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Comparative productivity and drought response of semi-tropical hybrids and open-pollinated varieties of sorghum

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SUMMARY

While the relative advantage of hybrids over open-pollinated varieties has long been established for temperate sorghums in developed countries, similar information for semi-tropical sorghums used in Africa and India is relatively scant, especially under conditions of drought stress. This study compared 23 hybrids with 21 open-pollinated varieties, all developed in India and/or Southern Africa. Materials were field-tested under conditions of stored soil moisture at two levels of drought stress (dryland or one supplemental irrigation) at Bet Dagan, Israel in 1989.

Irrespective of the water regime, grain yield and harvest index increased and leaf area index decreased with a shorter growth duration of the genotypes. Hybrids were earlier, had a larger leaf area index, more than double the harvest index and produced more grain compared with varieties. In spite of their longer growth duration, varieties were less water-stressed than hybrids, as judged by their midday leaf water potential, relative water content and the extent of leaf rolling. The relatively poor plant water status of the hybrids could be partly ascribed to their larger leaf area index. Hybrids produced more biomass per day than varieties under low stress while varieties produced more biomass per day than hybrids under high stress. Thus, in terms of plant water status and mean daily biomass production, varieties were more drought resistant than hybrids. However, the physiological superiority of the varieties under drought stress did not result in a higher grain yield because of their inherent relatively poor harvest index, typical of the tall and late African sorghums. The superior physiological resistance to drought stress of these varieties could be translated into a yield advantage under drought stress if their potential harvest index is improved.

INTRODUCTION

An important factor in the genetic improvement of sorghum (*Sorghum bicolor* L. Moench.) to increase and stabilize its production in semi-tropical environments is the assessment of hybrids compared with open-pollinated varieties. The problem is most urgent in some developing countries, where the transition from open-pollinated varieties (henceforth referred to as 'varieties') to hybrid seed production and utilization can be hampered by certain technological, economic and social limitations. The comparative studies of hybrids and varieties which led to the rapid adoption of sorghum hybrids in developed countries were almost exclusively performed with temperate sorghum varieties, typical of materials adapted to the USA. This information is not necessarily relevant to the semi-tropical sorghum which is commonly grown in India and Africa and consists of different germplasm than that utilized in temperate regions. This material not only differs in genetic background but also in terms of the selected traits, such as plant phenology and height. Specific studies with this material are therefore warranted in order to establish the relative merit of hybrids for semi-tropical conditions.

Many considerations are involved in the decision to adopt hybrids rather than varieties in a developing country. This work did not attempt to address all the issues, but was done to investigate whether semi-tropical hybrids have an advantage over improved semi-tropical varieties under variable conditions of drought stress. This study was also stimulated by our recent findings that some improved semi-tropical varieties may yield as well as temperate hybrids (Blum *et al.* 1989), while heterosis in temperate sorghum hybrids may be ascribed to physiological stability in response to environmental stress (Blum *et al.* 1990)

Table 1. *Parentage, days to heading, plant height and dryland grain yield at Bet Dagan, Israel, of SADCC/ICRISAT sorghum hybrids. All hybrids were developed by the SADCC/ICRISAT programme at Zimbabwe and were based on female lines from ICRISAT (India) or Texas A&M University (USA) and selected male lines from India or Zimbabwe*

Entry	Parentage	Days to heading	Height (cm)	Grain yield (g/m^2)
SDSH 49	ICSA19 × LARSVYT19	56	115	268
SDSH 2	D2A × SDS~~22~~2688	57	125	241
SDSH 6	D2A × SDS2850	56	125	240
SDSH 8	D2A × SDS4261	60	140	239
SDSH 76	SPL177A × SDS2690-2	61	145	226
SDSH 38	ATX623 × SDS238	67	170	219
SDSH 5	D2A × SDS22-1	56	125	214
SDSH 48	ICSA12 × LARSVYT13	65	120	212
SDSH 73	D2A × SDS3223	55	115	196
SDSH 3	D2A × SDS3227	62	125	196
SDSH 4	D2A × SDS3880	67	170	193
SDSH 1	D2A × SDS22	56	135	188
SDSH 47	SPL109A × SDS238	75	155	183
SDSH 65	M70079A × SDS348	67	105	176
SDSH 51	ICSA37 × LARSVY161	64	115	168
SDSH 35	M70079A × SDS3423	71	115	159
SDSH 74	M40079A × SDS2271	71	125	148
SDSH 61	SPL23A × SDS260	71	105	148
SDSH 28	SPL10A × SDS3185	77	115	138
SDSH 42	SPL9A × SDS107	79	95	131
SDSH 43	SPL23A × SDS511	66	120	128
SDSH 59	SPL23A × SDS1835	65	120	116
SDSH 57	SPL9A × SDS1835	86	90	51

