Evaluation of water productivity, stover feed quality and farmers' preferences on sweet sorghum cultivar types in the semi-arid regions of Zimbabwe

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Summary

Twenty sweet sorghum cultivars that included 17 improved cultivars (experimental grain, forage, dual and India released varieties) from India and 3 landraces from southern Africa were evaluated for their use as an alternative food and fodder crop for crop-livestock farmers. The trials were conducted during 2007/08 season in semi-arid conditions at Matopos Research Station, Zimbabwe. Three methods of assessment were applied to help identify suitable cultivars: grain and stover water productivity (WP), stover feed quality traits and farmers' assessment of cultivars in the field. Grain and stover WP ranged from 0.6 to 2.7 kg m^{-3} and 1.2 to 4.0 kg m^{-3} respectively. We observed significant differences in cultivar groups on plant height, time to maturity, harvest index, grain WP, nitrogen uptake, nitrogen harvest index and stover metabolizable energy and digestibility ($P < 0.001$), and sugar (Brix %) and stover WP ($P < 0.05$). In the improved grain and dual type cultivars, grain yield increased by 118% compared to landraces and by 69% over the forage type while in the India released variety type cultivars grain yield increased by 86% compared to landrace yields and by 44% over the forage cultivars with an increase in stover yield. The landrace type was superior to all sweet sorghum types on feed quality traits (metabolizable energy and digestibility). The farmers' assessment demonstrated the need to combine qualitative and quantitative screening methods. The farmers' combined analysis showed that forage and grain yield are important parameters to the farmers following crop-livestock production systems. Results of the three methods showed that the dual type SP1411 was the preferred cultivar. Future breeding activities should therefore be directed towards the trade-off between grain yield potential and stover feed quality in the quest for developing a wider range of dual purpose cultivars.

Introduction

Crop-livestock systems are the most common form of land use in the semi-arid areas of Zimbabwe. The natural grazing that takes place within these systems is mostly on lands regarded as marginal or incapable of arable production. Due to low production potential, overgrazing and insufficient fodder availability during the dry season are perennial resource management constraints which have led to widespread food and feed scarcity (Lenné and Thomas 2005). Grass quality is also low during the dry season with crude protein content dropping to as low as 10–20 g crude protein kg^{-1} dry matter (Elliot and Fokersten 1961). The shortage of dry season feed is a major factor contributing to high animal mortalities and less livestock products (Mapiye et al. 2006). With ever expanding croplands, crop residues have become a major source of feed in these mixed crop-livestock systems (Sibanda et al. 2011).

Nearly 70% of the crop residues are derived from cereals, with maize (*Zea mays*), sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) providing the largest portion in sub-Saharan Africa (Shumba 1984). These food crops have been developed for high grain yields, largely through improved harvest index (HI) resulting in lower production of crop residues for feed. Several crop improvement programs have now committed to improve the whole crop rather than only the grain (Rattunde 1998). These multipurpose crops will improve fodder yield and quality without additional land requirement (Reddy et al. 1995). Due to general water scarcity in these environments, improved multipurpose crops also offer an opportunity to increase overall water productivity (WP) in mixed farming systems.

In India, multipurpose sweet sorghum varieties that provide higher grain yields and more stover of higher quality have been developed. In general, sweet sorghum is more efficient on water use than maize (310 kg water kg^{-1} dry matter compared to 370 kg water kg^{-1} dry matter) and can be successfully grown in semi-arid areas of Zimbabwe where other food crops struggle to thrive (Chapman and Carter 1976). Water use efficiency is the ratio of net benefit from crops to the water required to produce those benefits (Kijne et al. 2003). Varietal differences of more than 10% for grain and fodder yields, and stover digestibility were reported in sorghum (Badve et al. 1993). Presently, most sweet sorghum cultivars grown by smallholder farmers in Zimbabwe are landraces that yield little grain. There is thus a strong need to select improved cultivars that will lead to higher grain and residue yields in farmers' fields.

In 2007, under ICRISAT-ILRI and the Department of Research and Specialist Services (DR&SS) collaboration, improved sweet sorghum lines from India were imported for evaluation in Zimbabwe. The objectives of this study were therefore to: (i) evaluate sweet sorghum types for agronomic and fodder quality traits; (ii) evaluate sweet sorghum cultivars for grain and stover WP; and (iii) assess farmer preferences of the sweet sorghum cultivars to meet their food and livestock feed requirements.

Materials and methods

Study sites. Field evaluation for rainfall WP, fodder quality and farmers' preferences was carried out at the Matopos Research Station, Zimbabwe (28° 24.46' E; 20° 25.64' S) during one cropping season (2007/08). The site is in the semi-arid tropics characterized by poor and erratic rainfall that ranges from 450 to 650 mm per annum. The soils are imperfectly drained clay derived from igneous or metamorphic rocks and classified as Pelli-Eutric Vertisol (World reference base 1998) or 3E.4 (Zimbabwe Soils Classification, Moyo 2001).

