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# Dual Purpose Sorghum as Source for Food and Feed for the Semi Arid Tropics (project No C8-092)

Final Report to US-Israel Cooperative Development Agency for International Development

G. Asbell, Z. Weinberg and Yaira Hen, Forage Preservation and By-Products Research Unit, The Volcani Center, Bet Dagan, Israel

T. Kipnis, Department of Field Crops and Natural Resources, The Volcani Center, Bet Dagan, Israel.

Mr Xaba Brenton, Malkerns Experimental Station, Ministry of Agriculture, Malkerns, Swaziland.

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# CONSERVATION ASPECTS

G. Ashbell, Z. Weinberg and Yaira Hen, Forage Preservation and By-Products Research Unit, The Volcani Center, Bet Dagan, Israel

## INTRODUCTION

The overall aim of the project was to introduce and advance a farm scale production of sorghum for food (grains) and high quality livestock feed (green biomass) for the semi-arid tropics. One purpose was to find simple and inexpensive technologies for conservation of the crop residue (the biomass, after grain harvest). Forage crops are preserved either by drying, as hay, or by ensiling. The method of preservation depends on the structure, properties and composition of the plants, climatic conditions and technologies available in a certain area. It is impossible to make hay of sorghum biomass because of its structure. On the other hand, modern ensiling is a sophisticated process which requires large capital investment in silos and machinery. Such processing does not fit small farms in less developed countries. Therefore, our approach throughout this project was to develop simple conservation technologies which would suit small farms in LDC's, such as in Swaziland.

Chemical composition, fibre content and nutritional value may vary between and within different sorghum cultivars (Dickerson, 1986). Forage sorghum is usually ensiled at the late to soft dough stage of maturity, when plants are fully grwon and have a dry matter (DM) content of 27-30% (Black et al., 1980). Dickerson (1986) ensiled various sorghum cultivars with DM content between 24 and 42% and obtained well-preserved silages, with low pH values and high content of lactic acid. The lower end of the DM content might be somewhat too low for adequate lactic acid fermentation (Woolford, 1984). One possibility to improve the ensiling fermentation of moist crops is to add inoculants of lactic acid bacteria (LAB) at ensiling (Seale, 1986, Spoelstra, 1991, Weinberg et al., 1980). The benefits

attributed to inoculants are fast and intensive production of lactic acid, rapid decline in pH and stabilization of the silage.

Another alternative to preserve moist forage crops is by chemicals. Anhydrous ammonia is applied to feedstuffs for its antifungal effects and for its contribution to non-protein nitrogen (NPN) (Huber, 1980, Bothast et al., 1973). Gaseous ammonia is toxic, corrosive, unpleasant to handle, and special safety precautions must be taken. Therefore, urea which generates ammonia in plant materials by action of enzymes, (urease) and was reported to satabilize silages upon aerobic exposure (McDonald et al., 1991) is preferred.

Our laboratory was responsible for the conservation aspects of the sorghum biomass. The challenge was to develop simple, inexpensive methods of preservation that would suit small farms in LDC's. For that purpose we had first to study the chemical composition of the biomass of various sorghum cultivars which met the criteria set by Field Crops partner of the project (that is, would be drought-tolerant and have high nutritional value). The next step was to test conservation methods in small scale under laboratory conditions, and then to test the promising methods under farm conditions. The progress of this study and its recommendations are summarized in this final report. More details can be found in the annual reports.

## Summary of the Experiments

### Experiment 1 - July 1989 - June 1990

The initial stage of the project was devoted to study the chemical composition and microbiological status of the biomass of dual-purpose sorghum, and to test their ensiling properties. Experiments also dealt with the effect of irrigation regime on the chemical composition of the biomass of various dual-purpose sorghum cultivars, and the concomitant silages. The biomass of the following dual-purpose sorghum varieties was used: SDBP, 8320, Ntulired, 1594-1 and 6078. Table 1 gives the ranges of chemical parameters of the biomass of the sorghum varieties studied before ensiling. Irrigation regime did not have a consistent effect on the chemical composition of the biomass of the various sorghum varieties, and in future work this question must be determined specifically for each new variety which is being tested.

Table 2 gives range of ensiling parameters of laboratory silages. There was no special problem with ensiling of the biomass under laboratory conditions. Except for lactic acid, ethanol was the major volatile fermentation product, probably produced by yeasts. Other VFA (acetic, propionic acids) were in small concentrations (usually <0.5% in DM). Ensiling losses or losses during aerobic exposure were, in general, reasonable. Carbon dioxide produced during aerobic exposure for 5 days ranged from 0 to 17 g/kg DM), and aerobic DM losses from 0 to 11.5 percent.

The predominant microorganisms on the fresh crop were lactobacilli, yeasts and moulds (log number of colony-forming units per g DM were 0.6-7.7, 0- 8.3, and 6.6-8.5, respectively). After ensiling yeasts were the major spoilage oranisms (3.6-7.8).

### Experiment 2 - July - December 1990

This period was devoted to further study the ensiling characteristics of sorghum biomass under laboratory conditions, and

to test an alternative method of preservation, namely, moist hay. For that purppose, the biomass of sorghum cultivar X-981 was used. There were two kinds of biomass, according to their distance from the irrigation line: "dry" at 30% DM and "moist", at 25% DM.
The ensiling experiments of the two kinds of biomass included control, and lactic acid bacterial inoculum. Moist hay experiments included a control and urea application at 0.5, 1.0 and 2.0% urea.
Results indicate that the silages that were obtained were of good quality. The rate of pH decline is shown in Figures 1 and 2. The inoculant was more effective in the moist biomass. The inoculated silages of the dry biomass was less stable upon aerobic exposure, as indicated by rise in pH (from 3.7 to 4.5) Impairement of the aerobic stability of silages by LAB inoculants occur also in other dry cereal crops (Weinberg et al. 1993), and is explained by lack of VFA which prtect the silages from yeasts and moulds.
The moist hay of all treatments spoiled already during the initial 2 weeks of storage. The number of yeasts and moulds was very high (over $10^{11}$ cfu/g DM). The hay of the drier biomass treated with 2% urea was somewhat less spoiled after 2 weeks. Therefore, we decided to try this treatment in the following season.

Experiment 3 - January - December 1991

In 1991 we repeated the experiment with moist hay treated with 2% urea. The biomass of cultivar X-981 was at 28% (we could not obtain drier biomass), and the moist hay spoiled rapidly, as in the previous year's experiment. We concluded that this method of preservation is not fit for dual-purpose sorghum biomass.
In addition we performed a practical ensiling experiment which might fit small farms in LDC's such as Swaziland: 2.5-3.0 chopped biomass was weighed into double layer plastic bags. Twenty one bags were buried in a 70 cm deep trench dug in a field near our laboratory. The trench was covered with soil. Evert month three bags were removed from the trench for analysis.

The trench silages were of good quality; they had pleasant aroma, typical texture, and no signs of spoilage. The chemical and microbiological analyses of the trench silages are given in Tables 3 and 4, respectively. Young silages (stored for less than 2 months), were not stable upon aerobic exposure, while more mature silages (90 days and more) were more stable. This was indicated by the extent of rise in pH, intensity of $CO_2$ production, and increase in the numbers of yeasts and moulds.

Experiments 4,5 1992, 1993

The trench experiments were repeated in 1992 and 1993, with the biomass of forage sorghum cultivars X-981 and FS3, at dry matter contents of 36 and 30%, respectively.
The silage of 1992 was completely spoiled (moulded), even after the first month of storage. We hypothesized that the ensiling failure of this year was caused by the fact that the trench was too dry. Therefore, $CO_2$ production in the trench was limited, and air penetrated into the bags and spoiled the silage.
In 1993 we devided the trench into irrigated and non-irrigated parts. The irrigated part was watered once a week. Carbon dioxide levels were 0 and 3.1% in the dry and moist parts of the trench, repectively. Silages from both parts of the trench were of good qaullity. Analysis of these silages is given in Table 6. It seems that the dry matter content plays an important role in the quality of the trench sorghum silages. If the biomass is too dry, fermentation in the trench might be too slow, and allow spoilage processes to take place. Therefore, in planning ensiling by this method, the dry matter content should not exceed 30%. An inoculum might speed up the ensiling fermentation, but cause problems during aerobic exposure.

## Discussion and Recommendations

Within the framework of this project our laboratory worked on developing simple preservation methods for dual-purpose sorghum biomass that should fit small farms in Swaziland. After determination of chemical and microbiological composition of the biomass of various sorghum cultivars, we tested two conservation methods: ensiling and moist hay treated with urea. Moist hay spoiled rapidly regardless treatment with urea, or moisture content. It seems that this method is not suitable for such material, probably because the dry matter content was too low. Ensiling in a trench in plastic bags is a suitable method. This method of ensiling does not require capital investment, can be accomplished by workers without need of sophisticated expensive machinery, and enables the farmer to retrieve small silage quantities at a time to feed a small herd. The following points should be considered: The dry matter content of the biomass should not exceed 30-32%. The soil on top of the trench should be moistened, by rain or by irrigation, to ensure proper sealing of the silage. Addition of LAB inoculants is not recommended in this case, because it complicates the ensiling operation, and because of the risk of enhanced aerobic deterioration with such inoculants.

References

1.Black, J.R., Ely, L.O., McCullough, M.E. and Sudweeks, E.M. 1980
Effect of stage of maturity and silage additives upon the yield of gross and digestible energy in sorghum silage. J. of Animal Science 37:994-99

2.Bothast, R.J., Lancaster, E.B. and Hasseltine, C.W. 1973.
Ammonia kills spoilage molds in corn. J. of Dairy Science 56:241-246.