MATERIALS AND METHODS

Twenty-three hybrids and 21 open-pollinated varieties developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and in Zimbabwe (South African Development Coordination Conference Sorghum and Millet Improvement Programme, SADCC/ICRISAT) were tested. The experiment was performed at Bet Dagan (on the Coastal Plain of Israel) on deep and fertile chromoxerert with a high available K content and an excellent water holding capacity. Fertilizer was applied before sowing at a rate of 120 kg/ha of N and 100 kg/ha of P_2O_5. The experiment was planted on 3 April 1989 in a split-split plot design with 4 replicates (two varieties had only 3 replicates). Each plot consisted of three rows 5 m long spaced 0.9 m apart and planted to 20 seeds per metre of row. The main treatment consisted of two water regimes, supplemental irrigation and dryland, each divided into two groups of entries, hybrids and varieties. The dryland treatment consisted of crop growth on stored soil moisture only where drought stress progressed with the season. Total available soil moisture was 289 mm as determined gravimetrically to a depth of 180 cm at sowing. The irrigated treatment was sprinkler irrigated once at 35 days after emergence (DAE) at the rate of 100 mm. This irrigation was not sufficient to attain stress free conditions throughout the season and the two treatments were considered to represent two levels of drought stress.

Heading date (determined when 50% of the stems fully exserted panicles) and plant height to the base of the panicle were recorded in all plots. Leaf area index (LAI) was determined in each dryland plot at heading by linear measurements of all visible leaves in a row section 1 m in length. Single leaf area was calculated by multiplying its length by its width by 0 [illegible]. The extent of leaf rolling (0 = no rolling, [illegible] = extreme rolling) was visually scored in all dryland plots at [illegible] weekly intervals beginning at 36 DAE.

The following data were recorded in the middle row of all dryland plots of a random sample of five hybrids and five varieties at [illegible] weekly intervals beginning at 36 DAE (one day after supplemental irrigation was applied to the irrigated treatment). Midday canopy temperatures were recorded with a hand held infrared thermometer (model [illegible], Telatemp Corporation, Fullerton, California) [illegible] to view only the leaf canopy. The target area diameter was approximately 30 cm. The thermometer provided a measure of canopy temperature as well as the leaf to air temperature differential. Canopy temperature of each plot in a block was expressed as a percent of the mean canopy temperature of the block. Midday leaf water potential (LWP) was measured with a pressure chamber (custom-made as described by Blum *et al.* 1973) in four uppermost and fully expanded leaves per plot. At the same time one 2 × 4 cm section was cut from each leaf and placed in a stoppered vial. These samples were processed in the laboratory for the measurement of midday relative water content (RWC). Leaf sections were weighed and floated on deionized water for 3 h at 10 °C, after which their wet and dry weights were recorded. In the morning, four additional top fully expanded leaf laminae were sampled from each plot of both treatments and placed with their cut edge in water. They were then transferred to the laboratory and remained in water at 10 °C overnight in order to regain full turgor. A sample was then taken from the mid-section of each leaf (excluding the midrib) and frozen at −18 °C, after which samples were thawed and measured for their osmotic potential by the psychrometric method. The difference in osmotic potential at full turgor between the dryland and the supplemental irrigation treatment was taken as an estimate of osmotic adjustment under dryland conditions.

The central row of each plot was harvested. Panicles were counted, oven dried and weighed before and after threshing. Kernel weight was determined in grain samples from each row section. The remaining stover was harvested at the ground surface and a sample of *c.* 1 kg of each row section was oven dried at 85 °C for 48 h. Total above-ground biomass included the dry matter of stover and whole panicles. Harvest index was calculated as the proportion of grain in the total biomass.