Experimental design and measurements. Twenty sweet sorghum cultivars which included landraces [Zimbabwe (1) and Kenya (2)], experimental lines [grain (9), fodder (3) and dual purpose (2)] and India released varieties (3) from ICRISAT-India were evaluated. The improved cultivar types were India released varieties and experimental lines (dual, grain and forage types). The cultivars were evaluated in a randomized complete block design (RCBD) with three replications. Plot size was 4 rows × 4 m long with plants spaced at 75 cm inter-row and 20 cm within the row. All cultivars were planted in end of December in 2007/08 season. Fertilizer was applied at 300 kg ha^{-1} compound D (7:14:7 for N:P:K) as basal fertilizer and top dressed with 69 kg ha^{-1} nitrogen (N). Plant height, time to 50% flowering and time to maturity were determined in three trial replicates. At harvest, grain and stover (aboveground biomass minus grain) yields were estimated from a net plot consisting of the two middle rows with a length of 3 m. The stover samples were oven-dried at 60°C for 48 h to determine dry weight and a sub-sample taken for analysis to determine fodder quality traits. Grain mass was converted to per hectare basis at 12.5% moisture content as final grain yield. Sugar (Brix %) was recorded at maturity. Nitrogen uptake and nitrogen harvest index (N-HI) were determined from the following equations:

N uptake (kg ha^{-1}) = (stover yield dry matter × stover N % × 10) + (grain yield at 12.5% moisture content × grain N % × 10)

N-HI = (grain yield at 12.5% moisture content × grain N % × 10) / N uptake

Water productivity and fodder quality traits. Grain and stover samples were analyzed for total N (N content * 6.25 = crude protein content). Stover was analyzed for metabolizable energy, in vitro organic matter digestibility (IVOMD), dry matter and ash content with Near Infra Red Spectroscopy (NIRS; Instrument FOSS 5000 Forage Analyzer with WINSI II software package). In this study rainfall use efficiency is derived from total rainfall received during the season, from 20 December 2007 to end of May 2008 using the following formula:

Rainfall water productivity = Grain (at 12.5% moisture content) or stover yield dry matter (kg) / total rainfall (m^3)

Farmers' preferences. Twenty farmers comprising 10 men and 10 women farmers were invited to Matopos Research Station for participatory varietal selection. Farmers with livestock were randomly selected from four wards of Nkayi, which is in the semi-arid area of Zimbabwe. Women and men farmer groups were invited separately to do the rankings and for discussions. Farmers were given three labels each, numbered as 1, 2 and 3 that represented their choice of best, better and good cultivars. They were asked to attach one label to experimental lines; the labels had a code referring to each individual farmer. Following the selection exercise, we discussed with each group the traits which they considered to be useful and the basis on which they made their selections.

Statistical analysis. Data analysis was done using GenStat 7.2 statistical package on agronomic and fodder quality traits and means were compared within and between cultivar groups. The grain and stover yields were analyzed with a covariate for plant population which was found to vary from 0.5 to 5.5 plants m^{-2}.

Results

Seasonal conditions. Rainfall from planting to harvesting was 164 mm, and its distribution was highly skewed to the vegetative stage, such that crops experienced very little moisture stress during the period. Further, the last rainfall of 55 mm received coincided closely with crop flowering. The extended period of terminal moisture stress during grain-filling would normally be expected to result in poor grain yield and very low HI. The unexpectedly high grain yields and HI recorded in the trial can be attributed to a combination of the high soil water-holding capacity of the clay soil and a largely full profile going into the grain-filling stage.

Agronomic and fodder quality traits. The average time to 50% flowering for 20 cultivars evaluated in this study is presented in Figure 1. The landrace cultivar types exhibit 17% variation in time to flowering (86–100 days), the forage types 12% (71–79 days), variety types 13% (79–89 days) and the grain types 20% (67–81 days). These variations within cultivar groups equally apply to overall crop duration, as differences in the duration of grain-filling within and between groups was not significant (P <0.05) and averaged 47 days.

There were significant differences (P <0.001) in plant height, time to maturity, grain yield, stover yield (P <0.05), HI, N uptake and N-HI between the different cultivar types (Table 1). Also significant differences were observed for some parameters within cultivar group (P <0.05), as indicated in Table 1, but are not discussed here.

