rainfall	Temperature	Rainfall	Temperature	Rainfall	Temperature
	mm	°C	mm	°C	mm	°C	mm	°C
August	32	34.1	11.4	36.7	33.0	31.3	22.0	33.2
September	10	35.2	1.2	37.9	12.0	29.1	18.0	32.7
October	3	33.6	0	37.2	0	24.8	0	26.3
November	4	26.6	0	32.5	0	21.2	2.0	23.8
December	6	23.9	0	28.5	0	15.8	0	17.7

Sources: Agricultural Meteorology Cell, Department of Agronomy, Bahauddin Zakariya University Multan and Meteorological Department, Railway Road, Okara, Punjab, Pakistan.

2.2. Experimental Details

Seeds of sorghum cultivar '*Ijar-2002*' (widely cultivated for fodder and grain purpose in the irrigated areas of Punjab, Pakistan) were obtained from the Fodder Research Institute, Sargodha, Pakistan. Crop was sown on 5th August 2015 and 2016 at Multan and Okara.

Different P-K levels (kg ha^{-1}) included in the study were T_0 (control); T_1 (40–0); T_2 (80–0); T_3 (0–40); T_4 (0–60); T_5 (40–40); T_6 (80–40) and T_7 (60–80). The fertilizer treatments were applied during sowing. Triple super phosphate (46% P_2O_5) and sulphate of potash (50% K_2SO_4) were used as sources of P and K, respectively. Experiment was laid out following randomized complete block design in a split-split plot arrangement (year as main plots, locations as subplots, and P-K levels as sub-subplots). The experiment was replicated four times with a net sub-plot size of 1.5 m × 4 m. Before this study, experimental fields were under cotton-wheat and maize-potato cropping systems at Multan and Okara, respectively.

2.3. Crop Husbandry

Before seedbed preparation, pre-soaking irrigation of ~10 cm was applied using tube well water. After attaining workable moisture level, the fields were tilled twice followed by planking with the help of tractor-drawn cultivator to achieve a fine seedbed at both locations. Sowing was carried out by using seed rate of 60 kg ha^{-1} in 30 cm spaced rows on 5th August during 2015 and 2016. Recommended dose (120 kg ha^{-1}) of N was applied using urea (46% N) as source. Thus, all fertilizer treatments received equal amount of N and P-K levels varied across the treatments. The full dose of P-K according to treatments and $^1/_3$ of the N was applied at the time of sowing as basal application, while remaining N was side-dressed at the time of first and second irrigations in equal splits. Three irrigations (each ~7.5 cm) were applied to the crops at both locations.

2.4. Data Collection

2.4.1. Fodder-Related Traits and Yield

Plant heights (cm) of ten randomly selected plants were measured at harvesting by using meter rod and averaged. The crop was harvested 65 days after sowing when the plants attained maximum biomass. Harvested crop bundles were weighed by using bench scales (Model Number: TCS-602) and converted into Mg (mega gram) ha^{-1}. Samples from these bundles were used to calculate the dry matter yield and converted into Mg per hectare.

2.4.2. Quality Attributes of Sorghum Fodder

The whole plant, leaf, and stem fractions of sorghum fodder were run through a fodder cutter and cut into 2 to 3 cm pieces. After cutting, the fodder was mixed and representative samples were drawn. The dry matter contents of fodder were recorded by following the method of Helrich [29]. Oven-dried samples were grinded in a laboratory mill and passed through 4 mm screen [30,31]. Dried fodder samples were used for determination of different quality parameters. The procedures of Association of Official Agricultural Chemists (AOAC) were adopted to determine different fodder quality parameters, i.e., crude protein percentage, crude fiber percentage, ash percentage, ether percentage, acid detergent fiber (ADF) and neutral detergent fiber (NDF) percentage. The cellulose and hemicellulose contents were determined through adopting procedure of Van Soest [32].