3.Dickerson, J.T. 1986
Yield, composition and nutritive value of forage sorghum silages; hybrid and stage of maturity effects. M.Sc. thesis, Kansas State University, KS, USA

4.Huber, J.T. 1980.
The use of ammonia in protein enrichment of feed by-products and animal wastes. In: **Upgrading Residues and By-Products for Animals.** ed. Huber, J.T., chapter 6, pp. 99-108, Boca Ranton, FL,CRC Press

5.McDonald, P., Henderson, A.R. and Heron, S.J.E. 1991
Microorganisms. In: **The Biochemistry of Silage,** 2nd edn., pp 81-152. Aberystwyth, UK. Chalcombe Publications.

6.Seale, D.R. 1986.
Bacterial inoculants as silage additives.J. of Applied Bacteriology **61** (Suppl) 9S-26S.

7.Spoelstra, S.F. 1991
Chemical and biological additives in forage conservation. In: **Proceedings of a Conference on Forage Conservation towards 2000.** eds. Pahlow, G. and Honig, H. Braunschweig, Germany, January 23-25. pp. 48-70.

8.Weinberg, Z.G., Ashbell, G. and Azrieli, A. 1988
The effect of applying lactic acid bacteria at ensilage on the chemical and microbiological composition of vetch, wheat and alfalfa silages. J. of Applied Bacteriology 64:1-7

9.Weinberg, Z.G., Ashbell, G., Hen, Y. and Azrieli, A. 1993.

The effect of applying lactic acid bacteria at ensiling on the aerobic stability of silages. Journal of Applied Bacteriology (in press)

10. Woolford, M.K. 1984
The chemistry of silage. In: The Silage Fermentation. pp. 89-91. Marcel Dekker, New York, NY, USA.

**General**

The project enabled our laboratory three visits to Swaziland, and one visit of Swazi researcher to visit our laboratory. The mutual visits were used for training the Swazi college in relevant methods, and to plan and perform laboratory and practical ensiling experiments in Swaziland.

In general, the project induced much work in our laboratory on preservation of forage sorghum which might become more important in Israel because of the water shortage. Research work in this area yielded the following international publications:

1. Ashbell, G., Weinberg, Z.G. and Kipnis, T. 1992.
Effect of biological additive, ammonia and irrigation with saline water on sorghum silage characteristics. South African Society of Animal Production, 31 Congress, Zithabiseni, Kwandebele, South Africa, April 13-16, p.N21

2. Meeske, R., Ashbell, G., Weinberg, Z.G. and Kipnis, T. 1993.
Ensiling forage sorghum at two stages of maturity with the addition of lactic acid bacterial inoculants. Animal Feed Science and Technology 43:165-175.

3. Ashbell, G. and Weinberg, Z.G. 1993.
The effect of applying ammonia to corn, wheat and sorghum upon ensilage. Canadian Agricultural Engineering 35:113-117.

4. Weinberg, Z.G., Ashbell, G., Hen, Y. and Azrieli, A. 1993.
The effect of applying lactic acid bacteria at ensiling on the aerobic stability of silages. Journal of Applied Bacteriology (in press)

Table 1. Chemical parameters of dual-purpose sorghum biomass

| Parameter | Lowest Value | Highest Value |
|---|---|---|
| Dry matter | 28 | 42 |
| pH | 5.2 | 6.0 |
| WSC | 13* | 27 |
| CP | 3 | 6 |
| Ash | 5 | 9 |
| NDF | 50 | 65 |
| ADF | 29 | 44 |
| ADL | 3 | 6 |

Data is given as percent in dry matter. WSC = water-soluble carbohydrates, CP = crude protein, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL = acid detergent lignin.

* One set of results of WSC was as low as 7.3% in DM, however, this was an unusually low value and not typical to sorghum biomass.

Table 2. Ensiling parameters of laboratory sorghum biomass silages

| Parameter | Lowest Value | Highest Value |
|---|---|---|
| pH | 3.6 | 4.6 |
| Residual WSC | 4 | 18 |
| Lactic acid | 2.5 | 11.3 |
| Ethanol | 0.7 | 5.6 |
| % DM ensiling losses | 0 | 16 |
| Lactobacilli | 5.7 | 8.0 |
| Yeasts | 2.8 | 7.8 |
| Moulds | NF | 2.6 |
| Enterobacteria | NF | 2.0 |
| Clostridial spores | NF | 3.9 |

Chemical data is given as percent in dry matter; microbiological data is given as log number of colony forming units per g DM.
WSC = water-soluble carbohydrates, NF = not found.

# Dual Purpose Sorghum as Source for Food and Feed for the Semi Arid Tropics (project No CB-092)

Report to US-Israel Cooperative Development Agency for International Development

Report period: 1992/1993

G. Asbell, Z. Weinberg and Yaira Hen, Forage Preservation and By-Products Research Unit, The Volcani Center, Bet Dagan, Israel

## Introduction

In 1992 a practical ensiling experiment was repeated, similar to an experiment performed in 1991. The biomass of sorghum cultivar X-981 at 36% DM was chopped and filled into double-layer plastic bags which were buried in a trench, about 70 cm deep. Treatnemts included control and inoculated forage (with $10^{5}$ cfu/g of Medipharm USA containing **Lactobacillus plantarum**, **Pediococcus** spp. and **Enterococcus faecium**). All bags were completely moulded already after 2 months of ensiling, with pH values of 7.4 and 4.8, for the control and inoculated silages. The silages were unsuitable for feeding, and after 5 days of exposure to air the pH was above 8.0 for both the control and inoculated silages. The numbers of yeasts and mould were very high ($>10^{7}$ cfg/g DM). This result was completely differnt from the results obtained in a similar experiment in 1991, with the same sorghum cultivar at 28% DM. Then the silages stored in the trench were of good qaulity. Our hypothesis for the failure of the experiment in 1992 was that the soil where the bags were buried was too dry. This resulted in no $CO_2$ production in the trench (which could serve as a preservative), and allowed air to penetrate.
The purpose of the experiment in 1993 was to test this hypothesis, and to test again the possibility to ensile forage crops in a simple method which would suit African farms.

## Experimental

The biomass of forage sorghum cultivar FS5 (Dekalb, USA) at 30% DM was ensiled in 6 plastic bags which were buried a trench as described above. Each bag contained 3 kg chopped sorghum biomass. Half of the trench was irrigated at least once a week for the entire period of storage, while the other part of the trench was left dry (there is no rain in Israel in summer). $CO_2$ levels in the differnt parts of the trench were measured with a gas analyser. After 2 months of ensiling the bags were removed from the trench, weighed and analysed. Analysis included the determination of DM content, pH, LAB, yeasts and moulds.

## Results and Discussion

$CO_2$ levels in the dry and moist parts of the trench were 0 and 3.1% respectively. Results of the silage analysis are given in Table 1. In general, the silages from both parts of the trench were of good quality, with the silage form the bags buried in the irrigated part were somewhat better.

The hypothesis which relates preseving properties to $CO_2$ levels in the irrigated trench was only partially proven. Probably, irrigated soil is less cracked and better sealed than dry soil. Therefore, the silages from the moist part of the trench were of better quality. However, this does not explain the different results among the experiments of 1991, 1992 and 1993. It seems that dry matter content plays an important role in the ensiling properties of sorghum biomass. If the biomass is too dry, fermentation in the trench might be too slow and allow spoilage processes to take place. This might have been the case in 1992 (36% DM, as compared with <30% DM of the biomass in 1991 and 1993). Lactic acid bacteria inoculum might speed up the ensiling fermentation, but as shown in previous reports and elsewhere, might impaire the aerobic stability of the silages.

Table 1. Analysis of the trench silages of sorghum FSS biomass

| | irrigated | non-irrigated |
|---|---|---|
| Perent DM | 27.2±0.4 | 26.1±0.7 |
| Percent DM loss | 11.7±1.0 | 15.1±2.5 |
| pH | 3.9 | 3.8 |
| LAB* | 8.6 | 8.4 |
| Yeasts | 8.4 | 8.2 |
| Moulds | 6.3 | 7.1 |
| Visual impression | good quality good smell | fair, some mould close to top of bags, suitable for feeding |

* LAB = lactobacilli. Microbiological data are given as log number of colony-forming units per g DM.

# Assessment of genotypic variation for dry matter production Under decreasing water supply in dual purpose sorghum

T. Kipnis, I. Korman
Levana Dabush, G. Crivat, I. Granoth and J. Rafi
Department of Natural Resources
Agricultural Research Organization

## INTRODUCTION

There is much detailed information on the response of sorghum to drought conditions. Most of the literature focuses attention on grain production and as a result little attention has been paid to the distrubution of the dry matter yield in the vegetative parts of the plant which affects the value of the crop as feed for ruminants.

This program deals with dual purpose sorghum where grain is produced for human consumption either as a source of carbohydrate or as a substrate for fermentation in the brewing industry, and the remaining canopy (stover) is used as animal feed. We presume that stover yield and quality of a dual purpose crop is as important as the grain. Selection of drought resistant sorghum cultivars is a crucial issue in this crop which is widely grown under drought stress conditions. Sorghum genotypes differ in yield under drought stress or in the rate of reduction in yield from non-stress to stress condition (e.g. Seetharama et al. 1982, 1983). Furthermore, the genetic variation for drought resistance depend on the mechanism involved (Blum et al. 1989). Decision on the proper selection criteria is not simple, and it is probably even more complicated to select sorghum with dual purpose triats than to select for either single purpose crop such as grain or forage sorghum

In this report we present results of the first field trial in the research program. This report covers the period from June to December 1989 and includes results of agronomical relevance. Other results, especially those concerning the quality of the stover will be presented in future reports.

## MATERIALS AND METHODS

A field experiment is being conducted on the central farm of the Agricultural Research Organization at Bet Dagan. the previous crop was wheat, grown under irrigation in the summer, followed by winter fallow. The soil type is a deep and fertile Vertisol.

The field was fertilized with 500, 400 and 400 kg $ha^{-1}$ of ammonioum sulphate, superphosphate and potassiun chloride respectively. Atrazin was applied twice at a rate of 700 and 900 g $ha^{-1}$ in winter and spring respectively.