Grain yield of improved grain and dual type cultivars increased by 128% compared to landrace yields and by 77% over the forage cultivars. The increase in grain yield was achieved without any decline in stover yield by dual cultivars. Grain yield of improved variety type cultivars

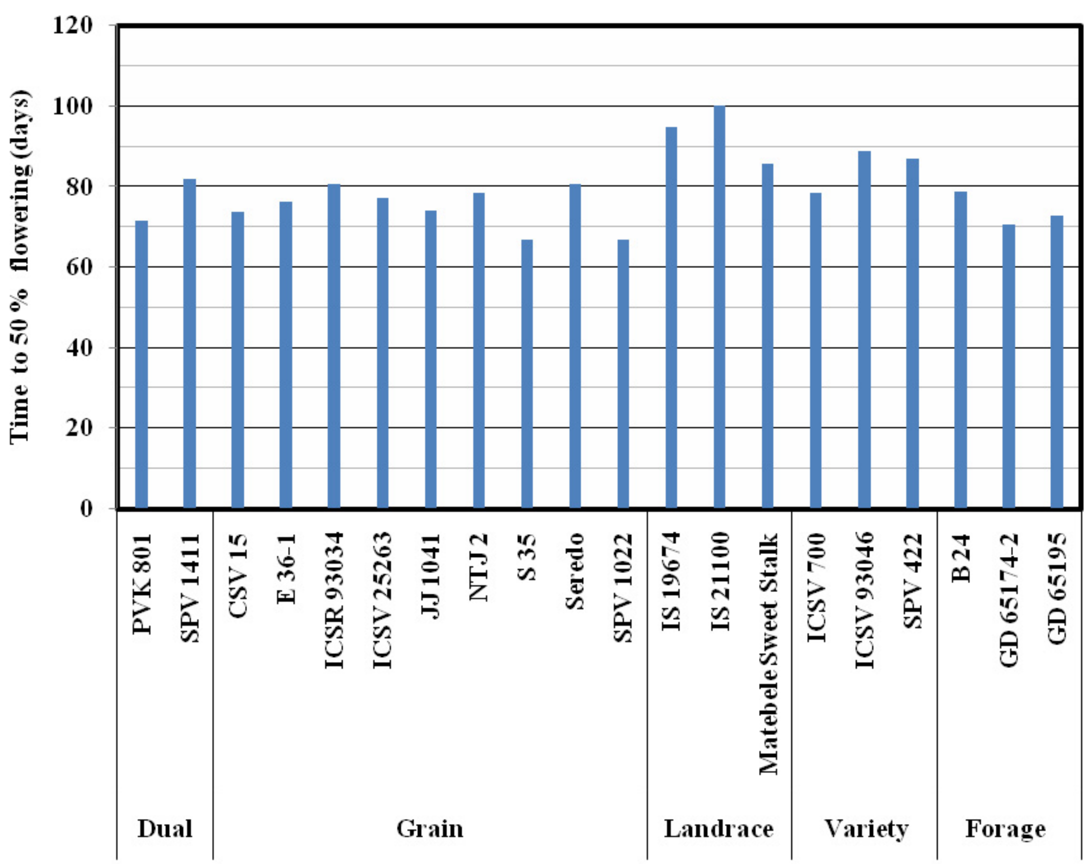

Figure 1. Time to 50% flowering for 20 sweet sorghum cultivars evaluated in the study.

increased by 86% compared to landrace yields and by 44% over the forage cultivars with a significant increase in stover yield. The grain yield increases for the improved grain and dual cultivars are associated with significantly shorter plant height and crop duration compared to the landraces and also significant increases in HI. The higher total biomass of the grain and dual cultivars resulted in higher N uptake and higher N off-take in the grain compared to the landraces and forage cultivars.

Differences in metabolizable energy content (mj kg^{-1}), digestibility (%), ash content (%) (P <0.001) and sugar (Brix %) (P <0.05) between the sweet sorghum cultivar groups were statistically significant (Table 2). The landraces had the highest metabolizable energy content and digestibility indicating that the landrace stover is the more favorable group from a feed quality perspective. In contrast, the level of these parameters in the grain and dual types indicated that the feed quality of the improved cultivar stover is inferior to that of the landraces. The India released variety type was comparable to landrace in metabolizable energy content, while forage type was also comparable in digestibility. Within the improved forage cultivar group there was quite large percentage increase in the stover digestibility (15%) and the metabolizable energy (16%) (data not shown) indicating that selection for improved feed quality within this cultivar group is possible. The landrace type had higher sugar (Brix %) but was not significantly different to dual and variety type. There were no differences in crude protein content between or within the different cultivar groups (Table 2).

Observed genetic variations and relationship to measured parameters. For the high fertility conditions of the trial, and in spite of lack of rainfall during grain-filling, grain yield responses across the 20 cultivars were strongly related to the uptake of N and the translocation of N and biomass to the seed component of total biomass (Fig. 2). The grain and dual types of improved sweet sorghum are generally superior in relation to both plant N dynamics compared to the improved forage, variety and

Table 1. Agronomic traits of sweet sorghum cultivar groups.