2.5. Statistical Procedure

The collected data using standard procedure were verified for normality by Shapiro-Wilk normality test, which directed a normal distribution. The analysis was completed on original data. Data were analyzed following three-way analysis of variance (ANOVA) on SAS software (Version 9.1; SAS Institute, Cary, NC, USA) [33], and means were compared by applying Tukey's honestly significant difference test at 95% probability level where ANOVA showed significant differences [34].

3. Results

Plant height, dry matter and fodder yield of sorghum were significantly affected by P and K application. Plant height significantly differed among years (F = 1431.80, p = 0.000), locations (F = 13356, p = 0.000), P-K levels (F = 2538.43, p = 0.000) and their interactions (Table 2). Plant height was 9% and 25% taller Okara compared to Multan during 2015 and 2016, respectively. The T_6 (80–40 kg ha^{-1}) produced 40.8% taller plants than T_0 (Table 3). Likewise, dry matter yield was significantly influenced by P-K levels (F = 7.70, p = 0.0000) during both years and locations (F = 10.22, p = 0.0022) (Table 2). The P-K levels, particularly T_6 (80–40 kg ha^{-1}), improved fodder yield by 40% compared to control (Table 3). Locations (F = 69.13, p = 0.0000), P-K levels (F = 32.68, p = 0.0000) and their interaction locations × P-K levels (F = 3.31, p = 0.0045) dominated on fodder yield. Higher dry matter yield (11%) was recorded at Okara than Multan. Similarly, higher fodder yield was produced (15.6%) at Okara than Multan. Moreover, T_6 (80–40 kg ha^{-1}) produced 40% higher fodder yield than T_0 (Table 3). Linear regression equation of dry matter yield and fodder yield (dependent) with yield attributes were calculated during both years, location and P-K levels. In case of regression equation (Table 4), dry matter yield showed highly significant dependence (90% and 91%) on plant height, while had non-significant effect on germination. Fodder yield showed significant dependence (83% and 84%) on plant height (Table 4).

Table 2. ANOVA table of growth and yield traits of sorghum during both years and locations.

S. O. V.	DF	Plant Height (cm)		Dry Matter Yield (Mg ha^{-1})		Fodder Yield (Mg ha^{-1})	
		MS	F-Value	MS	F-Value	MS	F-Value
Replication	2						
Years	1	11,305 **	1431.8	0.01 NS	0.01	6.90 NS	0.68
Locations	1	105,457 **	13,356.0	16.43 **	8.29	697.25 **	69.13
P-K levels	7	20,043 **	2538.43	15.25 **	7.70	329.59 **	32.68
Years × Locations	1	1866 **	236.39	20.25 **	10.22	5.44 NS	0.54
Years × P-K levels	7	345 **	43.67	0.16 NS	0.08	9.65 NS	0.96
Locations × P-K levels	7	2992 **	378.94	0.96 NS	0.48	33.39 **	3.31
Years × Locations × P-K levels	7	420 **	53.20	0.46 NS	0.23	10.61 NS	1.05
Error mean square		7.89		1.98		10.08	
General average		227.83		7.28		31.86	
C.V. %		1.23		19.33		9.97	

S.O.V., source of variation; MS, mean squares, NS, non-significant; ** = highly significant; C.V., coefficient of variation.

Table 3. Influence of P-K levels on sorghum growth, yield and yield traits during both years and locations.

Treatments	Plant Height (cm)	Dry Matter Yield (Mg ha^{-1})	Fodder Yield (Mg ha^{-1})
Years			
2015	238.7 A ± 2.5	7.3 ± 0.7	31.6 ± 1.8
2016	217.0 B ± 3.2	7.3 ± 0.7	32.1 ± 1.8
HSD 5%	1.14	NS	NS
Locations (Loc)			
Multan	194.7 B ± 2.7	6.8 B ± 0.7	29.2 B ± 1.8
Okara	261.0 A ± 2.9	7.7 A ± 0.7	34.5 A ± 1.8
HSD 5%	1.14	0.57	1.29
P-K levels (kg ha^{-1})			
T_0 (0–0)	176.3 G ± 2.6	5.4 D ± 0.7	23.0 E ± 1.8
T_1 (40–0)	196.5 F ± 2.8	6.2 CD ± 0.8	28.0 D ± 1.8