RESULTS

The detailed information on dryland yield and phenology for all entries is presented in Tables 1 and 2. A comparative summary for hybrid and variety means is presented in Table 3. For most traits measured, main (water stress level) and secondary (group) effects were significant, while stress level by group interactions were not (except for grain yield). All following comparisons of 'hybrids' and 'varieties' refer to the means of each of the two groups.

Hybrids yielded more grain than varieties, though varieties produced significantly more biomass than hybrids, under both stress levels. Consequently, hybrids had more than double the harvest index of varieties. Hybrids tended to have a shorter growth duration than varieties. Overall, grain yields significantly increased with shorter growth duration across all genotypes under both stress levels (Fig. 1). The rate of increase in yield with shorter growth duration did not differ between hybrids and varieties but was greater under low stress than under high stress conditions. No simple correlation was found between days to heading and biomass, neither for hybrids ($r = 0{\cdot}16$) nor for varieties ($r = 0{\cdot}09$). At both stress levels, hybrids had a greater number of panicles per unit area and a greater number of kernels per panicle, as compared with varieties (Table 3). On the other hand, varieties had heavier kernels than hybrids under both treatments.

For any given trait, the value under high stress as a percentage of that under low stress expressed the rate of change as drought stress increased and may be considered as a simple expression of the relative drought resistance for the tested level of stress (Table 3). In this sense, varieties were more resistant than hybrids for plant height, biomass, grain yield, kernels per panicle and kernel weight. Hybrids were relatively more resistant for harvest index and number of panicles per unit area. However, while the yield of varieties tended to change less than the yield of hybrids when stress increased, hybrids still yielded more than varieties because of their higher absolute yields, which could be ascribed at least partly to their high harvest index and large panicles. The significant stress level by group interaction for grain yield (Table 3) was a result of the fact that four varieties (but none of the hybrids) had reduced yield when given supplemental irrigation. This could not be ascribed to lodging (which did not occur in the trial) nor to mineral deficiencies under the good fertility conditions of the trial. These varieties were also characterized by a reduction in harvest index with supplemental irrigation, contrary to the general trend for an increase in harvest index with supplemental irrigation (Table 3). A representative example is cv. E117 1, which under supplemental irrigation produced as much as 1321 g/m^2 biomass with a harvest index of only 0·07 (0·09 under dryland). Apparently, such varieties were inefficient, using the improved moisture conditions for the production of stover but not grain.

Leaf area index increased with days to heading in both hybrids and varieties (Fig. 2). The variation in LAI was greater among hybrids than among varieties. However at almost any given growth duration, LAI was appreciably higher in hybrids than in varieties. It was *c.* 3 in varieties and between 3 and 6 in hybrids. The rate of increase in LAI with longer growth duration was also greater in hybrids than in varieties.

Plant water stress under dryland conditions, as expressed by LWP and RWC, increased in both hybrids and varieties as the season progressed (Fig. 3). However, on most dates of measurement, mean LWP and mean RWC were significantly lower in hybrids than in varieties, indicating relatively greater water deficits in hybrids. Mean canopy temperature over all genotypes increased from 28·5 °C to 30·4 °C during the 4-weekly measurement dates in the dryland trial. These values corresponded with mean leaf-to-air temperature differentials of −3·1 °C to 2·7 °C, indi-

Table 2. *Parentage, days to heading, plant height and dryland grain yield at Bet Dagan, Israel, of ICRISAT varieties of sorghum. All materials originated at ICRISAT (India) as germplasm lines or cross-bred lines and were subsequently further selected in the SADCC/ICRISAT programme at Zimbabwe*

