Late harvest associated with P and S fertilization enhances yield and quality of forage sorghum (*Sorghum bicolor* (L.) Moench), grown as a rainfed crop in Pakistan

Ahmad Sher¹, Lorenzo Barbanti²*, Muhammad Ansar¹, Abdul Manaf¹ and Shuaib Kaleem³

¹Department of Agronomy, PMAS-Arid Agriculture University Rawalpindi, Pakistan.
²Department of Agro-environmental Science and Technology (DiSTA), University of Bologna, Italy.
³Adaptive Research Farm, D. G. Khan, Pakistan.

Accepted 22 July, 2011

To investigate the effect of harvest time associated with P and S fertilization on yield and quality of forage sorghum (*Sorghum bicolor* (L.) Moench), grown as a rainfed crop in Pakistan, a field study was carried in summer 2009. Three levels of phosphorus (0, 30 and 60 kg P₂O₅ ha⁻¹), in combination with three levels of sulphur (0, 20 and 40 kg SO₄ ha⁻¹), in combination with three harvest times (35, 45 and 55 days after emergence; DAE), were tested in a factorial randomized block design. At each harvest, morphological, functional, yield and quality traits were assessed on plant samples. Extending the growing season from DAE 35 to 55 enhanced almost all the traits and greatly benefited dry biomass yield (ca. +100%). The longer growth also determined a higher efficiency in the accumulation of dry biomass per unit time and land surface (crop growth rate ca. +30%), as well as per unit time and leaf surface (net assimilation rate ca. +100%). Quality traits also improved when plants were harvested at a more advanced maturity: leaf hydrocyanic acid content, a toxic component to livestock, decreased by ca. 30%; stalk soluble-solid content, an indicator of forage juiciness and palatability, increased by ca. 50%. On concluding, the combined effects of harvest delay, P and S fertilization on sorghum are deemed able to significantly increase forage production in warm, relatively dry areas of the world.

**Key words:** Forage sorghum, phosphorus, sulphur, harvest time, crop growth rate (CGR), net assimilation rate (NAR), hydrocyanic acid (HCN).

**INTRODUCTION**

A very important sector of agriculture in Pakistan is livestock. It participates in agriculture for 53.2% of added value and in Gross Domestic Product for 11.4%. It is an important player in economy that 30 to 35 million people have 2 to 3 cattle and 5 to 6 sheep per family which provides 30 to 40% of their income (Government of Pakistan, 2010). In Pakistan, forage sorghum is grown on an area of 248,000 ha along with a total annual production of 15.4 Tg and an average yield of 26.9 Mg ha⁻¹ (fresh forage) (GOP, 2010). About 80% of the surface is located in the Punjab province, Pakistan, where almost 90% of the crop is harvested. This means an average yield of 29.1 Mg ha⁻¹, slightly above the Country’s average. Sorghum fodder contributes 30% to the total fodder production in Pakistan and 33% to the total fodder production in Punjab (Anonymous, 2008).

---

**Abbreviations:** a.s.l., Above sea level; ANOVA, analysis of variance; CGR, crop growth rate; DAE, days after emergence; H, harvest; HCN, hydrocyanic acid; K, potassium; LAI, leaf area index; LSR, leaf to stem ratio; N, nitrogen; NAR, net assimilation rate; P, phosphorus; S, sulphur; SNK, Scott – Newman-Keuls.

*Corresponding author. E-mail: lorenzo.barbanti@unibo.it.
Sorghum is an important rainy season fodder crop as it is nutritious, juicy, palatable, and well-liked by the cattle. Under ordinary conditions, sorghum is considered to be a good feed but when its normal growth is constrained by drought, frost, soil compaction, or imbalanced soil nutrients, hydrocyanic acid (HCN) content may develop from dhurrin glycosides to such an extent, that it becomes toxic when fed to animals. HCN, also known as Prussic acid, has been responsible for large losses of livestock in many countries. Since HCN dilutes in plant tissues during growth, farmers generally do not feed sorghum at the early stages of growth due to the risk of cyanide poisoning, but delay its supply until the forage is safe.