Table 3. *Cont.*

Treatments	Plant Height (cm)	Dry Matter Yield ($Mg\ ha^{-1}$)	Fodder Yield ($Mg\ ha^{-1}$)
T_2 (80–0)	195.0 F ± 3.2	7.0 B–D ± 0.8	30.0 CD ± 1.8
T_3 (0–40)	212.8 E ± 2.5	7.5 A–C ± 0.7	31.9 B–D ± 1.8
T_4 (0–60)	228.7 D ± 2.9	7.3 A–C ± 0.8	32.4 BC ± 1.8
T_5 (40–40)	248.6 C ± 2.7	8.2 AB ± 0.7	33.9 BC ± 1.8
T_6 (80–40)	298.0 A ± 2.8	9.1 A ± 0.7	40.9 A ± 1.8
T_7 (60–80)	265.8 B ± 3.2	7.6 A–C ± 0.8	34.7 B ± 1.8
HSD 5%	3.59	1.80	4.06
Interactions			
Years × Locations	**	**	NS
Years × P-K levels	**	NS	NS
Locations × P-K levels	**	NS	**
Years × Locations × P-K levels	**	NS	NS

NS, non-significant; ** = highly significant. Different letters in each column shows significant difference at 95% probability (HSD).

Table 4. Multiple linear regression equation of different sorghum yield traits on dry matter yield and fodder yield as affected by years, locations, and P-K levels during 2015 and 2016.

Regression Equation	Adj. (R^2)	R^2	GER	PLH
DMY = −1.958 + 0.004 × PLH + 0.276 × PAL − 0.059 × PAW + 0.028 × NPP + 1.478 × WET	90.6% ***	91.2% ***	NS	***
FDY = −4.940 + 0.288 × PLH − 1.054 × PAL − 0.052 × PAW + 0.207 × NPP + 3.824 × WET	82.9%	84%	NS	***

Dry matter yield, DMY; fodder yield, FDY; plant height, PLH; germination, GER. Significance codes: *** = significant; NS = non-significant.

Different quality traits of sorghum fodder like crude protein and fiber, ash, ether, acid and neutral detergent fiber and cellulose and hemicellulose contents were significantly affected by P-K levels (Table 5). Crude protein was significantly affected by P-K levels (F = 7.50, p = 0.0000) and varied in both years (F = 7.08, p = 0.0098). The P-K levels, particularly T_6 (80–40 kg ha^{-1}), increased crude protein contents by 26% in sorghum plants compared to T_0, while T_7 (60–80 kg ha^{-1}) and T_5 (40–40 kg ha^{-1}) were statistically similar with T_6 (80–40 kg ha^{-1}) (Table 6). Crude fiber was significantly influenced by locations (F = 4.43, p = 0.0392) and different P-K levels (F = 11.72, p = 0.000). At Multan, 2.98% higher crude fiber contents were recorded than Okara. Significantly higher (17.3%) crude fiber contents were recorded in control when plants were not fertilized as compared to T_7 (60–80 kg ha^{-1}), T_6 (80–40 kg ha^{-1}) and T_5 (40–40 kg ha^{-1}) (Table 6). Ash % was significantly affected by P-K levels (F = 7.44, p = 0.000). Significantly higher ash % (25%) contents were recorded when sorghum plants were fertilized with 80–40 kg ha^{-1} (T_6) compared to no fertilization treatment (T_0: 0–0 kg ha^{-1}) (Table 6). Significant effect of years (F = 23.92, p = 0.0000), locations (F = 8.11, p = 0.0059), P-K levels (F = 38.05, p = 0.0000) and interaction among years × locations (F = 4.48, p = 0.0382) were recorded on ether %. The T_6 (80–40 kg ha^{-1}) had 35% higher ether % than control and other fertilizer levels (Table 6). Statistically, 7% and 5% higher ether % was recorded at Okara compared to Multan during 2015 and 2016, respectively. Significant effect of both acid detergent fiber and neutral detergent fiber was recorded for locations (F = 16.04, p = 0.0002), (F = 20.82, p = 0.0000) and P-K levels (F = 0.22.48, p = 0.9079), (F = 7.90, p = 0.0000). Higher acid and neutral detergent fiber were produced (19% and 8%, respectively) in control, while in T_7 (60–80 kg ha^{-1}) sorghum plants had the lowest acid and neutral detergent fiber (Table 6). Overall, Multan location had higher acid and neutral detergent fiber than Okara (4% and 3%) during 2015 and 2016, respectively. Cellulose and hemicellulose contents were significantly influenced by locations (F = 17.24, p = 0.0001), (F = 10.10, p = 0.0023) and P-K levels (F = 20.25, p = 0.0000), (F = 3.48, p = 0.0032). Sorghum plants fertilized with T_6 (80–40 kg ha^{-1}) recorded 13% and 8% higher cellulose and hemicellulose contents than T_0 (0–0 kg ha^{-1}) (Table 6). Multan location recorded 3% and 4% higher cellulose and hemicellulose contents than Okara, respectively.