Sorghum was sown into wet soil on April 6, 1989. Gravimetric soil water measurements on the day of planting showed that the available soil water to a depth of 180 cm. amounted to 240 mm. No rainfall occurred from planting date onward, and the field was supplied with two light irrigations to assist germination. Fifteen cultivars were included in the experiment. Twelve of them were received from SADCC ICRISAT and they are thought to be among the best cultivars adapted to the region of South Africa. Two cultivars were received from Pioneer Hi-Breed, in Texas, U.S.A. and one was a dwarf drought resistant Israeli grain sorghum cultivar.

The African cultivars were: SDS 1513, SDS 1594-1, SDS 1710-1, SDS 2293-1,SDS 2293-6, SDS 2298, SDS 3168-3, Framida, Ntulired, Red Swazi, SDBP and Town. The American cultivars were P 8319 and P 8320. The Israeli cultivar was Hazerah 226.

The response to soil moisture content was studied with a line-source irrigation system. The seed was sown perpendicular to the line source in rows, 1 meter apart. Seedlings were thinned to 15 per meter. The experimental plots consists of two rows, 12 meter long, replicated three times. Each plot was divided into six, two meter long subplots. Irrigation commenced 45 days after sowing and the amount of water received by the subplots was measured by sets of rain gages installed every two meters in two of the plots. Water was applied late at night when wind velocity was low. Water was sprinkled above the canopy six

times at weekly intervals , and the amount of water applied was calculated so that the rain gages closest to the line source would receive 100% of the evaporation from a class A pan situated in vicinity.

The African and American cultivars appeared to be sensitive to bird damage. To prevent loss of grain yield, heads were covered with paper bags. An attempt was made to bag as many heads as possible, but this could not be accomplished with all cultivars. When bagging was possible all heads in a plot were bagged. Heads in one row of each cultivar were left unprotected in order to evaluate bird damage.

Seven cultivars were selected for complete harvest and analyses. They were selected according the development of the canopy and the appearance of the heads, and included both white and red grain cultivars. In the remaining eight cultivars bagging was performed on sample plants in each subplot so that distribution of the dry matter in the canopy could be measured and their quality traits could be analysed.

All the plants in each subplot were cut and weighed. Three plants in each subplot were sampled for canopy structure measurements. The sample plants were divided into 4 fractions: green leaf blade (GL), yellow leaf blade, (YL) stem+leaf sheath (ST) and heads (HD). A sample of all above ground canopy was used for dry matter determination. The samples were oven dried at 60C.

## RESULTS AND DISCUSSION

### Water availability

The amount and monthly distribution of rainfall in Lowveld and Middleveld regions of Swaziland are presented in Fig. 1. The growing season depends on water availability. It may generally start in November and finishes in late March. In the middleveld average fainfall during the growing season amounts to 550mm, whereas in the Lowveld it is 300mm. The growth of sorghum in the Lowveld seems to be under continuous-mild drought stress. If one assumes that the potential evapotranspiration for optimal growth of sorghum is approximately, 500mm, the distribution of rainfall over the season in the Lowveld indicates that it is unlikely that severe water stress will develop at critical stage for grain production.

The distribution and the amounts of the irrigation water supplied through the Line Source (LS) sprinkler system are presented in Figs 2 and 3. During the first five irrigations, water distribution was nearly equal in plots on both sides of the line. High wind velocity during the last irrigation impaired water distribution and this is evident in the total amount of water supplied. Of the water applied, maximum amounts were measured by the rain gages, placed two meters from the line. At this position, 660mm were available for plant growth, 420 mm of this, were supplied by irrigation and 240 mm were available as stored soil water. The distribution figures indicate that the plants in subplots at a distance of 10-12 m from the LS were grown solely on stored soil water. It should be noted that the amout of water available for sorghum growth in the Middleveld and Lowveld in Swaziland ccorrespond well to the range of water availability in our field trial.

### Agronomical aspects and dry matter yield

Some of the agronomic traits of five African, one American and one Israeli cultivar are presented in Table 1. Water gradient did not affect the number of days to heading and therefore data for different

cultivars are presented as the mean for all subplots. SDBP was the earliest among the African cultivars. this might be an advantage under conditions of water shortage, provided that number of heads produced under stress, relative to the number produced under non stress conditions is not lower than that of a drought resistant cultivar like Hazerah 226. SDBP surpassed all the African varieties in the number of heads produced under non stress conditions. Furthermore, in this cultivar head numbers showed greatest stability over all water levels. In comparision, P 8320 also showed excellent stability but produced fewer heads. Under non stress conditions the number of heads exserted by Ntulired was only slightly smaller than that of SDBP, however it was the most sensitive to progressive water stress.

Plant height of all cultivars was affected by water availability. In most of them height reduction was obvious only 6 m and further from the LS. There is considerable variability amongst the cultivars with regard to bird damage. Ntulired, SDBP and P 8320 suffered least damage.

Data for total dry matter production and for stover and heads yield under extreme water level treatments is presented in Table 2. No significant differences between cultivars were found in total DM yield at 2 m from the LS because of a large experimental error. At 12 m from the LS, the drought resistant Hazerah 226 yielded significantly more DM than most of the tall cultivars. The Israeli and the American cultivars were less sensitive to progressive water stress than african cultivars. At 12 m from the LS yields of Hazerah 226 and P 8320 were 8.7 and 31.4% lower than at 2 m. The reduction in total yield of African cultivars was considerably greater. Since the water gradient in the LS experimental design is not randomly distributed, the data for relative yield reduction cannot be analyzed statistically.

In contrast to total DM yield, significant differences in stover and head DM yield were found between the cultivars. SDS 1594-1 and SDS 2293-1 were harvested without heads due to very severe bird damage caused by insufficient bagging. SDS 2293-1 surpassed all other varieties in its stover yield, but is was also the most sensitive to

drought. The genetic variability between cultivars is expressed in the relative sensitivity of stover and head production to drought. Under moisture stress conditions relative yield reduction in Hazerah 226 is due to decreased head production, whereas in P 8320 it is low stover yields rather than diminished head yields that contribute to total yield reduction. Relative reduction of total yield is around 50% in both Framida and SDBP. However in Framida, head production is more sensitive and stover production is less sensitive to moisture stress than in SDBP. The advantage of SDBP explained by its higher head yield in both stress and non stress conditions.

Comparable agronomic attributes and stover DM yield of the other eight African cultivars appear in Table 3. Two of the cultivars deserve further attention. They are: a) Red Swazi for its high head number and stability (except at 12 m from LS), its high stover yield and its earliness. b) SDS 1513 for its head number stability over all water levels.

Water production functions

The linear regressions fitted to head and stover DM yield data as a function of total water are presented in fig 4 and 5. Total water applied and not evapotranspiration was taken as the basis for the water production function. Soil water content for each cultivar over all the water gradient subplots could not be measured on the day of harvest. Consequently we are unable to calculate the actual water requirement. Based on a number of gravimetric measurements of soil water content it seems likely that the difference between total water applied and total evapotranspiration varies in the range of 0-120 mm.

Analysis of water production function for head DM yield indicates that differences between the intercepts of the regressions are responsible more than differences in the slopes or the overall response of the cultivars to a reduction in water supply. Among the African cultivars, highest stability in head yield overall water levels was found in SDBP. In contrast, there were significant differences between the slopes of the stover production functions (fig. 5). Two cultivars,

SDS 2293-1 and Ntulired were highly sensitive to drought where as SDBP was less sensitive in stover production by a factor of approximately 2.

Water use efficiency

The water use efficiency (WUE), i,e, D.M. production of heads and stover as a function of total water applied is illustrated in Fig. 6. The values given for stover production are higher than is known for many forage crops. In most cases there was an increase in WUE with the decrease of water availability to the plants. This indicates that the water stress which gradually developed, especially at distances of 10-12 m from the LS, was only light, and the amount of stored soil water (240 mm) was not low enough to bring about severe stress which could adversely affect stomatal apperture, photosynthesis, growth and thus WUE. Fig. 6 distinguishes between distinct WUE for head production from that of the stover. Except for the dwarf grain type Hazerah 226, the WUE of the stover was higher than that of the heads. Head WUE in Framida and Ntulired was very low, and decreased slightly with decreasing water availability. Among the non dwarf cultivars the highest increase in head WUE as a function of the distance from the LS was found in SDBP. Furthermore, it was the most stable cultivar as the difference between WUE of the stover and the heads remained constant whereas in all other cultivars this difference increased along the water gradient.

Stability and adaptability in sorghum to decreasing water supply

To assess the performance of sorghum cultivars over a range of available water content a technique suggested by Finlay and Wilkinson (1963), Eberhard and Russel (1966) and Samuel at al., 1970 was used. For each cultivar a linear regression of the individual yield (y-axis) on the mean yields of all cultivars for each available water content (x-axis) is computed. The mean yields provides a numerical grading and was suggested a useful evaluation of the environment. This will be referred hereafter as the "environmental index". In fig. 7 the regressions for 7 sorghum cultivars are presented together with a line which represents the population mean (mean of all cultivar yields and

available water contents). cultivars characterized by a regression coefficient (b) of the order of 1 have an average stability over all conditions of water availability tested. Cultivars with regression coefficient lower than 1 have above average stability whereas varieties with coefficients higher than 1 are very sensitive to changes in the environment (water availability). Hazerah 226 (b= 0.159) is the most stable cultivar and SDS 2293-1 (b= 2.164) is the most sesitive one. SDBP with a regression coefficient of 0.953 represent nearly average stability over all conditions of water supply. The regression line of SDS 2293-1 intersect the population mean line at an environmental index of 2.1 kg/m. This indicate that the cultivar is specifically adapted to high yielding environment i.e. high levels of water supply at which mean DM yields higher than 2.1 kg/m can be achieved. On the other hand it performs very poor at low levels of water supply. Hazerah 226 represent the opposite characteristics. It posseses very good stability over a range of water supply while producing above average yields, indicating good adaption to low yielding environment.