Phosphorus (P) provides the energy used in the synthesis of sucrose, starch and proteins. Low usage of P in relation to N has been identified as one of the major factors limiting higher crop yields. In Pakistan, farmers mainly apply N accounting for 79.7% of total fertilizer usage, while P$_2$O$_5$ and K$_2$O represent only 19.7 and 0.6%, respectively, (NFDC, 2010). To achieve higher yield of crops it is essential to provide them with the optimum level of nutrients, according to soil nutrient status. Modern sorghum cultivars need a high amount of phosphorus for initial growth and development, as a status. Modern sorghum cultivars need a high amount of phosphorus for initial growth and development, as a condition to express their yield potential (Chaubey et al., 1992).

Sulphur (S) is an essential element for plant and animal nutrition whose deficiencies have been increasing throughout the world (Platou and Irish, 1982). The use of S-free fertilizers, such as many mineral fertilizers, has created widespread deficiency of S in soils (Chaubey et al., 1992). Sulphur fertilization can increase the yield and the quality of forages in the areas of S deficient soils (Andrew, 1977; Spears et al., 1985; Pandithararne et al., 1986; Puoli et al., 1991; Hallmark and Brown, 1994). Moreover, S fertilization is known to improve nitrogen (N) utilization efficiency by the crops (Goh and Kee, 1978; Schnug and Haneklaus, 1993).

Studies on sorghum fertilization have generally addressed nitrogen, the most important nutrient for yield and quality. Conversely, little attention has been paid to phosphorus and, among secondary nutrients, sulphur. Therefore, the role of these two nutrients in forage sorghum is still quite unexplored in the area where most of the crop is grown in Pakistan. Given these premises, the present study was undertaken to investigate the effects of P and S fertilization on yield and quality at three harvest times of forage sorghum (Sorghum bicolor (L.) Moench), grown in the typical conditions (rain fed crop) of Punjab (Pakistan).

MATERIALS AND METHODS

In summer 2009, a field study was carried out at Koont Research Farm (33° 56' N, 72° 52' E, 498 m a.s.l.), Pir Mehr A li Shah Arid Agriculture University, Rawalpindi, Punjab (Pakistan). Before sowing, two composite soil samples (0 to 15 and 15 to 30 cm depth) were collected in the experimental site and were analyzed for physical-chemical properties. The soil was a sandy-loam with an almost neutral pH. The organic matter and total N content was low, especially in the deeper layer. The P status was poor: less than 5 mg P kg$^{-1}$ with the Olsen method (Olsen and Sommers, 1982) in both soil layers. Three levels of phosphorus (0, 30 and 60 kg P$_2$O$_5$ ha$^{-1}$) as triple super phosphate, in combination with three levels of sulphur (0, 20 and 40 kg SO$_2$ ha$^{-1}$) as gypsum, in combination with three harvest times, were tested in soil plots. The 27 treatment combinations were arranged in a factorial randomized block design with four replications, totalling 108 plots. The forage sorghum cultivar “Chakwal sorghum” was sown on August 2, 2009, by means of a hand driller. A seed rate of 75 kg ha$^{-1}$ was distributed in rows at a 0.3 m distance. Four rows composed each plot, whose net surface was 4.8 m$^2$ (that is, 4 × 1.2 m). A basic rate of 60 kg N ha$^{-1}$ as urea was applied at seed bed preparation, just prior to sowing. Seedling emergence occurred on August 7, 2009. In the early growth stages, the plots were hand weeded. The three harvests were set at the pre-booting sorghum stage (35 days after emergence, DAE), booting (45 DAE) and 50% heading (55 DAE).

The main weather parameters (maximum and minimum temperature, precipitation and average relative humidity) were recorded on a daily base during crop cycle at the farm meteorological station. Crop evapo-transpiration ($ET_c$) was calculated according to the Hargreaves method for reference evapo-transpiration ($ET_0$; Hargreaves and Samani, 1985) and to specific crop coefficients (Allen et al., 1986). During the 55 days of crop cycle, daily maximum and minimum temperatures consistently remained at 35 ± 2.4°C and 21 ± 2.5°C, respectively. The relative humidity averaged 64 ± 10.5%. A total of 116 mm rain fell, all in the first half of crop cycle. $ET_c$ over the whole cycle amounted to 293 mm; therefore a relevant deficit (177 mm) was shown between potential crop consumption ($ET_c$) and natural supply (precipitation). However, a total of 270 mm rainfall had been received in the previous two months (July and August); this large amount should have replenished soil moisture reserves, to the benefit of rainfed sorghum.