Multiple linear regression equation for dry matter and fodder yields (dependent) with fodder quality traits were calculated during both years, location, and P-K levels included in the study. In case of regression equation (Table 7), dry matter yield showed highly significant dependence (86% and 87%) on crude protein, crude fiber, ash content, ether content, acid detergent fiber, neutral detergent fiber, while significant effect on hemicellulose and non-significant on cellulose content. Fodder yield showed highly significant dependence (88% and 89%) on crude fiber, ash content, ether contents, while significant effect on crude protein and cellulose content and non-significant effect on acid detergent fiber, neutral detergent fiber and hemicellulose content (Table 7).

Table 5. ANOVA table of fodder quality traits of sorghum during both years and locations.

S. O. V.	DF	Crude Protein (%)		Crude Fiber (%)		Ash (%)		Ether (%)		Acid Detergent Fiber (%)		Neutral Detergent Fiber (%)		Cellulose Content (%)		Hemicellulose Content (%)	
		MS	F-Value	MS	F-Value	MS	F-Value	MS	F-Value	MS	F-Value	MS	F-Value	MS	F-Value	MS	F-Value
Replication	2																
Years	1	7.40 **	7.08	0.80 NS	0.21	2.43 NS	2.44	0.37 **	23.92	0.66 NS	0.42	0.77 NS	0.63	0.042 NS	0.03	0.05 NS	0.02
Locations	1	0.02 NS	0.03	17.16 *	4.43	0.96 NS	0.96	0.12 **	8.11	25.27 **	16.04	25.89 **	20.82	24.03 **	17.24	24.60 **	10.10
P-K levels	7	7.85 **	7.50	45.38 **	11.72	7.44 **	7.44	0.60 **	38.05	35.42 **	22.48	9.82 **	7.90	28.22 **	20.25	8.46 **	3.48
Years × Locations	1	0.37 NS	0.35	0.006 NS	0.00	0.54 NS	0.55	0.07 *	4.48	0.0001 NS	0.00	0.003 NS	0.00	0.002 NS	0.00	0.0009 NS	0.00
Years × P-K levels	7	0.44 NS	0.43	0.034 NS	0.01	0.068 NS	0.07	0.006 NS	0.38	0.005 NS	0.00	0.017 NS	0.01	0.0002 NS	0.00	0.0007 NS	0.00
Locations × P-K levels	7	0.21 NS	0.21	0.408 NS	0.11	0.205 NS	0.20	0.01 NS	0.86	0.012 NS	0.01	0.005 NS	0.00	0.001 NS	0.00	0.003 NS	0.00
Years × Locations × P-K levels	7	0.17 NS	0.17	0.01 NS	0.00	0.163 NS	0.16	0.002 NS	0.17	0.009 NS	0.01	0.004 NS	0.00	0.001	0.00	0.0004 NS	0.00
Error mean square		1.04		3.87		0.99		0.01		1.57		1.24		1.39		2.43	
General average		8.08		28.00		8.69		1.55		24.86		37.26		29.84		24.32	
C.V. %		12.65		7.03		11.51		8.10		5.05		2.99		3.96		6.41	

NS, non-significant; * = significant; ** = highly significant.