A further analysis of the behaviour of all the cultivars tested in this trial is illustrated in Fig. 8. The regression coefficients calculated for each cultivar and shown in Fig. 7 were plotted against the environmental index (mean DM yields of all cultivars obtained under the various levels of water supply). Each plot is represented by a single point which indicate the association between the level of stability and the average yield performance of each cultivar. The vertical and horizontal broken lines in Fig. 8 represent the population mean yield and the average stability respectively. Hazerah 226, Ntulired and SDS 2293-1 have above average DM yield, but the two african cultivars have greater sensitivity to environmental change and are adapted only to growing conditions with high level of water supply. Hazerah 226 is a typical drought resistant grain sorghum. It produces relatively high yields and shows greatest stability over the range of water conditions, however, it cannot be considered good dual purpose cultivar because of its relatively low stover yield (Table 2). Although P 8320 and SDS 1594-1 posseses above average stability their average yields were the lowest. Framida and SDBP are the two cultivars falling closet to the average stability and population mean yield ( the intersection of the

broken lines). Framida is superior to SDBP in total yield and stability but it produces fewer heads under both favorable and unfavorable water supply (tables 1,2). An important result is that the variability between cultivars in yield stability is inversely proportional to their mean yield over all the water supply levels. Except for Hazerah 226, the tall cultivars which give the highest mean yields also possess below average stability, i.e. they can be regarded as drought susceptible cultivars and vise versa. It should be noted that early varieties (based on days to heading) tend to be adapted to unfavorable soil water conditions whereas the late varieties tend to be specifically adapted to non stress water regime as they only yield well under those growing conditions.

Canopy Structure

Fig. 9 shows the relative distribution of dry matter in the canopy. Assuming that grain production is the primary objective or at least of equal importance as stover production, then a cultivar with a mean harvest index (based on head weight) of 50% is superior to a more vegetative cultivar. Among the dual purpose entries, P8320 and SDBP possess the highest mean harvest index, of the two, SDBP is less sensitive to changes in water supply. Another important feature of a dual purpose type of sorghum is the "stay green ability". Fig. 10 shows the relative yields of green leaves and heads as a function of change in water supply. In general the relative weight of green leaves was found to be inversely proportional to the relative weight of heads. This was particularly evident at distances of 6 to 12 m from the LS. and amongst cultivars which were highly sensitive to unfavorable water conditions in the number of heads produced and head weights. Canopy structure should have a significant affect on the quality of the stover, and this will be taken into consideration in later stages of the research. At this stage, SDBP appears to be promising cultivar for the environmental conditions in Swaziland.

References

Blum, A., Mayer, J. and Golan, J. 1989. Agronomic and physiological assessments of genotypic variation for drought resistance in sorghum. Aust. J. Agric. Res. 40: 49-61.

Eberhart, S.A. and Russell, W.A. 1966. Stability parameters for comparing varieties. Crop Sci. 6: 36-40.

Finlay, K.W. and Wilkinson, G.N. 1963. The analysis of adaption in a plant breeding program. aust. J. Agric. Res. 14: 742-754.

Mkhatshwa, P.D. 1988. The present status and future strategy on improvement and utilization of sorghum and millets as feed and forage in Swaziland. Proc. of the forth regional workshop or sorghum and millets for Southern Africa. pp. 88-98 (SADCC/ICRISAT).

Seetharama, N., Subba Redy, B.V., Peacock, J.M. and Bininger, F.R. 1982. Sorghum improvement for drought resistance. In" Drought resistance in crops with emphasis on rice" pp. 317-338. (IRRI: :Los Banas, Philippines).

Seetherama, N., Sivakumar, M.V.K., Bidinger, F.R., Sardar Singh, Maiti, R.K., Reddy, B.V.S., Peacock, J.M. Reddy,S.J., Mahalakshmi, V., Sachrn, R.C., Shiv Raj, A., Murthy, S.R.K., Narayanan, A., Tissa Kannangara, Durley, R.C. and Simpson, G.M. 1983. Physiological basis for increasing and stabilising yield under drought in sorghum. Proc. Indian Natn. sci. Acad. B 49 No. 5 pp. 498-523.

Table 1. Effect of water availability (distance from LS) on agronomic variables of sorghum cultivars.

| DISTANCE (m) * | HEAD EXSERTION (d.a.e.) # | HARVEST (d.a.e.) | HEAD No. (per m) | HEIGHT (cm) | GRAIN MOISTURE (%) & | BIRD DAMAGE (%) & |
|---|---|---|---|---|---|---|
| | | | CV: HAZERAH 226 | | | |
| 2 | 56 | 115 | 18.1±0.7 | 122.5±2.5 | 11.8 | 0 |
| 4 | " | " | 15.9±1.4 | 120.0±5.0 | " | " |
| 6 | " | " | 18.1±1.2 | 115.0±0.0 | " | " |
| 8 | " | " | 16.3±1.3 | 107.5±2.5 | " | " |
| 10 | " | " | 15.5±0.4 | 100.0±0.0 | " | " |
| 12 | " | " | 15.5±0.7 | 90.0±0.0 | " | " |
| | | | CV: SDS 1594-1 | | | |
| 2 | 99 | 134 | 9.8±1.3 | 270.0±0.0 | 16.0 | 100 |
| 4 | " | " | 9.1±1.9 | 265.0±5.0 | " | " |
| 6 | " | " | 8.2±1.2 | 220.0±0.0 | " | " |
| 8 | " | " | 7.0±0.9 | 175.0±5.0 | " | " |
| 10 | " | " | 6.3±1.1 | 150.0±0.0 | " | " |
| 12 | " | " | 5.4±0.6 | 150.0±0.0 | " | " |
| | | | CV: P 8320 | | | |
| 2 | 84 | 128 | 9.2±0.7 | 237.5±2.5 | 15.0 | 35 |
| 4 | " | " | 8.9±1.1 | 235.0±5.0 | " | 35 |
| 6 | " | " | 9.1±0.7 | 225.0±5.0 | " | 30 |
| 8 | " | " | 9.8±0.2 | 187.5±7.5 | " | 30 |
| 10 | " | " | 11.±0.5 | 150.0±10.0 | " | 25 |
| 12 | " | " | 7.5±0.4 | 150.0±40.0 | " | 20 |
| | | | CV: NTULIRED | | | |
| 2 | 95 | 130 | 12.8±1.3 | 410.0±0.0 | 15.0 | 25 |
| 4 | " | " | 10.4±2.4 | 415.0±5.0 | " | " |
| 6 | " | " | 9.1±0.2 | 360.0±20.0 | " | " |
| 8 | " | " | 4.2±1.2 | 252.5±22.5 | " | " |
| 10 | " | " | 0.8±0.3 | 195.0±15.0 | " | " |
| 12 | " | " | 0.0±0.0 | 170.0±7.5 | " | " |

* distance from line source
\# days after emergence to 50 % head exsertion
$ days after emergence
& cultivar mean on the day of harvest

Table 1. (continued)

| DISTANCE (m) | HEAD EXSERTION (d.a.e.) | HARVEST (d.a.e.) | HEAD No. (per m) | HEIGHT (cm) | GRAIN MOISTURE (%) | BIRD DAMAGE (%) |
|---|---|---|---|---|---|---|
| | | | CV: FRAMIDA | | | |
| 2 | 77 | 120 | 5.3±0.3 | 275.0±5.0 | 16.0 | 70 |
| 4 | " | " | 6.3±0.3 | 270.0±10.0 | " | " |
| 6 | " | " | 6.5±0.0 | 230.0±10.0 | " | " |
| 8 | " | " | 7.6±3.1 | 197.5±22.5 | " | " |
| 10 | " | " | 8.2±0.6 | 170.0±10.0 | " | " |
| 12 | " | " | 4.5±0.5 | 160.0±0.0 | " | " |
| | | | CV: SDBP | | | |
| 2 | 63 | 120 | 14.8±0.8 | 315.0±5.0 | 9.7 | 35 |
| 4 | " | " | 12.5±0.5 | 285.0±5.0 | " | " |
| 6 | " | " | 13.3±1.3 | 280.0±0.0 | " | " |
| 8 | " | " | 13.4±1.1 | 270.0±0.0 | " | " |
| 10 | " | " | 13.1±0.1 | 250.0±0.0 | " | " |
| 12 | " | " | 13.5±0.5 | 160.0±0.0 | " | " |
| | | | CV: SDS 2293-1 | | | |
| 2 | 84 | 130 | 8.7±0.7 | 300.0±0.0 | 11.0 | 100 |
| 4 | " | " | 8.2±1.2 | 300.0±0.0 | " | " |
| 6 | " | " | 7.5±0.5 | 255.0±15.0 | " | " |
| 8 | " | " | 6.7±1.3 | 175.0±5.0 | " | " |
| 10 | " | " | 4.3±0.4 | 165.0±5.0 | " | " |
| 12 | " | " | 5.5±1.5 | 160.0±0.0 | " | " |

Table 2. Yield components (kg. D.M/m) of sorghum cultivars under non stress and maximum stres conditions.

| YIELD VARIABLE | DISTANCE FROM LINE (m) | HAZERAH 226 | SDS 1594-1 | CULTIVAR P 8320 | NTULIRED | FRAMIDA | SDBP | SDS 2293-1 | CV (%) |
|---|---|---|---|---|---|---|---|---|---|
| stover | 2 | 0.91 d $ | 2.44 bc | 2.06 cd | 3.55 ab | 3.04 abc | 2.58abc | 4.36 a | 22.9 |
| stover | 12 | 0.95 b | 1.65 a | 1.39 ab | 1.43 ab | 1.71 a | 1.13 b | 1.27 ab | 16.4 |
| yield reduction (%) | & | -4.3 | 32.4 | 46.5 | 59.7 | 43.7 | 56.2 | 70.9 | |
| head | 2 | 1.84 a | | 0.55 c | 0.32 d | 0.44 cd | 0.97 b | | 11.6 |
| head | 12 | 1.56 a | | 0.4 0 bc | 0.00 d | 0.19 cd | 0.52 b | | 21.1 |
| yield reduction (%) | | 15.2 | | 27.3 | 100 | 56.8 | 46.4 | | |
| total | 2 | 2.75 a | 2.44 a | 2.61 a | 3.87 a | 3.48 a | 3.55 a | 4.36 a | 20.5 |
| total | 12 | 2.51 a | 1.65 b | 1.79 b | 1.43 b | 1.90 ab | 1.65 b | 1.27 b | 17 |
| yield reduction (%) | | 8.7 | 32.4 | 31.4 | 63.1 | 45.4 | 53.5 | 70.9 | |

$ Yields within a row followed by the same letter are not significantly different at 5% level of probability by Duncan's Multiple Range Test.