Cultivar type	Plant height (m)	Time to maturity (days)	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index	Nitrogen uptake (kg ha^{-1})	Nitrogen-harvest index
Landrace	2.5[1]	143	1.4	3.3	0.27	36	0.59
Forage	2.0	121	1.8	3.8[1]	0.34[1]	46	0.64[1]
Grain	1.7	121[1]	3.5	3.0[1]	0.54	70	0.81
Dual	2.0[1]	124[1]	3.2	3.9	0.45[1]	59	0.73
Variety	2.2	132	2.6	4.5	0.36	61	0.64
Mean	2.0	126	2.9	3.5	0.44	61	0.67
Significance[2]	***	***	***	*	***	***	***
SED	0.12	2.76	0.49	0.55	0.05	8.8	0.05
CV (%)	13.4	4.8	36.7	34.1	25.7	31.2	14

1. Significant differences (P <0.05) were observed within cultivar type for these parameters.
2. * = Significantly different between cultivar type at P = 0.05; and *** = P <0.001.

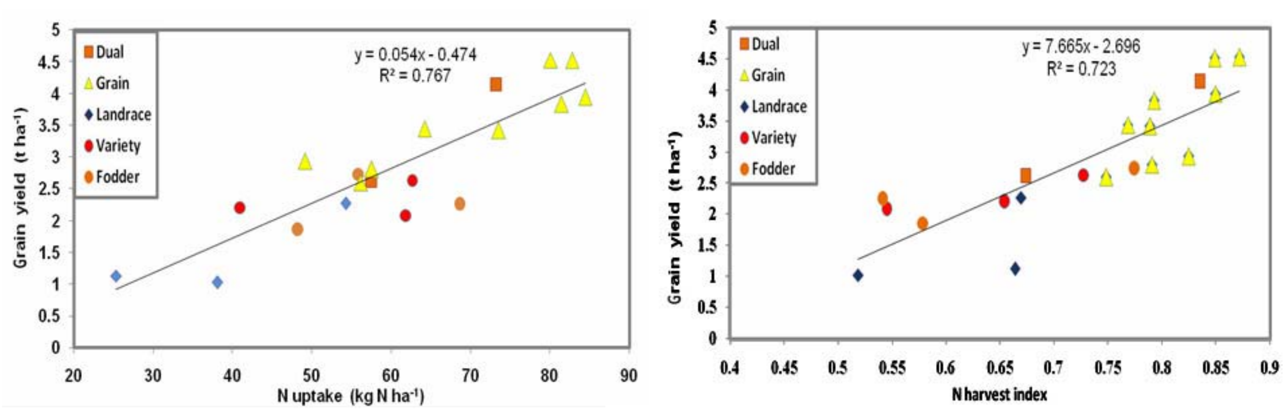

Figure 2. Grain yield relationship to N uptake and N harvest index for improved (dual, variety, grain, forage) and landrace cultivars of sweet sorghum.

landrace types. Across cultivars, HI and grain yield displayed negative relationships to plant height and crop duration (data not shown), with the relationship to plant height (r^2 = 0.64 and 0.62, respectively) much stronger compared to crop duration (r^2 = 0.36 and 0.34).

Grain yield and digestibility were highly negatively correlated (r = –0.78) while stover yield and digestibility were loosely positively (r = 0.30) correlated (Fig. 3). Among the high grain yielders (>3.0 t ha^{-1}) digestibility could be increased from 42 to 46%; increases beyond this to 50% would lower grain yield to below 2.5 t ha^{-1} while increase in digestibility by the same margin would have a slight increment on stover yield. Two India released variety (ICSV 700, ICSV 93046), two forage (GD 65195, B 24) and one dual (SPV 1411) type cultivars had higher digestibility compared to the landrace cultivars.

Water productivity. The trade-off between grain and stover WP across the 20 cultivars is summarized in Figure 4. Water productivity of the dual and grain cultivars generally cluster between 1.6 and 2.7 kg grain m^{-3} of rainfall and 1.2 and 2.6 kg stover m^{-3} of rainfall. In contrast, the forage, variety and landrace cultivars have distinctly lower grain WP (0.6 to 1.7 kg m^{-3}) compared to the grain and dual types but mostly an equivalent range of stover WP. Two cultivars, one fodder (B24) and one India released variety (ICSV 93046), were outside the general cluster range with quite high stover WP (4.0 and 3.5 kg m^{-3} respectively) but also low grain WP (1.4 and 1.3 kg m^{-3} respectively). At above 1.5 kg m^{-3} stover WP, one should choose mostly the grain types to increase grain WP to above 1.6 kg m^{-3}.

Table 2. Fodder quality traits of sweet sorghum cultivar groups.