Table 6. Influence of P-K levels on sorghum quality traits during both years and locations.

Treatments	Crude Protein (%)	Crude Fiber (%)	Ash (%)	Ether (%)	Acid Detergent fiber (%)	Neutral Detergent Fiber (%)	Cellulose Content (%)	Hemicellulose Content (%)
				Years				
2015	8.4 A ± 0.5	28.1 ± 1.0	8.8 ± 0.5	1.6 A ± 0.07	24.9 ± 0.6	37.4 ± 0.5	29.9 ± 0.6	24.4 ± 0.8
2016	7.8 B ± 0.3	27.9 ± 0.9	8.5 ± 0.6	1.5 B ± 0.08	24.8 ± 0.6	37.2 ± 0.6	29.8 ± 0.6	24.3 ± 0.9
HSD 5%	0.41	NS	NS	0.05	NS	NS	NS	NS
				Locations				
Multan	8.1 A ± 0.7	28.4 A ± 0.9	8.8 ± 0.5	1.5 B ± 0.07	25.4 A ± 0.6	37.8 A ± 0.5	30.3 A ± 0.6	24.8 A ± 0.8
Okara	8.1 A ± 0.7	27.6 B ± 0.9	8.6 ± 0.6	1.6 A ± 0.08	24.4 B ± 0.6	36.7 B ± 0.6	29.3 B ± 0.6	23.8 B ± 0.9
HSD 5%	NS	0.80	NS	0.05	0.51	0.45	0.48	0.63
				P-K levels (kg ha^{-1})				
T_0 (0–0)	7.0 D ± 0.7	30.8 A ± 1.1	7.6 C ± 0.6	1.2 F ± 0.04	28.0 A ± 0.5	38.8 A ± 0.6	27.7 E ± 0.6	23.3 B ± 0.8
T_1 (40–0)	7.6 CD ± 0.8	30.2 A ± 0.8	8.1 BC ± 0.5	1.3 EF ± 0.05	26.3 B ± 0.6	38.1 AB ± 0.5	27.8 DE ± 0.6	23.4 AB ± 0.8
T_2 (80–0)	7.8 B–D ± 0.7	29.7 AB ± 0.9	8.6 BC ± 0.5	1.5 DE ± 0.1	24.8 BC ± 0.6	37.5 A–C ± 0.6	29.3 CD ± 0.6	23.7 AB ± 0.8
T_3 (0–40)	7.5 CD ± 0.7	26.9 C ± 0.9	8.3 BC ± 0.5	1.5 DE ± 0.7	24.7 C ± 0.6	37.1 B–D ± 0.5	30.3 BC ± 0.6	24.4 AB ± 0.8
T_4 (0–60)	7.9 B–D ± 0.7	27.5 BC ± 1.1	8.5 BC ± 0.6	1.6 CD ± 0.1	25.4 BC ± 0.7	37.2 B–D ± 0.5	29.7 C ± 0.6	24.1 AB ± 0.9
T_5 (40–40)	8.5 A–C ± 0.7	27.0 C ± 0.8	9.2 AB ± 0.6	1.7 BC ± 0.1	23.9 CD ± 0.7	36.9 B–D ± 0.6	30.8 A–C ± 0.6	25.0 AB ± 0.9
T_6 (80–40)	9.4 A ± 0.6	26.6 C ± 0.9	10.1 A ± 0.6	1.9 A ± 0.07	23.1 D ± 0.6	36.6 CD ± 0.6	31.9 A ± 0.6	25.4 A ± 0.9
T_7 (60–80)	9.0 AB ± 0.6	25.4 C ± 0.9	9.1 AB ± 0.6	1.8 AB ± 0.5	22.8 D ± 0.6	35.9 D ± 0.6	31.3 AB ± 0.6	25.3 A ± 0.8
HSD 5%	1.30	2.51	1.27	0.16	1.60	1.42	1.50	1.99
				Interactions				
Years × Locations	NS	NS	NS	*	NS	NS	NS	NS
Years × P-K levels	NS	NS	NS	NS	NS	NS	NS	NS
Locations × P-K levels	NS	NS	NS	NS	NS	NS	NS	NS
Years × Locations × P-K levels	NS	NS	NS	NS	NS	NS	NS	NS

NS, non-significant; * = significant. Different letters in each column shows significant difference at 95% probability (HSD).