Entry	Source	Days to heading	Height (cm)	Grain yield (g/m²)
IS 18530-1	DR* germplasm line from ICRISAT India	67	235	226
IS 18530-2	DR germplasm line from ICRISAT India	66	230	198
IS22126	DR germplasm line from ICRISAT India	72	165	191
IS 2874-1	DR germplasm line from ICRISAT India	69	215	175
D 71396	DR line from ICRISAT India	79	225	173
SPV-138	Indian variety	88	175	159
E 117-1	DR line from ICRISAT India	80	260	128
IS 22343-1	DR germplasm line from ICRISAT India	83	200	128
IS 8564	DR germplasm line from ICRISAT India	70	165	89
E 1257	DR germplasm line from ICRISAT India	71	235	87
SPV 86	Indian variety	76	125	78
D 69707-2	DR line from ICRISAT India	91	105	64
F 1734-2	DR line from ICRISAT India	76	195	53
IS 10748	DR germplasm line from ICRISAT India	79	185	51
IS 1347-2	DR germplasm line from ICRISAT India	86	155	43
M35-1	Indian variety	88	165	40
IS 1347-1	DR germplasm line from ICRISAT India	86	175	30
IS 2871-2	DR germplasm line from ICRISAT India	91	130	17
IS 2871-1	DR germplasm line from ICRISAT India	91	105	15
D 69707-1	DR germplasm line from ICRISAT India	91	95	13
IS 22353-2	DR germplasm line from ICRISAT India	91	155	9

* Classified as being 'drought resistant', based on past field performance tests.

Table 3. *Mean phenology, productivity and yield components (± S.E.) for hybrids and varieties of sorghum subjected to two levels of drought stress (dryland, high stress; supplemental irrigation, low stress), at Bet Dagan, Israel, 1989*

	Low stress		High stress		Drought resistance index*			
	Hybrids	Varieties	Hybrids	Varieties	Hybrids	Varieties	Stress level effect†	Group effect†
Days to heading	61·9 ± 1·41	79·5 ± 2·02	64·9 ± 1·77	80·5 ± 1·85	104·8	101·3	1·19	86·4
Plant height (cm)	172 ± 6·4	212 ± 9·3	124 ± 4·3	176 ± 10·2	72·1	81·1	21·15	21·10
Biomass (g/m²)	1085 ± 40·9	1230 ± 74·0	753 ± 22·0	1019 ± 59·8	69·4	82·8	28·38	16·29
Grain yield (g/m²)	295 ± 16·0	124 ± 11·8	182 ± 10·4	94 ± 15·2	61·8	75·1	27·49	89·76
Harvest index	0·27 ± 0·010	0·13 ± 0·011	0·25 ± 0·013	0·09 ± 0·009	92·6	69·2	4·90	116·58
No. of panicles/m²	14·3 ± 0·48	10·5 ± 0·75	14·1 ± 0·66	8·4 ± 0·68	98·6	80·0	3·12	50·10
No. of kernels/panicle	970 ± 63·4	547 ± 41·3	735 ± 53·3	443 ± 63·2	75·8	81·0	9·06	40·06
Kernel weight (mg)	23·1 ± 0·56	24·5 ± 1·27	19·8 ± 0·45	23·7 ± 1·04	85·7	96·7	5·51	9·01

* Value at high stress expressed as a percentage of value at low stress.

† *F* ratio. Stress level by group interaction was significant ($P \leq 0{\cdot}05$) only for grain yield.

cating a general trend for an increase in plant water stress with time under dryland conditions. On each date of measurement, genotypes differed significantly ($P \leq 0{\cdot}05$) in canopy temperature. However, in spite of the difference in their leaf water status, the two groups did not differ in mean canopy temperature.

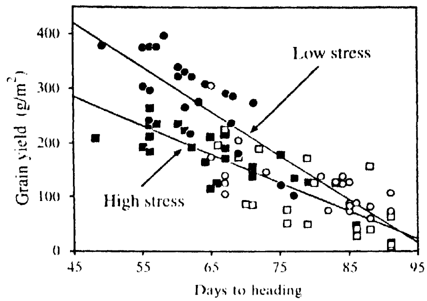

Fig. 1. The relationship between grain yield and days from emergence to heading for 23 hybrids and 21 varieties of sorghum subjected to high stress (dryland: hybrids, ■; varieties, □; $y = 521 - 5{\cdot}26x$, $r^2 = 0{\cdot}70$) and low stress (supplemental irrigation: hybrids, ●; varieties, ○; $y = 785 - 8{\cdot}11x$, $r^2 = 0{\cdot}76$).