& Yield reduction % = 1-(Y12/Y2)x100.

Table 3. Effect of water availability (distance from LS) on agronomic variables of sorghum cultivars.

| DISTANCE (m) * | HEAD EXSERTION (d.a.e.) # | HARVEST (d.a.e.) $ | HEADS NO. (per m) | HIGHT (cm) | GRAIN MOISTURE (%) | BIRD DAMAGE (%) | PDM (%) & | STOVER DM. YIELD (kg/m) |
|---|---|---|---|---|---|---|---|---|
| | | | | CV: SDS 1513 | | | | |
| 2 | 77 | 126 | 10.0±0.8 | 330.0±11.0 | 11 | 25 | 28.9±1.2 | 3.7±0.2 |
| 4 | " | " | 13.5±1.2 | 295.0±8.6 | " | 25 | 31.9±1.4 | 2.6±0.2 |
| 6 | " | " | 11.5±1.0 | 270.0±8.2 | " | 0 | 32.2±0.9 | 2.0±0.1 |
| 8 | " | " | 12.0±0.9 | 240.0±3.8 | " | 0 | 33.4±0.8 | 1.8±0.1 |
| 10 | " | " | 11.0±0.9 | 200.0±10.6 | " | 0 | 35.0±2.0 | 1.3±0.2 |
| 12 | " | " | 9.8±0.6 | 170.0±5.2 | " | 0 | 34.6±1.6 | 1.0±0.1 |
| | | | | CV: RED SWAZI | | | | |
| 2 | 71 | 115 | 14.3±1.4 | 188.3±7.3 | 13 | 50 | 47.1±1.2 | 3.7±0.1 |
| 4 | " | " | 13.5±1.7 | 188.3±8.8 | " | " | 43.5±1.2 | 3.1±0.3 |
| 6 | " | " | 8.2±4.0 | 185.0±2.9 | " | " | 49.0±5.0 | 2.8±0.1 |
| 8 | " | " | 10.2±5.1 | 155.0±16.1 | " | " | 52.0±2.1 | 3.2±0.1 |
| 10 | " | " | 13.4±1.3 | 136.7±8.8 | " | " | 50.2±0.9 | 3.1±0.1 |
| 12 | " | " | 5.5±2.8 | 115.0±15.0 | " | " | 51.0±1.0 | 2.1±0.2 |
| | | | | CV:SDS 2298 | | | | |
| 2 | 80 | 126 | 10.5±1.4 | 292.5±2.5 | 11 | 40 | 35.5±0.9 | 2.9±0.8 |
| 4 | " | " | 4.8±0.3 | 275.0±0.0 | " | " | 34.0±0.9 | 2.2±0.2 |
| 6 | " | " | 6.8±1.3 | 255.0±15.0 | " | " | 29.8±4.9 | 1.7±0.1 |
| 8 | " | " | 7.8±0.8 | 220.0±20.0 | " | " | 32.1±1.3 | 1.9±0.1 |
| 10 | " | " | 7.5±1.0 | 185.0±15.0 | " | " | 34.1±0.9 | 1.2±0.2 |
| 12 | " | " | 5.9±0.4 | 170.0±12.5 | " | " | 35.4±2.2 | 1.1±0.0 |
| | | | | CV: P 8319 | | | | |
| 2 | 80 | 128 | 11.7±0.7 | 205.0±5.0 | 16 | 15 | 27.5±1.0 | 1.9±0.1 |
| 4 | " | " | 12.2±0.6 | 200.0±10.0 | " | " | 31.0±0.3 | 1.4±0.1 |
| 6 | " | " | 11.3±0.9 | 187.5±2.5 | " | " | 37.2±2.7 | 1.5±0.1 |
| 8 | " | " | 11.9±0.8 | 155.0±15.0 | " | " | 39.8±3.8 | 1.5±0.2 |
| 10 | " | " | 11.3±1.3 | 130.0±0.0 | " | " | 36.3±2.6 | 1.0±0.1 |
| 12 | " | " | 7.3±1.5 | 120.0±0.0 | " | " | 33.9±1.2 | 1.2±0.1 |

* distance from line source
\# days after emergence to 50 % head exsertion
$ days after emergence
& D.M percentage

Table 3. (continued)

| DISTANCE (m) | HEAD EXSERTION (d.a.e.) | HARVEST (d.a.e.) | HEADS NO. (per m) | HIGHT (cm) | GRAIN MOISTURE (%) | BIRD DAMAGE (%) | PDM (%) | STOVER DM. YIELD (kg/m) |
|---|---|---|---|---|---|---|---|---|
| | | | | CV: 2293-6 | | | | |
| 2 | 84 | 126 | 5.5±1.2 | 325.0±25.0 | 19 | 50 | 32.9±1.4 | 3.8±0.8 |
| 4 | " | " | 4.8±0.8 | 330.0±0.0 | " | " | 33.4±1.6 | 2.7±0.7 |
| 6 | " | " | 5.0±1.5 | 255.0±5.0 | " | " | 36.5±0.4 | 2.3±0.0 |
| 8 | " | " | 8.6±1.4 | 197.5±7.5 | " | " | 32.1±0.1 | 2.1±0.5 |
| 10 | " | " | 6.6±2.9 | 175.0±5.0 | " | " | 33.3±1.2 | 1.7±0.1 |
| 12 | " | " | 3.0±0.6 | 160.0±9.5 | " | " | 37.4±2.0 | 1.5±0.0 |
| | | | | CV: 1710-1 | | | | |
| 2 | 95 | 130 | 9.0±1.0 | 270.0±0.0 | 15 | 100 | 25.3±0.3 | 2.7±0.2 |
| 4 | " | " | 8.4±0.7 | 260.0±0.0 | " | " | 27.4±1.1 | 2.2±0.4 |
| 6 | " | " | 6.±1.9 | 210.0±0.0 | " | " | 28.5±0.7 | 1.8±0.6 |
| 8 | " | " | 5.4±1.9 | 180.0±0.0 | " | " | 30.4±2.3 | 1.8±0.7 |
| 10 | " | " | 2.5±1.5 | 145.0±5.0 | " | " | 29.3±0.3 | 1.3±0.2 |
| 12 | " | " | 1.7±0.3 | 130.0±6.2 | " | " | 29.9±1.3 | 0.8±0.1 |
| | | | | CV: SDS 3168-3 | | | | |
| 2 | 80 | 126 | 7.1±1.7 | 232.5±7.5 | 18 | 50 | 27.1±0.5 | 2.2±0.2 |
| 4 | " | " | 7.8±1.2 | 230.0±0.0 | " | " | 29.4±3.2 | 1.7±0.2 |
| 6 | " | " | 5.2±0.2 | 225.0±5.0 | " | " | 31.8±1.4 | 2.0±0.6 |
| 8 | " | " | 8.9±0.4 | 175.0±15.0 | " | " | 31.9±0.9 | 1.4±0.3 |
| 10 | " | " | 8.7±0.0 | 157.5±2.5 | " | " | 32.6±1.5 | 1.3±0.0 |
| 12 | " | " | 9.0±0.3 | 150.0±6.3 | " | " | 31.4±0.8 | 1.1±0.2 |
| | | | | CV: TOWN | | | | |
| 2 | 99 | 130 | 8.2±0.8 | 400.0±0.0 | 15 | 100 | 31.9±1.1 | 3.3±0.3 |
| 4 | " | " | 5.6±0.9 | 370.0±5.0 | " | " | 38.1±2.4 | 2.6±0.5 |
| 6 | " | " | 3.3±0.3 | 300.0±0.0 | " | " | 35.2±0.4 | 2.0±0.3 |
| 8 | " | " | 3.0±1.5 | 290.0±0.0 | " | " | 31.6±1.7 | 1.6±0.2 |
| 10 | " | " | 1.5±0.1 | 240.0±0.0 | " | " | 30.9±0.8 | 1.4±0.1 |
| 12 | " | " | 2.0±0.2 | 187.5±2.5 | " | " | 31.9±1.1 | 1.7±0.1 |

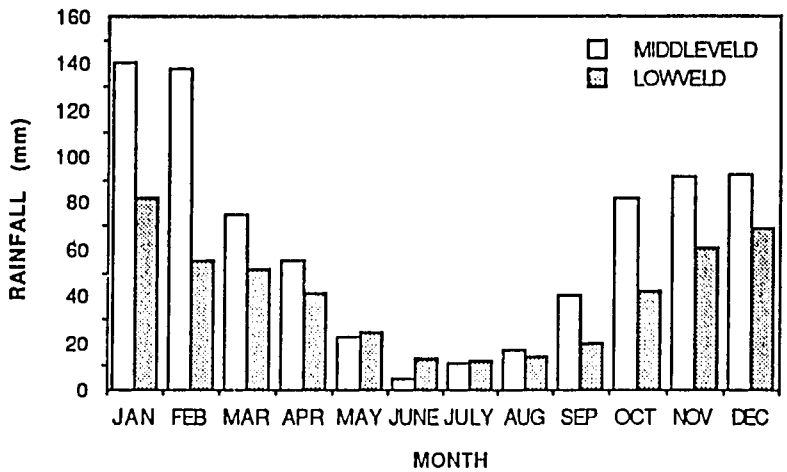


Fig. 1. Mean monthly rainfall for Manzini (Middleveld) over 21 years and for Lavumisa (Lowveld) over 31 years (Mkhatshwa 1988).