Table 7. Multiple linear regression equation of different sorghum quality traits on dry matter yield and fodder yield as affected by years, locations and P-K levels during 2015 and 2016.

Regression Equation	Adj. (R^2)	R^2	CPR	CRF	ASH	ETH	ADF	NDF	CLC	HCC
DMY = 25.530 + 0.755 × CRP − 0.778 × CRF + 0.793 × ASH−4.138 × ETH−0.749 × ADF + 1.079 × NDF − 0.194×CLC − 0.771 × HCC	86.2% ***	87.4% ***	***	***	**	***	**	**	NS	.
FDY = 205.490 + 1.335 × CRP − 2.282 × CRF + 5.987 × ASH − 12.792 × ETH − 1.020 × ADF − 0.799 × NDF − 1.790 × CLC − 1.811 × HCC	87.6% ***	88.7% ***	.	***	***	**	NS	NS	.	NS

Dry matter yield, DMY; fodder yield, FDY; crude protein, CRP; crude fiber, CRF; ash content, ASH; ether content, ETH; acid detergent fiber, ADF; neutral detergent fiber, NDF; cellulose content, CLC; hemicellulose content, HCC. Significance codes: 0 = "***"; 0.001 = "**"; 0.05 = "."; 0.1 "NS".

4. Discussion

Application of P-K in Aridisol significantly improved fodder yield and quality of sorghum (Tables 2–7). The substantial improvement (44%) in sorghum plant height with the application of 80–40 kg ha^{-1} P-K (Table 3) revealed the balanced availability of nutrients to the plants [35–37]. Moreover, better and efficient utilization of nutrients might bring variation within P-K levels, leading to improved plant height, which contributed towards higher fodder yield [38]. Optimum P-K level (i.e., 80–40 kg ha^{-1}) resulted in the improvement of physiological activities that resulted in improved plant height [23]. Furthermore, P-K have significant role in crop growth; therefore, biomass or plant size was increased [39]. Higher production of amino acids and growth-promoting chemicals within plants leads towards improvement in meristematic activities such as cell division, enlargement, and elongation, which resulted in taller plant height [40]. Suitable application of K leads to the synthesis of proteins, opening and closing of stomata and osmotic adjustments [26]. The shorter plant height in control treatment might be due to nutrient deficiency leading to weak plant metabolism without fertilizers [41].

Availability of balanced nutrients improves meristematic and physiological activities [36,42–44]. This resulted in increased resource use efficiency and more dry matter accumulation per unit area/time as well as higher yield. Being a C_4 plant, sorghum has deep and extensive root system, which helped in more uptakes of P and K leading to more plant growth [45,46]. Soil application of 80–40 kg P-K ha^{-1} increased 40% and 44% dry mater yield and fodder yield, respectively (Table 3). Balanced nutrient application might promote enzyme activities which triggered sorghum growth and development, consequently improving the yield of sorghum [44]. Higher dry matter and fodder yield in T_6 (80–40 kg ha^{-1}) is a result of better soil nutrients suitable for nutrient uptake and accessibility, which resulted in accelerated cell division, enlargement and elongation. Sufficient nutrients availability flourished growth and resulted in higher fodder yield [45]. This supports our hypothesis that balanced fertilization and favorable weather conditions improved availability and uptake of plant nutrients, particularly in silty-clay-loam soil, which enhanced meristematic and physiological activities [36]. High temperature during 2016 might impacted the quantity and quality traits of sorghum, as well as large-scale fodder production pattern (Table 1). Our results corroborate the findings of Mathur and Jajaoo [46], that higher temperature had adverse effects in metabolism stability and reactions within cells which disturb metabolism in plants, such as crude protein, crude fiber, ash %, ether %, acid and neutral detergent fiber and cellulose and hemicellulose contents. Moreover, high temperature and change in sowing dates decreased nutrient availability and protein concentrations that leads to lower nutritional quality of edible portions of food and forage crops [35]. Furthermore, high temperature can decrease nutritional quality of crops through a reduction in protein, K and calcium levels [47] (Table 6). Our results showed that less rainfall and high temperature (Table 1) significantly reduced forage quality and crude protein content (Table 6) [48].