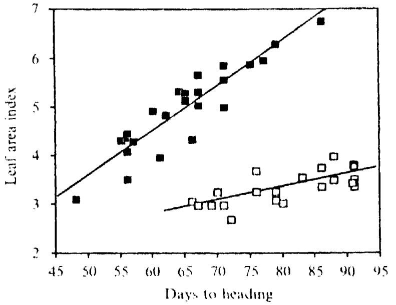

Fig. 2. The relationship between leaf area index at heading and days from emergence to heading for 23 hybrids, ■ ($y = -0{\cdot}93 + 0{\cdot}0091x$, $r^2 = 0{\cdot}84$) and 21 varieties, □ ($y = 1{\cdot}12 + 0{\cdot}0027$, $r^2 = 0{\cdot}53$) of sorghum, grown under the dryland treatment.

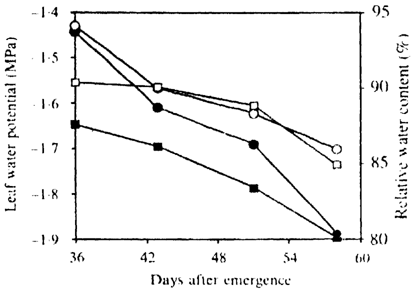

Fig. 3. Mean leaf water potential (LWP: hybrids, ■; varieties, □) and mean relative water content (RWC: hybrids, ●; varieties, ○) under the dryland treatment on five sampling dates. Except for data on the first date, differences between hybrid and variety means for RWC and LWP were significant at $P < 0{\cdot}05$.

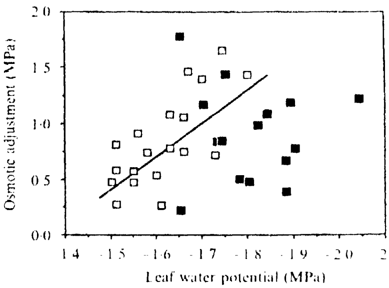

Fig. 4. The relationship between osmotic adjustment and leaf water potential for five varieties of sorghum over four sampling dates under dryland treatment, □ ($y = -4{\cdot}52 - 3{\cdot}326x$, $r^2 = 0{\cdot}50$). There was no such significant association for hybrids, ■.

expressed either as absolute values or as a percentage of the mean of the block (Table 4).

Although osmotic adjustment differed significantly among genotypes, varieties were not statistically different from hybrids (Table 4). However, in varieties, osmotic adjustment increased linearly with the reduction in LWP (Fig. 4). In some varieties and hybrids osmotic adjustment reached *c.* 1·5 MPa at

Table 4. *Comparison between hybrid and variety means* (± S.E.) *of sorghum grown at Bet Dagan, Israel, 1989, and the summary of the analysis of variance between the two groups for data on plant water relations in the dryland treatment. Data are means over all sampling dates*

Variable	Units	Hybrids	Varieties	*F* ratio
Mean canopy temperature	%*	99·9 ± 0·43	100·0 ± 0·51	0·002
Leaf rolling score	(0 5)	2·28 ± 0·28	1·5 ± 0·20	4·53
Leaf water potential (LWP)	MPa	−1.80 ± 0·031	−1·61 ± 0·019	19·6
Relative water content (RWC)	%	87·0 ± 0·88	89·5 ± 0·77	23·1
Osmotic adjustment	MPa	0·89 ± 0·046	0·77 ± 0·073	1·3

* As a percentage of the mean temperature of the block.

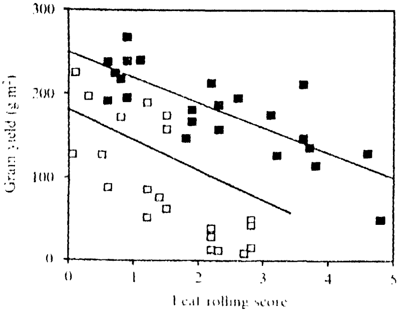

Fig. 5. The relationship between grain yield and mean leaf rolling score for 23 hybrids, ■ ($y = 249 - 30{\cdot}1x$, $r^2 = 0{\cdot}64$) and 21 varieties, □ ($y = 182 - 58{\cdot}6x$, $r^2 = 0{\cdot}60$) of sorghum, grown under the dryland treatment.

a LWP of *c.* − 1·7 MPa. While 50% of the pooled variation in osmotic adjustment among varieties and among dates of sampling within varieties could be explained by LWP, in hybrids practically none of the variation in osmotic adjustment could be attributed to LWP (Fig. 4). Osmotic adjustment was not correlated across genotypes with dryland biomass ($r = 0{\cdot}08$) or grain yield ($r = 0{\cdot}30$).