Cultivar	Sugar (Brix %)	ME[1] (mj kg^{-1})	Digestibility (%)	Ash content (%)	Crude protein (g kg^{-1})
Landrace	16.4	7.6[2]	50.2	7.6	25.8
Forage	13.0	7.3[2]	48.7[2]	8.2	27.4
Grain	11.2	6.6	44.2	10.1	27.1
Dual	14.6	7.1	47.5	9.5	26.7
Variety	14.8	7.4	48.6	8.5	29.2
Mean	13.2	7.1	46.7	9.1	27.2
Significance (0.05)[3]	*	***	***	***	NS
SED	2.1	0.2	1.5	0.5	2.0
CV (%)	35.5	7.4	7.1	11.4	16.1

1. ME = Metabolizable energy.
2. Significant differences (P = <0.05) were observed within cultivar type for these parameters.
3. * = Significantly different between cultivar type at P = 0.05; and *** = P <0.001; NS = Not significantly different.

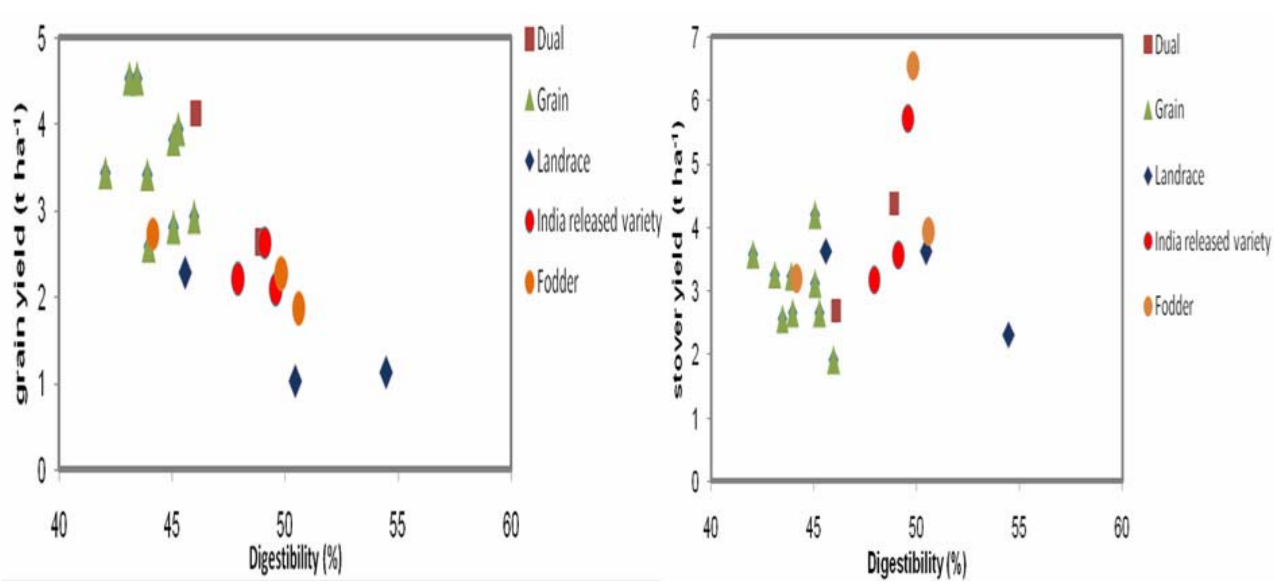

Figure 3. Relationship between grain yield and stover yield with digestibility of dry stover (stem + leaf material) for improved (dual, variety, grain, forage) and landrace cultivars of sweet sorghum.

Farmers' assessment. Only 7 of the 20 cultivars in the field study were included in the 60 choices made by farmers (Table 3). Women farmers displayed a clear preference for the grain cultivar types with 66% of their selections allocated to just two grain cultivars (S 35 and ICSR 93034). Overall, men selections also favored the grain/dual cultivar types but their selections were much less concentrated compared to the women farmers. In particular, it was found that four men farmers had a clear bias in allocating their preferences to the landrace and variety cultivar group (only one woman farmer displayed a similar bias), suggesting that for this sub-group of farmers, sweet sorghum would be mainly used as a feed source for their livestock production.

Discussions with the farmer groups about their preference selections resulted in a range of 'reasons' listed for each preference category (Table 4). This list is perhaps not exhaustive, but our analysis show that for men farmers, selection reasons related to grain yield (66% of total) dominated those related to stover yield (33%). For women farmers, reasons related to grain yield (45%) also dominated those related to stover yield (27%), but a third reason related to processing quality (28%) also emerged. Indirectly, this reason, which was explained in terms of 'less chaff during grain processing', would favor grain yield.

The seven cultivars selected by women and men farmers were also analyzed for grain and stover WP (Fig. 5). Here a more quantitative assessment of the farmer choices is possible. Figure 5 shows that the women farmers' selections were effectively favoring forage production over grain production, as stover WP of all three women cultivar selections are higher than the associated grain WP. For men, the WP analysis indicates an overall preference to grain production as two of the three selections have much higher grain WP than stover

Table 3. Preference allocation by men and women farmers for sweet sorghum cultivars.