On all plots at each harvest time, sorghum samples on a 1 m$^2$ surface were cut at the base, counted, weighed and a representative sub-sample was oven-dried at 105°C. In a nother sub-sample, plant height and leaf area (CI-202L leaf area meter, Forestry Suppliers Inc, Jackson, MS; USA) were measured, then leaves and stems were separated, weighed and oven-dried at 105°C. Another fresh leaf sample was submitted to the analysis of HCN content, according to the formula by Bradbury et al. (1999). Another fresh stem sample was crushed at mid-height, to obtain juice to determine the soluble-solid content (Brix value; %) in a hand held refractometer (Sino Technology, Fujian, China). The complex of determinations allowed to calculate: leaf to stem ratio (LSR; g g$^{-1}$), leaf area index (LAI; m$^2$ m$^{-2}$), dry biomass yield (DBY; Mg ha$^{-1}$). In addition to these, two functional traits of plant growth were assessed, according to the formula by Bradbury et al. (1999): i) crop growth rate ($CGR$; g m$^{-2}$ d$^{-1}$), expressing the efficiency of dry biomass accumulation per unit land surface per day of growth; corresponding to the DBY divided by the DAE at each harvest; ii) net assimilation rate ($NAR$; g m$^{-2}$ d$^{-1}$), expressing the efficiency of dry biomass accumulation per unit leaf surface per day of growth.

For each trait the whole dataset was submitted to the analysis of variance (ANOVA) of the three single factors, their three first-order interactions and their second-order interaction, according to the experimental scheme. Prior to ANOVA, normal distribution and equal variance of data were controlled through the Kolmogorov-Smirnov and the Bartlett test, respectively. The Scott - Newman-Keuls test at $P \leq 0.05$ was adopted to separate means of statistically-significant ANOVA sources. The statistical procedure was carried out through the CoStat 6.3 software (CoHort Software, Monterey, CA, USA). To save space, only significant first-order interactions are not displayed.
RESULTS

Morphological traits

Plant height

Plant height is associated with the growth and biomass of the crop: the taller the plant, the higher dry biomass yield and, potentially, soluble sugar yield. Plant height showed a significant difference among treatments (Table 1): delaying harvest determined a 25% increase in plant height, compared to a 10% increase with P and S supply. Only a significant interaction was observed among the three factors (H × S; Figure 2a), showing a weaker response to S application in the intermediate harvest. The lack of interaction between P and S indicates an additive effect of the two nutrients.

Leaf to stem ratio

LSR is one of the most significant parameters determining forage quality, since leaves are more nutritious and palatable to livestock than the stem. The three single factors enhanced the ratio (Table 1), thus having a beneficial effect. Nutrient (P and S) supply was more effective than harvest delay; this is in contrast to what observed in the other morphological traits. All the interactions were significant, apart from P × S (Figures 1a and 2b). Their combined effect outlines a higher responsiveness of both nutrients in the late than in the early harvest.

Leaf area index

LAI was influenced by the three single treatments and all their interactions (Table 1). Harvest, phosphorus and sulphur were equally influential, determining a ca. 50% increase in trait level. According to the interactions (Fig. 1.b, 2.c, 3.a), P was a stronger promoter of leaf expansion in the early harvest; S in the late one. Given their complementary behaviour, it is no surprise that the two nutrients positively interacted (Figure 3a). In the complex of the three factors (data not shown), the late harvest effect tended to prevail.

Yield and functional traits

Dry biomass yield

DBY is the single most prominent parameter indicating the forage yield of any crop. Significant differences were shown in this trait, depending on the three single factors and the P × S interaction (Table 1). Harvest time was the most influential factor on DBY (ca. +100%), but also P and S were very effective (+83 and +65%, respectively). The P × S interaction (Figure 3b) clearly indicates the need of both nutrients to achieve a top yield level (+180% over the control receiving no P and S supply), which is consistent with the basic principles of plant nutrition (Marschner, 1995).

Crop growth rate

CGR, the functional trait describing biomass growth efficiency per unit land surface, was enhanced by the three single factors (Table 1), but especially by P and S fertilization (ca. +80%). Compared to this, harvest time exhibited a remarkable increase (ca. +30%) only in the last (DAE 55) vs. the previous two times (DAE 35 and 45). The significant P × S interaction (Figure 3c) shows a combined effect of the two nutrients (+190% over the control), compared to their single use.