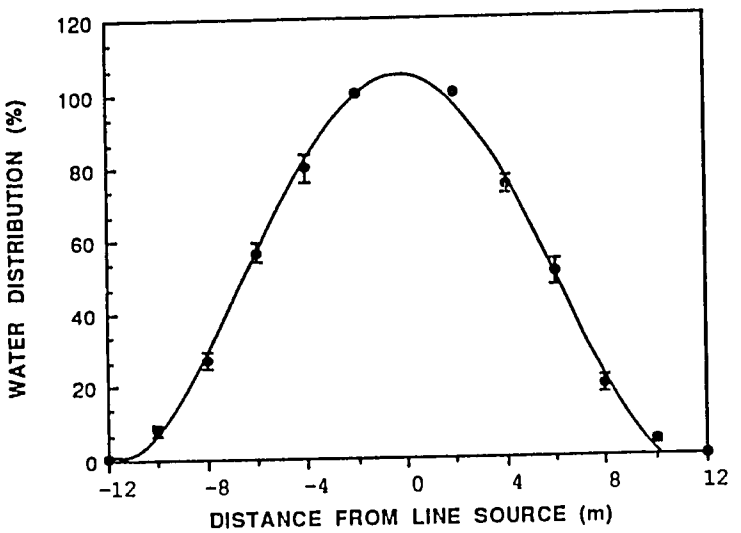


Fig. 2. Water distribution as a function of distance from line source (6 irrigations ±s.e)

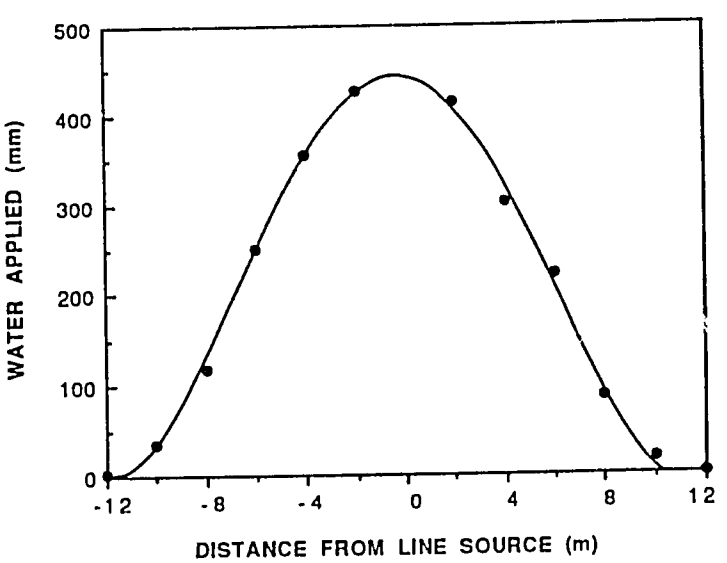


Fig. 3. Amount of water applied as a function of distance from line source

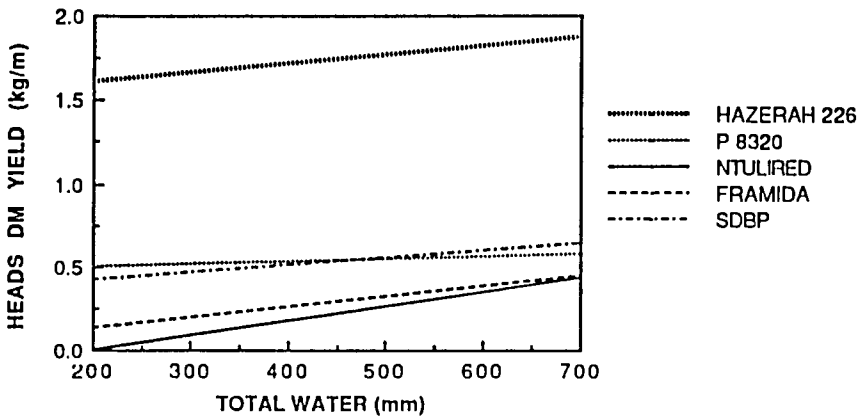


Fig.4. Water production function for head dry matter yield
(total water=soil water content on the day of planting+irrigation water)

Regression equations (n=6)

| | | |
|---|---|---|
| Hazerah 226 | Y= 1.508+0.0005x | $R^2$=0.614n.s |
| P 8320 | Y= 0.457+0.0002x | $R^2$=0.223n.s |
| Ntulired | Y=-0.198+0.0009x | $R^2$=0.820 * |
| Framida | Y= 0.003+0.0006x | $R^2$=0.965 ** |
| SDBP | Y= 0.326+0.0004x | $R^2$=0.663 * |

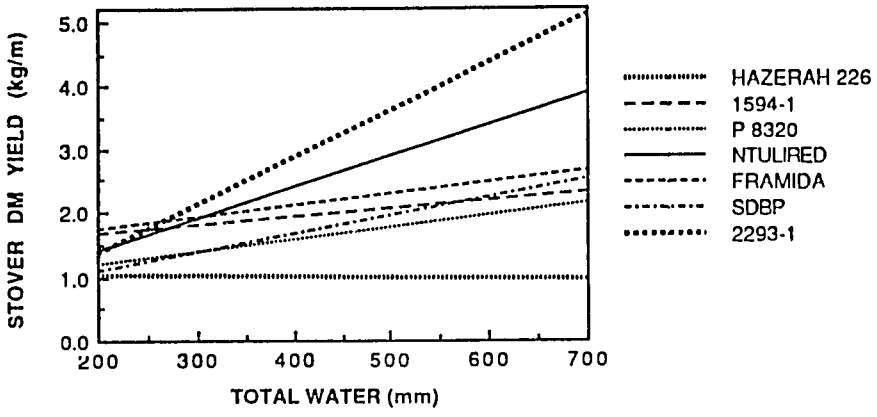


Fig. 5. Water production function for stover dry matter yield
(total water= soil water content on the day of planting+ irrigation water)

Regression equations (n=6)

| | | | |
|---|---|---|---|
| Hazerah 226 | Y= 1.059-0.0002x | $R^2$=0.157 | n.s |
| 1594-1 | Y= 1.410+0.0012x | $R^2$=0.651 | n.s |
| P 8320 | Y= 0.831+0.0018x | $R^2$=0.862 | ** |
| Ntulired | Y= 0.391+0.0049x | $R^2$=0.980 | ** |
| Framida | Y= 1.356+0.0018x | $R^2$=0.419 | n.s |
| SDBP | Y= 0.504+0.0028x | $R^2$=0.898 | ** |
| 2293-1 | Y= -0.120+0.0074x | $R^2$=0.929 | ** |

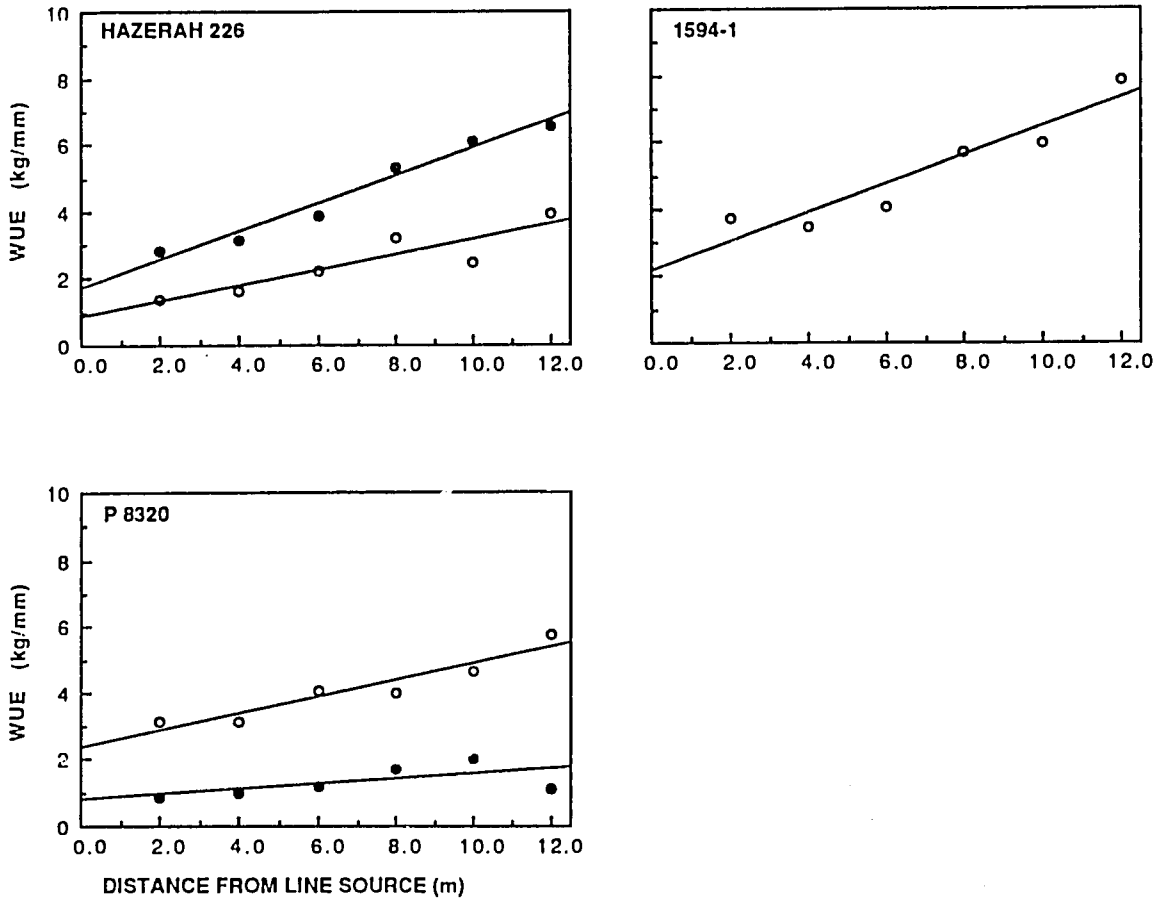


Fig. 6. Water use efficiency (total water basis) as a function of distance from line source