		Men preferences			Women preferences		
Type	Cultivar	Best	Better	Good	Best	Better	Good
Landrace	IS 19674	3	2				1
Variety	SPV 422	1	2	4	1	5	1
Grain	S 35					4	6
	E 36-1	5	1			1	
	ICSR 93034			1	9		1
Dual	PVK 801	1	1	5			1
	SPV 1411		4				
Total count		10	10	10	10	10	10

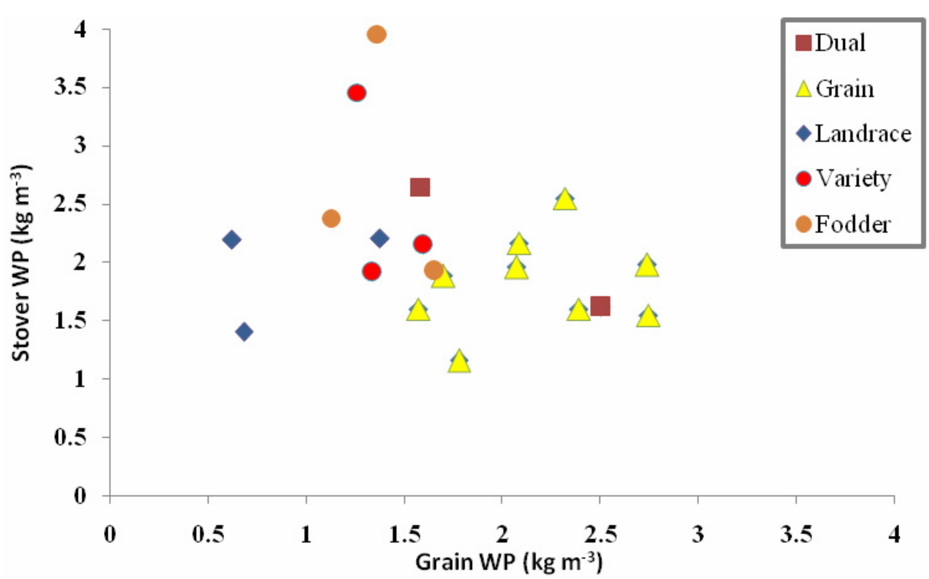

Figure 4. Relationship between grain and stover water productivity (WP) for improved (dual, variety, grain, forage) and landrace cultivars of sweet sorghum.

WP. What is most noteworthy in Figure 5 is that the best cultivar selection (a landrace) by the 'forage orientated' farmer sub-group identified above, ignored the two cultivars having the highest stover WP.

Discussion

This study screened five types of sweet sorghum cultivars (landraces and improved forage, variety, grain and dual types) to evaluate their suitability for increasing uptake and productivity in smallholder farming systems in the semi-arid regions of Zimbabwe. Three methods of assessment were applied to help identify suitable cultivars: stover and grain WP, feed quality traits and farmer assessment of cultivars in the field. Of the three, the farmer assessment results proved the most complicated to interpret.

Analysis of farmer preference rankings (Table 3) and results of farmer discussions (Table 4) both strongly pointed to grain yield being more important to farmers' needs than forage production, although it was also apparent from the ranking results that for a sub-set of farmers (25% of total) this preference was the reverse. However, analysis of farmer rankings here could be considered an artifact, since in the field, farmers did not make selections based on cultivar type, but rather by visually assessing the individual cultivars and responding to physical attributes such as the size of the plants, leaves, grains and heads, as reflected in the 'reasons' tabulated in Table 4. In combining the qualitative and quantitative data results (Fig. 5) a different preference set emerged. This indicated that the three cultivars selected by women farmers actually had higher forage production than grain production, whereas the men selections, overall, could be considered to have a bias towards grain production.

However, what is apparent in Figure 5 is a general clustering of grain and stover productivity amongst the cultivars selected by the farmers (between 1.3 and 2.7 kg m^{-3} of rainfall for both parameters) and the broad distribution of farmer selections within this cluster. It is also illustrative that even for the 'forage orientated' farmer sub-group identified from Table 3, their best cultivar selection did not include either of the two cultivars having the highest stover WP. Taken together, these results suggest that both forage and grain yield are important parameters to farmers operating crop-livestock production systems. This assessment adds support to arguments of Rattunde (1998) that breeding dual-purpose cultivars is the most appropriate strategy for targeting these farming systems.

The relationship between grain yield and fodder quality (Fig. 3) shows that as digestibility increases to about 50%, grain yield would decline while stover yield increases. This means that the farmers who prioritize livestock production would have to compromise on grain yield as they select cultivars with superior fodder quality traits. Information on the results of feed quality traits was not available at the time of farmer assessments. Here again, results of this study are in line with the observations of Rattunde (1998) that improved cultivars, particularly the grain types, have poorer quality stover compared to the lower grain-yielding landraces (Fig. 3). Five improved cultivars (2 variety – ICSV 700, ICSV 93046; 2 forage – GD 65195, B 24; and 1 dual – SPV 1411) did have stover quality comparable to the landraces, but only one of these, the dual cultivar, was included in the farmer selections. The other four, which included the two cultivars having the highest stover WP, had low grain WP ranging from 1.1 to 1.4 kg m^{-3} of rainfall. The apparent trade-off between grain yield

Table 4. Reasons of preferences of men and women farmer groups for the sweet sorghum cultivars.