Net assimilation rate

NAR, the functional trait describing biomass growth per unit leaf surface, was equally influenced by the three single factors (Table 1): NAR was more than doubled by harvest time, P and S fertilization. The significant H × P and P × S interactions (Figures 1c and 3d) display some sort of antagonism, that is, NAR was more enhanced by each single factor, than by their combinations.

Quality traits

Leaf HCN

Delaying the harvest and supplying P and S to the crop were very effective in decreasing HCN content in sorghum leaves (Table 1). P exerted the strongest curb on this trait (-42%); harvest delay and S fertilization exhibited similar effects (ca. -28%). The significant interactions (Figures 1d and 3e) showed a stronger reduction of HCN operated by either P or S, in the early than in the late harvest. Therefore, the two nutrients reduced the risks associated with HCN especially at an early growth stage, when such risks are most feared.

Brix value

The Brix value of fresh stalks was positively influenced by all the three single factors (Table 1). Delaying the harvest determined almost a 50% increase; P and S supply determined an approximate 30% increase. The significant H × P and H × S interactions (Figures 1e and 2d) outline a synergy between harvest lateness and either nutrient. The lack of a significant P × S interaction indicates an additive effect between them.
Table 1. Effects of harvest time, phosphorus and sulphur supply on morphological, yield and functional and quality traits of forage sorghum in a plot experiment carried out in Pakistan in summer 2009.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Morphology</th>
<th>Yield and functional</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant height (m)</td>
<td>LSR (g g⁻¹)</td>
<td>LAI (m² m⁻²)</td>
</tr>
<tr>
<td>Harvest (H) (DAE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>1.15 c</td>
<td>0.74 b</td>
<td>1.5 c</td>
</tr>
<tr>
<td>45</td>
<td>1.34 b</td>
<td>0.72 c</td>
<td>1.7 b</td>
</tr>
<tr>
<td>55</td>
<td>1.43 a</td>
<td>0.78 a</td>
<td>2.3 a</td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>P₂O₅ (P) (kg ha⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.24 c</td>
<td>0.68 c</td>
<td>1.5 c</td>
</tr>
<tr>
<td>30</td>
<td>1.32 b</td>
<td>0.75 b</td>
<td>1.7 b</td>
</tr>
<tr>
<td>60</td>
<td>1.36 a</td>
<td>0.81 a</td>
<td>2.3 a</td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>SO₄ (S) (kg ha⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.23 c</td>
<td>0.69 c</td>
<td>1.6 c</td>
</tr>
<tr>
<td>20</td>
<td>1.32 b</td>
<td>0.76 b</td>
<td>1.7 b</td>
</tr>
<tr>
<td>40</td>
<td>1.37 a</td>
<td>0.79 a</td>
<td>2.3 a</td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>H × P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.065 ns</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>H × S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.014*</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>P × S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.546 ns</td>
<td>0.492 ns</td>
<td>0.002*</td>
</tr>
<tr>
<td>H × P × S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.282 ns</td>
<td>0.002*</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>C.V. (%)</td>
<td>3.3</td>
<td>4.2</td>
<td>11.1</td>
</tr>
</tbody>
</table>

LSR: leaf to stem ratio (dry matter basis); LAI: leaf area index; DBY: dry biomass yield; CGR: crop growth rate; NAR: net assimilation rate; HCN: hydrogen cyanide content in fresh leaves; Brix value: soluble-solid content in fresh stalks. ns, *, ** mean non-significant, significant at P ≤ 0.05 and P ≤ 0.01, respectively. Different letters indicate significantly-different means (SNK test; P ≤ 0.05).
Figure 1. Significant Harvest x P interactions in morphological, functional, yield and quality traits of forage sorghum in a plot experiment carried out in Pakistan in summer 2009. 1.a, leaf to stem ratio (LSR); 1.b, leaf area index (LAI); 1.c, net assimilation rate (NAR); 1.d, hydrocyanic acid content in fresh leaves; 1.e, solid-soluble content (Brix value) in fresh stalks. Different letters indicate significantly-different means (SNK test; \( P \leq 0.05 \)).