Leaf rolling was quite evident as moisture stress increased. On average, leaf rolling was greater in hybrids than in varieties (Table 4), which corresponded with the respective mean difference in plant water status between the two groups. However, leaf rolling could not be simply related to LWP, RWC or osmotic adjustment across all genotypes, though it was reasonably well related to grain yield under the dryland treatment (Fig. 5). An increase in leaf rolling appeared to indicate lower dryland yields in both hybrids and varieties. However, for the same rate of leaf rolling, hybrids yielded more than varieties, apparently as a function of the inherent difference in yielding ability between the two groups (Table 3).

A general linear model analysis of the effect of LWP, RWC and osmotic adjustment on dryland grain yield was performed separately for varieties and hybrids (not shown). No significant effects were revealed, indicating that there was no significant association between grain yield and plant water status of the genotypes under dryland conditions.

DISCUSSION

Rapid simple techniques for estimating genotypic variations in plant water status in sorghum nurseries are constantly being sought. Canopy temperature was found here to be of no value in predicting variations in plant water stress among sorghum genotypes. This supports our previous results for sorghum (Blum *et al.* 1989), but it is in contrast with results of others under different conditions of water stress and with genotypes that could have been less diverse in their canopy structure than those tested here (Chaudhuri *et al.* 1986).

Leaf rolling is an established symptom of wilting in cereals (Jones 1979) and delayed leaf rolling under drought stress is being used as one component of a selection index for drought resistance in rice (Chang *et al.* 1982) and sorghum (Rosenow *et al.* 1983). In a previous study, greater leaf rolling was indicative of reduced leaf water potential in different sorghum genotypes (Blum *et al.* 1989). This was not confirmed for the genotypes studied here, though reduced leaf rolling was associated with higher dryland yield within each of the two groups studied. More recent information for sorghum grown under harsh conditions indicates that the predictive value of leaf rolling as a symptom of water stress in variable genetic materials may depend on the conditions of stress. Flower *et al.* (1990) concluded that while drought resistant sorghum varieties had better osmotic adjustment and consequently less leaf rolling under stress as compared with susceptible varieties, these responses did not influence growth under very dry and hot conditions. Matthews *et al.* (1990*a*, *b*) found that two sorghum lines selected for better recovery after severe drought stress tended to manifest greater leaf rolling under stress as compared with two lines selected for poor recovery under stress. Their results suggest that leaf rolling during severe stress is conducive to plant regrowth upon recovery from stress. The conditions of drought stress in our study were completely different from those of Matthews *et al.* (1990*a*, *b*), who subjected plants to severe stress and measured its effect upon recovery after irrigation. In our study, sorghum developed as stress increased very gradually until harvest, without any recovery phase. Evidently, the implications of genotypic variation in leaf rolling vary with the type of drought stress, its severity and duration. Under relatively mild conditions of stress, delayed leaf rolling may be associated with sustained plant growth and production. However, under severe drought and heat stress conditions, greater leaf rolling may be associated with better chances for regrowth upon recovery.

Hybrids yielded more grain than varieties, irrespective of the water regime and despite being under greater plant water stress than the varieties. Hybrids produced a greater number of kernels per panicle as well as a larger number of panicles per unit area than varieties. This is a typical expression of hybrid vigour in sorghum (Arnon & Blum 1963). On average, hybrids and varieties also differed in phenology, LAI, biomass, harvest index and plant water status under drought stress.