Rank	Cultivar preferred by women	Reasons[1]	Cultivar preferred by men	Reasons[1]
1	ICSR 93034	– Large grain and head[a] – More tillers than other varieties[b] – Plant height is average, hence matures early[a] – Easier to process (less chaff)[c]	E36-1	– Large grain and head[a] – Shorter height, hence early maturing[a] – Leafy, hence good as livestock feed[b] – Many long roots and also thick stems[b]
2	SPV 422	– Easier to process (less chaff), hence less labor requirements[c] – Higher biomass yield[b] – Head size comparable to ICSR 93034[a]	SPV 1411	– Large grained[a] – Early maturing[a] – Leafy, hence good as livestock feed[b]
3	S 35	– Tillers a lot, hence more heads per plot[a,b] – Large grain and head[a] – Easier to process (less chaff)[c]	PVK 801	– Grain is good for human consumption[a] – Large grained[a]

1. Allocation of 'farmer reason' as factor related to: a = grain yield; b = stover yield; and c = processing.

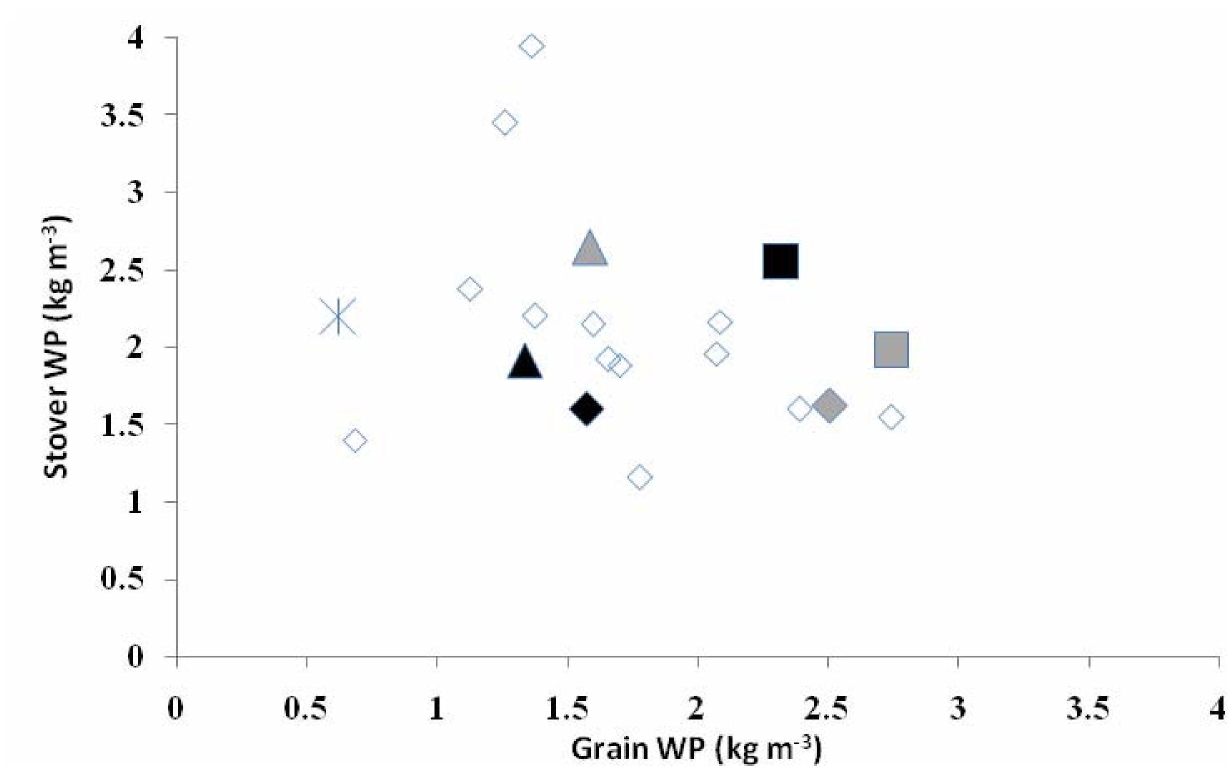

Figure 5. Farmer cultivar selections within the grain and stover water productivity (WP) relationship. [Note: Women (black) and men (gray) selections for best (■, ■), better (▲, ▲) and good (◆, ◆) based on highest cultivar count recorded in each category in Table 3; ✶ is the 'best' selection by 3 of the 4 men farmers with a bias towards forage production; ◇ indicates cultivars not selected by farmers.]

potential and stover feed quality is something that breeding programs will need to target in the quest for developing a wider range of dual-purpose cultivars.