Figure 2. Significant Harvest x S interactions in morphological and quality traits of forage sorghum in a plot experiment carried out in Pakistan in summer 2009. 2.a, plant height; 2.b, leaf to stem ratio (LSR) 2.c, leaf area index (LAI); 2.d, solid-soluble content (Brix value) in fresh stalks. Different letters indicate significantly-different means (SNK test; \( P \leq 0.05 \)).
DISCUSSION

Morphological traits

The beneficial effects of supplying P and S and delaying the harvest until a more advanced maturity were remarked by sorghum behaviour in terms of morphology, yield and quality. Plant morphology anticipated the results at harvest: the application of phosphorus and sulphur enhanced plant height and leaf area index, which are important components of yield, since they are associated with growth and biomass of the crop. A significant increase in forage sorghum height and leaf number with N and P application had already been observed by Medina et al. (1984). Similar findings were reported by Rashid (1994), concluding that more than 90% soils of Pakistan require moderate to high P fertilization for optimum plant growth. In this experiment, LAI was low, compared to several field trials: in fertilizer experiments on forage sorghum Pholsen and Sornsungnoen (2004), and Pholsen and Sukrsi (2004) found LAI ranges of 3 to 4.5 m² m⁻² and 2 to 3.5 m² m⁻², respectively, at DAE 49. Bhatt (1995) attained 5 m² m⁻² at DAE 60. Quite higher values (about 7 m² m⁻²) were observed by Pholsen and Sukrsi (2007) at DAE 49 in another experiment, as well as by Bahrami and Ghenateghestani (2004) at mid-flowering, and by Channappagoudar et al. (2009) at heading. In contrast to this, average LAI values averaging 2.5 m² m⁻² were found in forage sorghum subjected to repeated grazing cycles (Simili et al. 2010). It appears, therefore, that the LAI values observed in our experiment rank in the low range for this crop. However, the high trait responsiveness to all factors and interactions (Table 1) indicates a possibility of LAI enhancement, which positively reflected on growth and yield at harvest.

Yield and functional traits

The effects observed in dry biomass yield imply that fresh forage yield (trait not shown) varied in the same way as dry biomass yield, but within a narrower range. It appears, therefore, that the plant harvested in unfavourable conditions (early and, especially, P and S deficient) tended to cope with such constraints by diluting its tissues, in order to extend its size. At the onset of more favourable conditions (late harvest, P and S supply), the plant recovered more in terms of dry than fresh biomass, thus concentrating its tissues.

The application of phosphorus, sulphur and the delay in harvest increased dry biomass yield. Similar results in sorghum were found by Patel et al. (2003), who reported that, the application of 80 kg P ha⁻¹ and 20 kg S ha⁻¹ determined the same effect on dry matter yield (+13%). Wheeler et al. (1980), Chaudhry et al. (1984) and Chand et al. (1992) also reported similar responses to phosphorus in sorghum. In our experiment, the good yield response to P application is consistent with the low
soil P status: about 5 mg P kg$^{-1}$, compared to a threshold of adequacy at 10 mg P kg$^{-1}$ (Memon, 1996). The equally good response to S application is not supported by a soil nutrient assessment in our experiment, although a positive response of sorghum to sulphur in Pakistan has already been shown and explained by soil nutrient deficiency (Panwar et al., 1998).

The improvement in the two functional traits associated with plant growth and yield, CGR and NAR, is consistent with the more favourable conditions brought about by a longer growth in conditions of nutrient adequacy. In forage sorghum at variable N-K rates, Pholsen and Sornsungnoen (2004) found a CGR ranging between 19 and 22 g m$^{-2}$ d$^{-1}$ at DAE 49. In another fertilizer experiment, Pholsen and Sukrsi (2004) observed a quite lower CGR (7 to 10 g m$^{-2}$ d$^{-1}$) at DAE 49. In forage sorghum at variable plant density, a top CGR of about 18 g m$^{-2}$ d$^{-1}$ was recorded over a 100-day growth (Bhatt, 1995). In sweet sorghum varieties evaluated for forage use, Channappagoudar et al. (2009) found a CGR range of 15 to 35 g m$^{-2}$ d$^{-1}$ at 50% flowering. At last, in forage sorghum varieties subjected to a double cut, Carrillo and Ruiz (2004) found a CGR between 14 and 27 g m$^{-2}$ d$^{-1}$. Therefore, the results obtained in our experiment rank among the top CGR levels recorded in warm areas of the world (Thailand, India, Mexico, Pakistan). More to this, the possibility to increasing CGR from 15 g m$^{-2}$ d$^{-1}$ (no P and S supply) to 44 g m$^{-2}$ d$^{-1}$ (full P and S fertilization) (Figures 3c) represents a remarkable opportunity to improve farming efficiency, involving a higher forage output on a lower crop surface.