● head, o stover

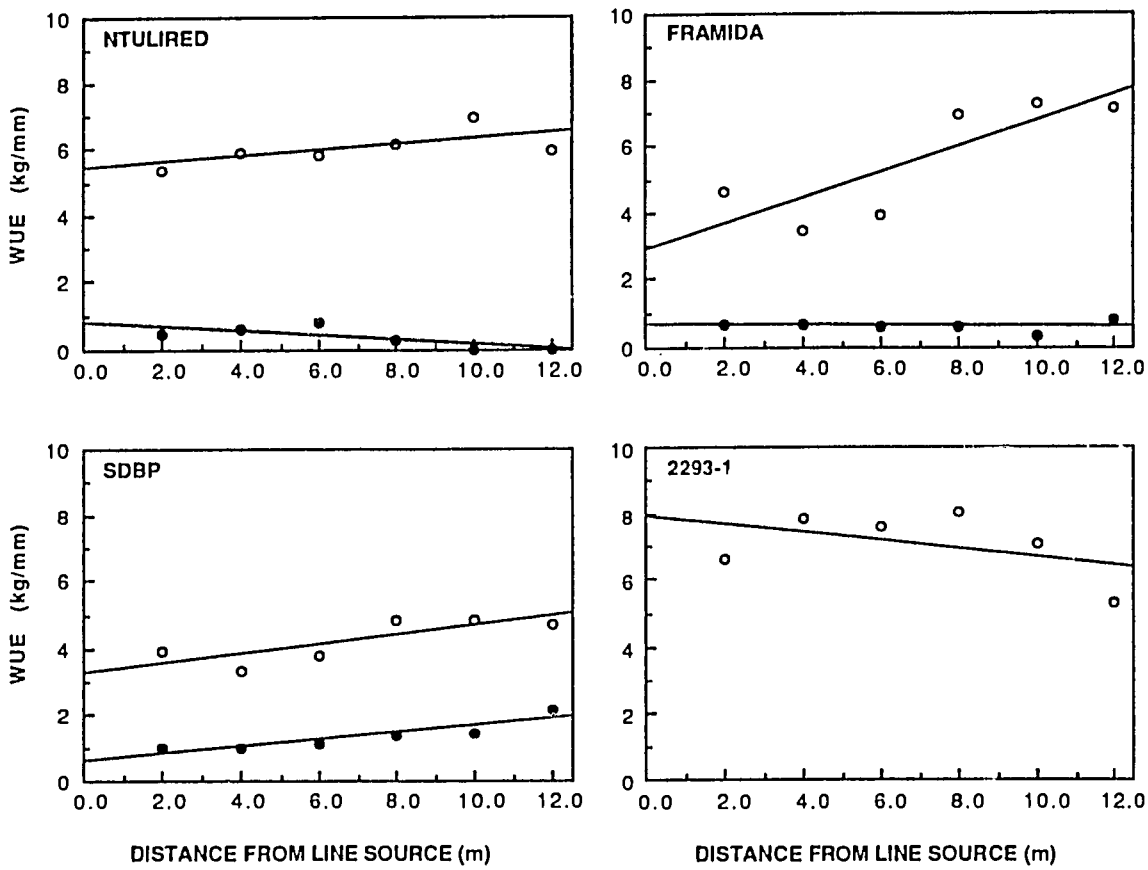


Fig. 6. (continued)

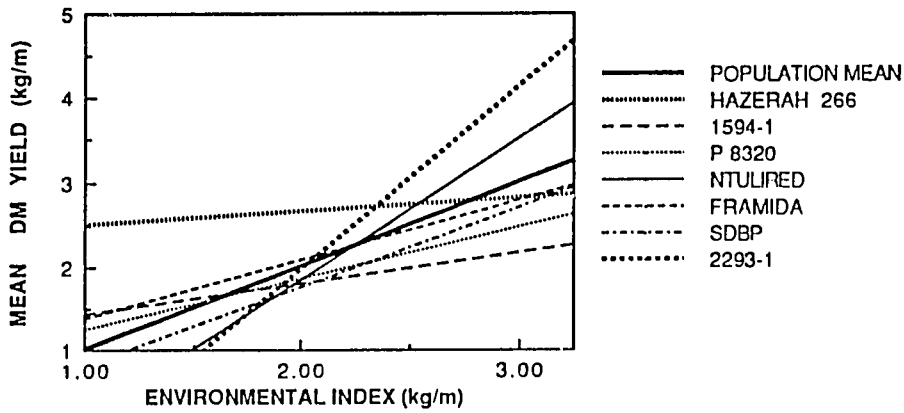


Fig.7. Over all relationship between cultivar performance and environmental index
x axis: mean D.M yield of all cultivars in each of the water regimes.
y axis: D.M yield of individual cultivar in each of the water regimes.
population mean: 1/1 line.

Regression coefficients (b)

| | |
|---|---|
| Hazerah 226 | 0.159 |
| 1594-1 | 0.365 |
| P 8320 | 0.611 |
| Ntulired | 1.675 |
| Framida | 0.709 |
| SDBP | 0.953 |
| 2293-1 | 2.164 |

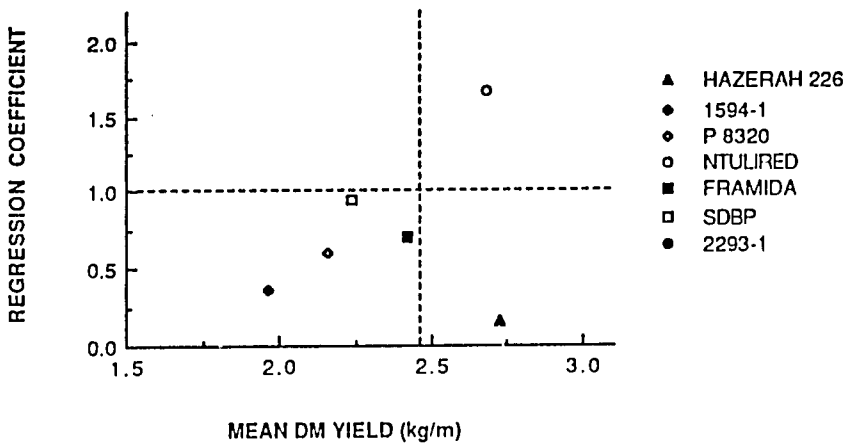


Fig. 8 . The relationship of cultivar adaptation to moisture environment and mean DM yield (the coefficients used are those presented in fig.7.)
Horizontal broken line : average stability
Vertical broken line : population mean yield

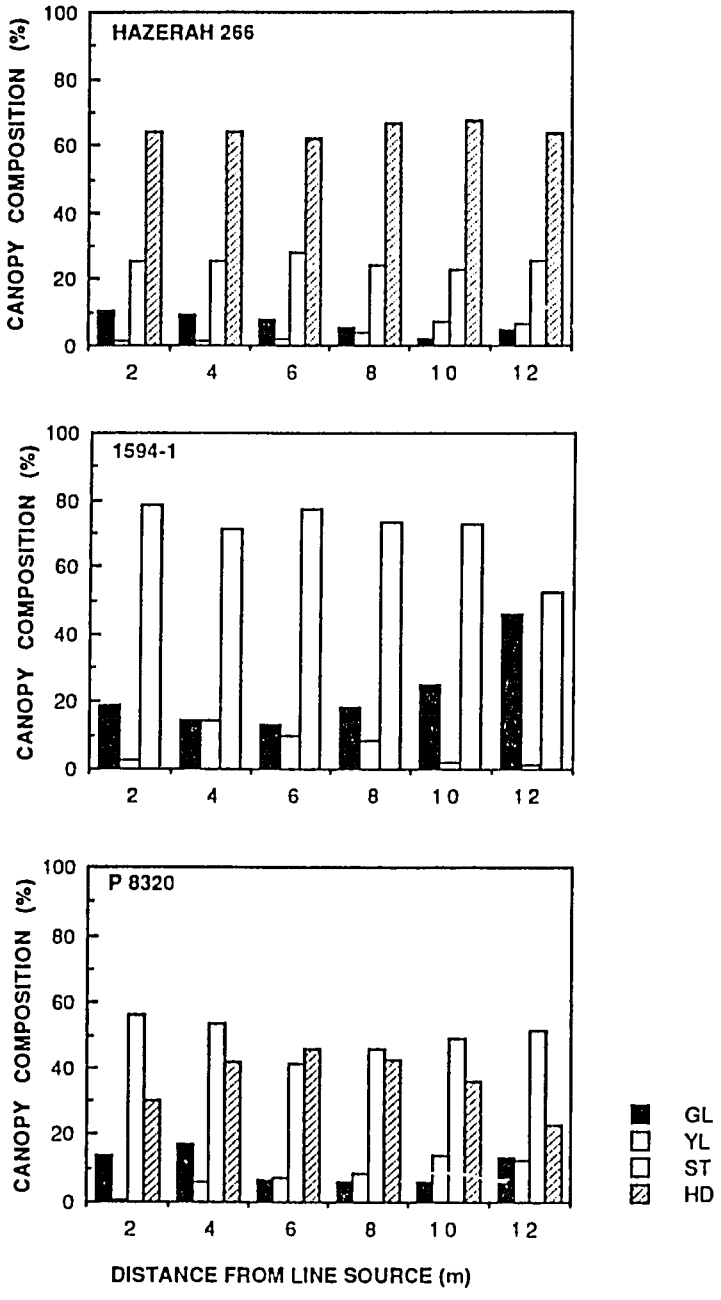


Fig.9. Canopy composition (% of total dry weight) as function of distance from line source.
GL: green leaf, YL: yellow leaf, ST: stem, HD: head