For the high fertility and adequate moisture conditions of the field evaluation in this study, the grain cultivar types performed equally well as the dual types in terms of grain and stover yield. This result no doubt contributed to grain cultivar types (E36-1 and ICSR 93034) having been selected as the 'best' cultivars by both men and women farmers. The variety type also has shown to be better in respect to WP, fodder quality and farmers' preferences. Since yield differences between cultivars was strongly related to plant N uptake (Fig. 2) and farmers in the drier regions use limited fertility inputs (Twomlow et al. 2010), it is imperative to conduct further screening of the cultivars under low fertility and water stressed conditions. This is currently underway.

Conclusion

While interpretations of the farmer assessment of cultivars is somewhat limited by the small sample size (20) in this study, the analysis of their selection results provided an example of the difficulties and misleading conclusions that may result when only qualitative information is available and demonstrated the value of combining qualitative and quantitative screening results for analysis. Only the dual type cultivar, SPV 1411, performed well in terms of all three selection criteria used in the screening study, namely, high WP, better quality feed traits and farmer selection. Variation that exists in grain and stover yield, and fodder quality traits among and within sweet sorghum types means that selection for these traits is possible. It remains to be seen how the cultivars perform in trials conducted under fertility and moisture (ie, sandy soils) conditions more closely aligned to the conditions and management found in farmers' fields.

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References

Badve VC, Nisal PR, Joshi AL and **Rangnekar DV.** 1993. Pages 370–377 *in* Feeding of ruminants on fibrous crop residues. Proceedings of the International Workshop, National Dairy Research Institute, Karnal, Haryana, India, 4–8 Feb 1991 (Singh K and Schiere JB, eds.). India: Indo-Dutch Project on Bioconversion of Crop Residues.

Chapman SR and **Carter LP.** 1976. Crop production, principle and practices. Pages 1–12 *in* Sweet sorghum: A water saving bio-energy crop (Reddy BVS, Kumar AA and Ramesh S, eds.). Patancheru 502 324, Andhra Pradesh, India: ICRISAT; and Chatham, UK: Natural Resources Institute.

Elliot RC and **Fokersten K.** 1961. Seasonal changes in composition and yield of veld grass. Rhodesia Agricultural Journal 58:186–187.

Kijne JW, Barker R and **Molden D.** 2003. Water productivity in agriculture. Wallingford, UK: CAB International.

Lenné JM and **Thomas D.** 2005. Addressing poverty through crop-livestock integration: the contribution of past research to future challenges. Pages 13–26 *in* Integrating livestock-crop systems to meet the challenges of globalization (Rowlinson P, Wachirapakorn C, Pakdee P and Wanapat M, eds.). AHAT/BSAS International Conference, Nov 14–18, Khon Kaen, Thailand.

Mapiye C, Mwale M, Chikumba N, Poshiwa X, Mupangwa JF and **Mugabe PH.** 2006. A review of improved forages grasses in Zimbabwe. Tropical and Subtropical Agroecoststems 6:125–131.

Moyo M. 2001. Representative soil profiles of ICRISAT research sites. Chemistry and Soil Research Institute. Soils Report No. A666. Harare, Zimbabwe: AREX. 97 pp.

Rattunde HFW. 1998. Early-maturing dual-purpose sorghums: agronomic trait variations and covariation among landraces. Plant Breeding 177:33–36.

Reddy BVS, Hash CT, Stenhouse JW, Nigam SN, Singh L and **van Rheenen HA.** 1995. Crop improvement for livestock feed at ICRISAT Asia Centre. Pages 85–90 *in* Crop improvement and its impact on the feeding value of straw and stovers of grain cereals in India (Seetharam A, Subbarao A and Schiere JB, eds.). New Delhi, India: Indian Council of Agricultural Research; and Wageningen, The Netherlands: Department of Tropical Animal Production Agricultural University.

Shumba EM. 1984. Animals and the cropping systems in the communal areas of Zimbabwe. Zimbabwe Science News 18:99–102.

Sibanda A, Homann-Kee Tui S, Van Rooyen A, Dimes J, Nkomboni D and **Sisito G.** 2011. Understanding user communities' perception of changes in rangeland use and productivity: Evidence from Nkayi district, Zimbabwe. Experimental Agriculture, Volume 47 (S1), Cambridge University Press 2011 (DOI: 10.1017/S0014479710000943).

Twomlow S, Rohrbach D, Dimes J, Mupangwa W, Ncube B, Hove L, Moyo M, Mashingaidze N and **Maphosa P.** 2010. Micro-dosing as a pathway to Africa's Green Revolution: evidence from broad-scale on-farm trials. Nutrient Cycling in Agro-ecosystems, Special Edition (DOI: 10.1007/s10705-008-9200-4).