NAR is seldom assessed in forage and sweet sorghum, despite the fact that LAI and yield are quite often recorded. In the only experiment where NAR was recorded in forage sorghum (Carrillo and Ruiz, 2004), a range of 4 to 8 g m$^{-2}$ d$^{-1}$ was observed in six genotypes in optimum (water and nutrients) growth conditions. Our results feature a range between 3 g m$^{-2}$ d$^{-1}$ (no P and S supply) and 16 g m$^{-2}$ d$^{-1}$ (full P and S fertilization) (Figures 3d). The latter value may compare with the Carrillo and Ruiz (2004) experiment, as optimum growth condition; therefore it is perceived that the modest LAI registered in our experiment was compensated by a high photosynthetic efficiency, proved by the high NAR.

**Quality traits**

Leaf HCN declined with harvest time, as well as with P and S fertilization. Prussic acid poisoning is caused by cyanide production in several types of plants under specific growth conditions. Sorghum and some closely related species are the plants most commonly associated with prussic acid poisoning. Cyanide poisoning is related to the amount of forage consumed and the animal physiological condition, but HCN levels exceeding 200 mg kg$^{-1}$ on a wet weight (as is) basis are dangerous for livestock. Prussic acid concentrations are higher in fresh forage than in silage or hay, because HCN is volatile and dissipates as the forage dries. Sulphur application detoxifies HCN through the reaction with the sulphides or S-containing amino acids, producing non-toxic thiocyanate (Singh et al., 1983). Likewise, phosphorus application increases nitrogen utilization through protein synthesis; the latter nutrient otherwise accumulates in the plants as cyanide, leading to HCN. Raafat et al. (1968) stated that higher P concentrations increase sucrose formation in sorghum plants; in turn, sucrose inhibits the formation of dhurrin glycosides from glucose. These results are in accordance with those of Wheeler et al. (1980), who reported a 34% reduction in HCN content by the application of phosphorus. Similarly, also Gorashi et al. (1980), Singh et al. (1983) and Chand et al. (1992) reported reductions in HCN content through P applications. In contrast to phosphorus, N fertilizer was shown to increase HCN content in sorghum forage (Gorashi et al., 1980; Bahrani and Ghenateghestani, 2004).

In forage sorghum, Brix values are generally lower than in sweet sorghum. Such circumstance is confirmed by the higher Brix shown in experiments dealing with sweet sorghum: Channappagoudar et al. (2009) obtained Brix levels ranging between 13 and 19% in a series of genotypes; Bian et al. (2006) about the same range in a segregating population. In forage sorghum, Pholsen and Sornsungnoen (2004) found Brix values between 10.5 and 12%; Pholsen and Sukrsi (2007) between 11 and 12.5. Therefore, the Brix values observed in our experiment are in a very high range, attaining a level of 18 at 50% heading (Table 1), which is more typical of sweet than forage sorghum. In late harvest, P and S fertilizations allow to further enhance the trait to 21%. Stem Brix value is considered an indicator of forage quality and palatability in maize (Bian et al., 2009); therefore, the high levels shown in our experiment and the effects carried out by the three investigated factors are the premises for a good forage quality, adding a further benefit to the higher yield determined by late harvest, P and S fertilization.

**Conclusion**

Forage sorghum is the first ring of a food chain of great interest in many warm, relatively dry areas of the world. In our plot experiment, the crop has been able to accumulate more than 20 Mg ha$^{-1}$ of dry biomass in a two-month period, showing a remarkable efficiency per unit time and land used. A higher forage production is, therefore, possible on a lower crop surface.

Beside a longer growth season, adequate P and S supply has proved fundamental to achieve such goal. In contrast to extended crop season, fertilization has a cost which is more difficult to afford in developing countries. However, sources of nutrients cheaper than mineral fertilizers may be used, such as manure. Further studies
may be needed to draw nutrient response curves according to soil status and other cropping factors, in order to enhance nutrient efficiency and promote fertilizer economic use.

ACKNOWLEDGEMENTS

The Higher Education Commission, Pakistan, is gratefully acknowledged for financial support under their program “International Research Support Initiative Program” (IRSIIP). The authors warmly thank Mr. Shah Nawaz for help in data collecting and sorghum analysis.

REFERENCES