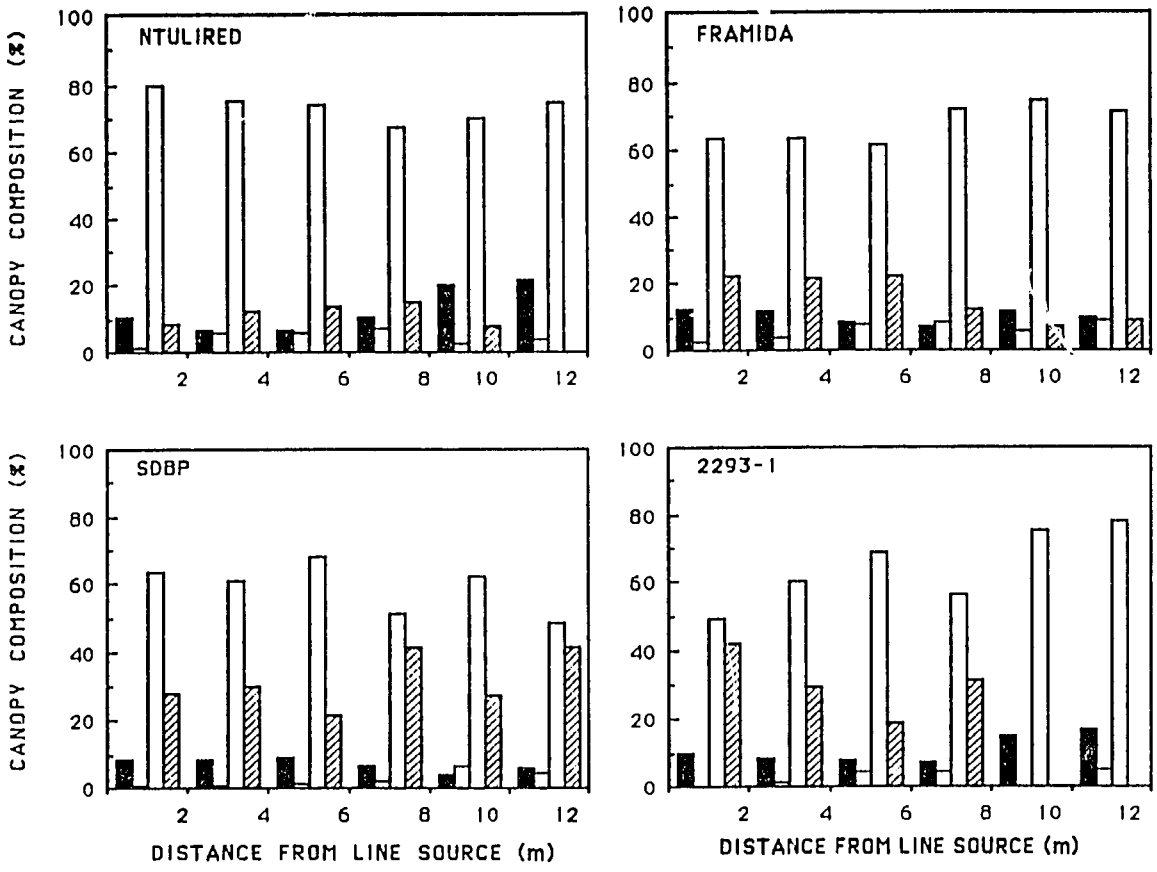


Fig. 9. (continued)

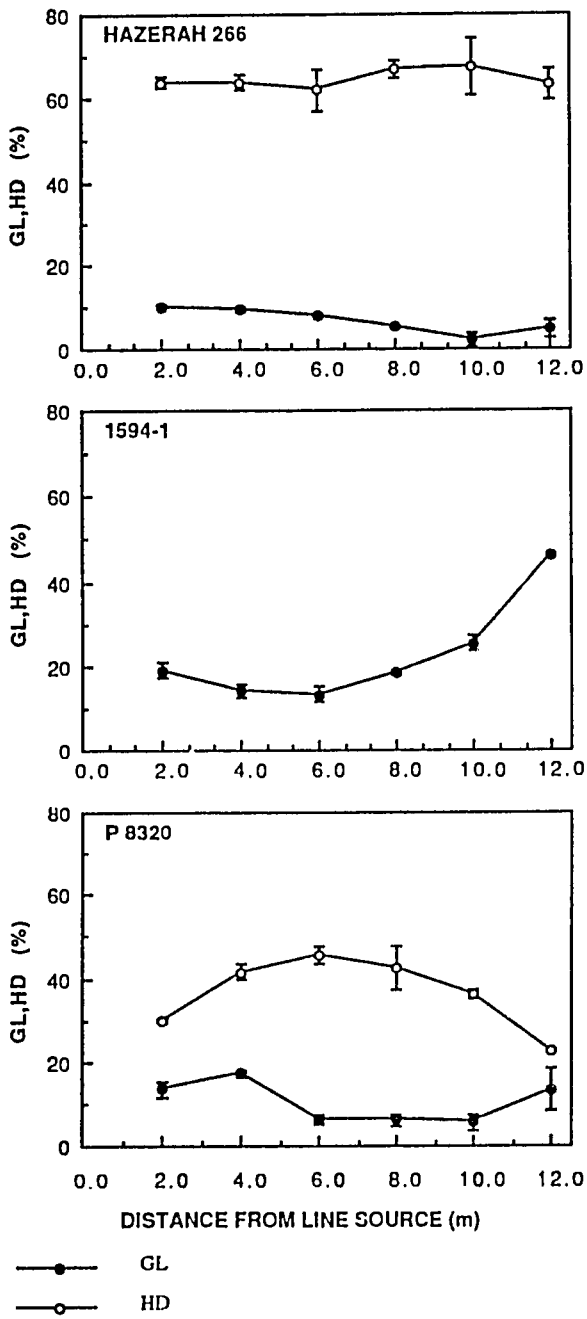


Fig.10. relative yield (%) of green leaves (GL), and head (HD) as a function of distance from line source.

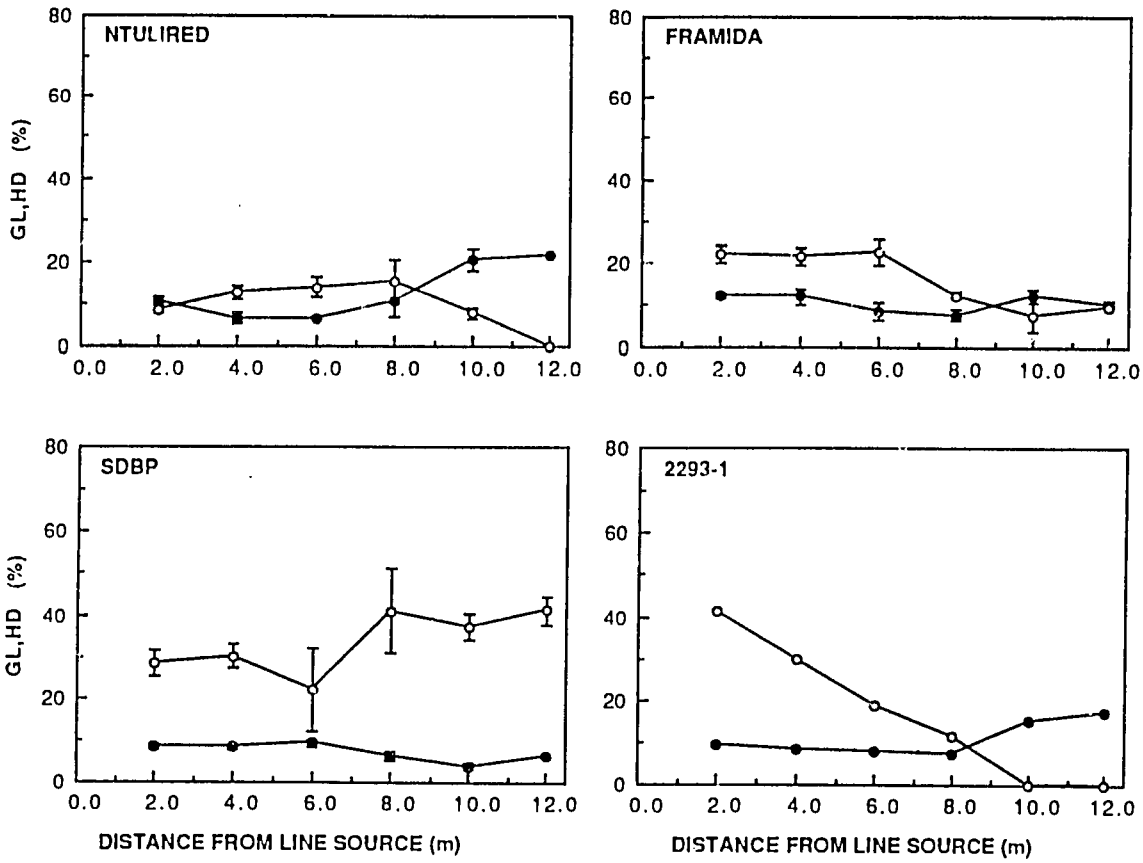


Fig. 10. (continued)

GL
HD