Forage quality is mainly determined by crude protein and fiber [49]. Soil application of 80–40 kg ha^{-1} P-K improved crude protein (26%) compared to the rest of the treatments (Table 6). In our results, significant improvements were recorded in crude protein that might be linked with the availability of P that played an important role in development of structural component like DNA and RNA that has dominant role in protein synthesis [50]. Phosphorus is main constituent of ATP that is required in many metabolic processes that leads to photosynthetic and protein activity [50]. Moreover, higher crude protein-containing fodder is considered a good quality fodder that is due to improvement in the proximate compositions at different developmental stages [51]. The weak plants had lower ability to develop potential and adapt mechanisms, which enhanced the P and K uptake under nutrients starvation [52]. Our study further supported the results of Jégo et al. [53], indicating that high temperature along with lower nutrients' availability reduces plants growth and contents of crude protein and increase crude fiber and acid and neutral detergent fiber contents. Soil applied 80–40 kg ha^{-1} P-K showed 14% lower crude fiber than control and other treatments that have lower P-K levels (Table 6). It is proven that fodder having lower crude fiber is superior in quality and vice versa and most of the studies supports our hypothesis that lower and control treatments had higher crude fiber and lower crude protein content and vice versa [51]. However, contradictory findings were reported by Eltelib and Eltom [54] that higher nutrients' levels increased crude fiber, whereas current results showed that higher crude fiber was measured at control and lower nutrients levels (Table 5). Soil applied 80–40 kg ha^{-1} P-K significantly improved ash % and ether % in sorghum than control and other treatments (Table 6). Our findings are further supported by earlier results [55] indicating maximum total ash and ether contents content at higher rate of P and K fertilizer levels (80–40 kg ha^{-1}) (Table 6). Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were lowered by 18% and 8% at 80–40 kg ha^{-1} P-K application than control and other treatments (Table 6) which might be due to higher lignin contents. These results supported our hypothesis that balanced nutrients application significantly influences forage quality [11]. Moreover, plant cell walls constituents (i.e., ADF, NDF cellulose, hemicelluloses, lignin, and tannins), which represent crude fiber content in forage, have a large influence on fodder digestibility.

Several studies reported that sorghum plants grown under balanced fertilization and harvested at mature stage have higher crude fiber than plants harvested at the booting stage [15,56] (Table 6). On the contrary, Atis et al. [57] revealed that lignin content tended to increase with prolonged maturity from booting stage to physiological maturity stage. The increase in fodder crude fiber with development of growing stage may be due to increased concentration of cell wall constituents within stem and leaves as well as decreased soluble proportion of the cell [56]. This could be due to lignin accumulation and synthesis during secondary cell wall development [11]. Furthermore, balanced fertilization resulted in lower concentration of acid and neutral detergent fiber and increased in lignin, which reduced the digestibility of the plant [58].

5. Conclusions

Soil incorporated 80–40 kg ha^{-1} P-K noticeably improved the growth and fodder yield of better quality of sorghum cultivated at both locations (i.e., Multan and Okara) in Aridisol in both years. The results reveal that sufficient nutrient availability is necessary for improving the yield and fodder quality of sorghum. However, the nutrients' requirement may vary according to soil type and fertilizer levels must be selected based on the fertility status of the soils. For Aridisol, 80–40 P-K kg ha^{-1} significantly improved the yield and quality of fodder sorghum. Thus, this is recommended for such soils. Nevertheless, long-term studies are needed to obtain more reliable results regarding yield and soil health.

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