Early heading allows better plant water status under conditions of stored soil moisture (Blum 1970; Blum *et al.* 1989). However, in this trial, hybrids were

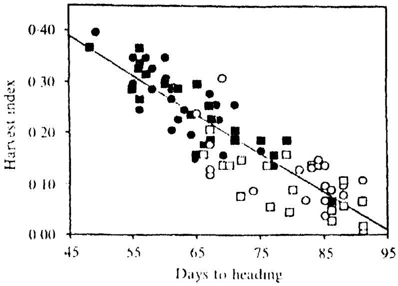

Fig. 6. The relationship between number of days from emergence to heading and harvest index across all genotypes under two moisture regimes ($y = 0{\cdot}731 - 0{\cdot}00076x$, $r^2 = 0{\cdot}78$). (High stress: hybrids, ■ and varieties, □; low stress: hybrids, ● and varieties, ○).

under greater plant water deficit despite their relatively earlier heading. Hybrids suffered a greater plant water stress most probably because of their relatively large leaf area, as compared with varieties. Under conditions of stored soil moisture and with the soil surface being dry and tilled, total canopy water use would be expected to be proportional to LAI during most of the growing season (Ritchie & Burnett 1971). The expected greater daily water use in hybrids as a function of their larger LAI should indeed decrease their leaf water status more than in varieties under these stored soil moisture conditions.

Despite their relatively smaller LAI, varieties produced more biomass than hybrids, either because of their relatively better plant water status and/or their longer growth duration. When biomass production was adjusted for growth duration, a significant ($P \leqslant 0{\cdot}05$) treatment by group interaction for biomass per day was revealed. With this interaction, hybrids had a better mean daily biomass production than varieties under supplemental irrigation (17·8 *v.* 15·7 g/m^2 per day respectively) while varieties had a better mean daily biomass production than hybrids under dryland conditions (12·9 *v.* 11·5 g/m^2 per day, respectively). This interaction therefore reflects the relatively greater drought resistance of the varieties and the greater potential productivity of the hybrids, in terms of biomass.

Varieties were very inefficient in partitioning biomass into grain, as compared with hybrids. Thus, hybrids yielded more grain than varieties under these stress conditions because of their larger harvest index and in spite of their relatively greater plant water deficit and lower total biomass production. Harvest index appeared to have a major effect on grain yield variation among genotypes in this experiment, where drought stress progressed with the season. While Fig. 1 indicates that the grain yield of different genotypes increased with shorter growth duration, Fig. 6 shows that harvest index was the main factor linked with growth duration. Harvest index improved with shorter growth duration, irrespective of the water regime or the biomass production of the genotype. Deficiencies in harvest index and assimilate partitioning to the panicle appear to characterize the tall and late endemic sorghums of Africa (Goldsworthy 1970; Willey & Basiime 1973) and these deficiencies seem to persist, at least partially, in most varieties studied here, irrespective of the water regime.

Osmotic adjustment has already been implicated as an important component of drought resistance in sorghum (Blum & Sullivan 1986). Recent work by Ludlow *et al.* (1990) with six sorghum hybrids clearly showed that maximum osmotic adjustment was positively associated with genotype yield under drought stress. In another study (Flower *et al.* 1990), sorghum lines defined as 'drought resistant' had a better capacity for osmotic adjustment than lines defined as 'susceptible', though the effect of this advantage on plant production could not be demonstrated under severe stress. In our study, genotypic LWP, RWC and osmotic adjustment could not be directly related to dryland grain yield or to biomass, at least partly because of the negative association between osmotic adjustment and LWP in the varieties and partly perhaps because of the large diversity among the genotypes in phenology, LAI and potential productivity. The dependence of osmotic adjustment on leaf water potential under field conditions has already been noted (Blum *et al.* 1989) and it poses a problem in deriving an understanding of the effect of plant water relations on sorghum production in field evaluations of diverse genetic material. Evidently, in such cases, the importance of osmotic adjustment as a component of drought resistance cannot be shown by a simple correlation with yield across genotypes. Such a correlation could perhaps be derived with relatively similar genotypes (Ludlow *et al.* 1990) in phenology, plant size and the various components of the plant water balance in the field.

In conclusion, the yield advantage of the semi-tropical sorghum hybrids over the semi-tropical sorghum varieties under different conditions of water supply is a function of the greater potential productivity of the hybrids resulting from hybrid vigour and in spite of their greater plant water deficit under drought stress. Certain components of this productivity, such as the large LAI, may constitute a disadvantage under more stressful conditions. While the varieties appeared to be more drought resistant than the hybrids, this advantage was not translated into grain yield, primarily because of the unimproved state of the varieties with respect to biomass partitioning into grain, typical of the tall and late African sorghums. Our results and those of others (Goldsworthy 1970; Willey & Basiime 1973) suggest that the improvement of harvest index in these varieties should