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Compiled by
Vivien J. Escott

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DROUGHT-TOLERANT CROPS: THEIR NATURE AND VALUE IN DROUGHT SITUATIONS

H. Doggett

The two most important factors influencing crop growth and therefore crop yield, are water and temperature. A measure of the efficiency of water use is the ratio of yield (generally total dry matter) to water loss. Water may be lost from the crop through ordinary evaporation from the plant surfaces and from the soil, and also through transpiration, the loss of moisture from the interior of the plant through the stomata. One measure of the relationship between crop yield and water use is Water Use Efficiency, or WUE. This is defined as the ratio

$$\frac{\text{Yield (dry weight)}}{\text{Evapotranspiration}} \text{ or WUE} = \frac{Y}{ET}$$

Temperature affects the rate of evapotranspiration, and also the rate of the plants' photosynthesis and respiration. Temperature effects are difficult to separate from water loss effects, so that drought, especially in the tropics, is the resultant of both water loss and temperature levels. A prolonged spell of sunshine results both in increased evapotranspiration and higher temperatures. When water gets short within the plant, the cooling effect of transpiration is lessened, the stomata usually close, and so the temperatures of the plant tissues rise.

Plants which can grow successfully in drought situations usually have mechanisms to diminish transpiration during dry spells. They also possess cytoplasm that can survive periods of high temperature, and recover their normal function quickly when the drought has ended. Root systems are also important, and must be able to scavenge efficiently for water. They are often well branched and occupy the soil volume rather fully. Some crop plants' roots may penetrate deeply and be able to take advantage of moisture at depth. Water loss that cannot be replaced from the dry soil results in very powerful tensions within the root tissues, and these may collapse irreversibly unless internal thickening is strong enough to withstand the forces. We expect plants adapted to drought situations to have special mechanisms to endure heat and to reduce water loss. They must possess a root system able to recover from drought when water is once more available in the soil.

We shall not look in detail at drought resistance mechanisms. However, it is important to emphasize that the ability to endure drought results from the integration of a whole series of morphological and physical characteristics, and is very complex. Plant breeding is sometimes credited with miraculous powers. "Breeding for drought resistance" to some laymen sounds just as straightforward as breeding for shorter plant height, or for resistance to a disease such as rust in wheat. The procedure is expected to result in substantial yield increases. Nothing could be further from the truth: the dry matter yield potential is determined by the moisture available and the temperature regime, subject to satisfactory soil conditions and to nutrient requirements being met. It is indeed possible by breeding to bring about steady improvement in the performance of drought-resistant plant species; but there is nothing revolutionary in sight, no "drought revolution" from plant breeding.

CEREALS

All cereals are most vulnerable to drought damage during the period of inflorescence development and flowering and the timing of this growth period is of critical importance. In the Great Plains of the U.S.A., wheat grows during a cool part of the year and avoids the worst stress by maturing just as the hottest and driest period of the year begins. Sorghum, by contrast, is planted in the spring and grows through the hot summer. The optimum temperatures for wheats are about 5°C below those for sorghums. Further, the WUE for sorghum is about double that for wheat: sorghum can produce twice as much dry matter as can wheat for the same quantity of available moisture. This is shown in Table 1.

Table 1. Water use efficiency of wheat and sorghum

(Hays, Kansas, period 1966 - 1976)

	Irrigation water (ha-cm)	WUE (kg grain/ha per cm of water)
Wheat		
	42	44
	48	50
	51	50
Sorghum		
	36	75
	39	81

Other figures from the Great Plains show that sorghum has better WUE than does maize when the water supply is reduced. Measurements at Samaru, Nigeria, showed that pearl millet used 330 mm of water in 85 days, maize 486 mm in 117 days, and groundnuts 438 mm in 125 days. The millet produced 1 kg of dry matter for every 148 kg of water used, the maize used 353 kg of water, and the groundnuts used 518 kg of water to produce 1 kg of dry matter (Eastin et al. 1983; Elston and Bunting 1980).

Timing is the key factor for successful cropping in drought areas. Plant breeders can often develop crop types that match the period during the rainy season when the chances are highest that there will be enough rain. Usually this involves developing varieties with short maturity length. In this way, optimum dry matter production can be obtained in many seasons. Photoperiod sensitivity is the major factor in controlling the appropriate maturity length for many tropical crops. Flowering is triggered by appropriate night and day lengths, so on average takes place at the appropriate time before the rains have ended. Further, plant breeders can select varieties that partition the dry weight produced so that there is more grain and less straw, i.e. the harvest index is higher. That may not always match best the needs of the livestock owners, who need the straw as feed.

Maize can sometimes be adapted to fit the rainfall pattern of dry areas in this way. Thus, at Katumani in eastern Kenya, Dowker developed a short-term maize that could use the two months of reliable rain that fell, producing consistent, modest yields. However, maize is not able to withstand much water stress, especially during the reproductive phase. Maize tissues themselves appear to be more heat tolerant than are those of sorghum, but its stomata close tightly, shutting off transpiration, so there is no cooling. Sorghum stomata remain slightly open, and slow transpiration keeps the tissues cool enough to survive.

Plant breeding can do a great deal to correct weakenesses to minimize the losses from the yield-reducers. Resistance to diseases and pests can make a big contribution. In millet, downy mildew, ergot, and smut can take a heavy toll. Charcoal rot, bed rot, anthracnose and sooty-stripe can be damaging to sorghum. Millet is troubled by earhead caterpillars, and to some extent by stem-borers, although these are much more serious in sorghum, as are midge and shoot-flies. Plant breeding has already made good progress in helping to reduce crop losses from such causes. In cowpea, photoperiod insensitive types may show good adaptation to the drier areas: bruchid disease and striga resistance are being transferred to the best of the traditional photoperiod sensitive types. Dwarf Pigeon Pea developed in India has become a relatively short-term crop when planted for the rabi season (Rai and Witcombe 1985).

Witchweed (Striga) causes serious crop loss on sorghum, millet and cowpea in Africa, the extent of which has been overlooked for a long time. Plant breeding can do much to reduce this, but again, must not be isolated from the importance of improved inputs. Given the regular use of high inputs, Striga is a far less important parasite, but during the long period while input levels are increasing, Striga resistance has a key role to play.

Pearl millet is more efficient in water utilization than is sorghum, and also has higher heat tolerance. Some types have a very short duration of growth, as little as 70-80 days. Pearl millet spends less of its life cycle in the vulnerable reproductive stage - one quarter of its maturity length as compared with one third for sorghum. Also, the grain-filling period of pearl millet is some 15-20 percent shorter than in sorghum. Thus, the two major cereals best adapted to drought conditions in the tropics are pearl millet and sorghum, but grain production depends upon the amount of water available.

SORGHUM

More is known about genetic differences in drought response for sorghum than for pearl millet. The cv Shallu (a Guinea type) performs poorly under drought stress. Others, such as CK60 (a Kafir) and the hybrid RS610, continue to complete their life cycle fairly normally, in spite of the stress. Yet others are able to utilize stored soil moisture extensively, and some of these expend relatively little of their total water use during the pre-flowering period. Examples of these are Feteritas (Caudatums) and Durras, including the Indian type M35-1. Genotypes differ by as much as 20 percent in the amounts of stored soil moisture extracted (Blum 1974).

Hybrid sorghum deserves more attention in drought-prone areas. In 1969, I reported that hybrids show a constant yield increase compared to varieties over a wide range of yield levels. Results are shown in Table 2 and in Figure 1 (Doggett 1969).

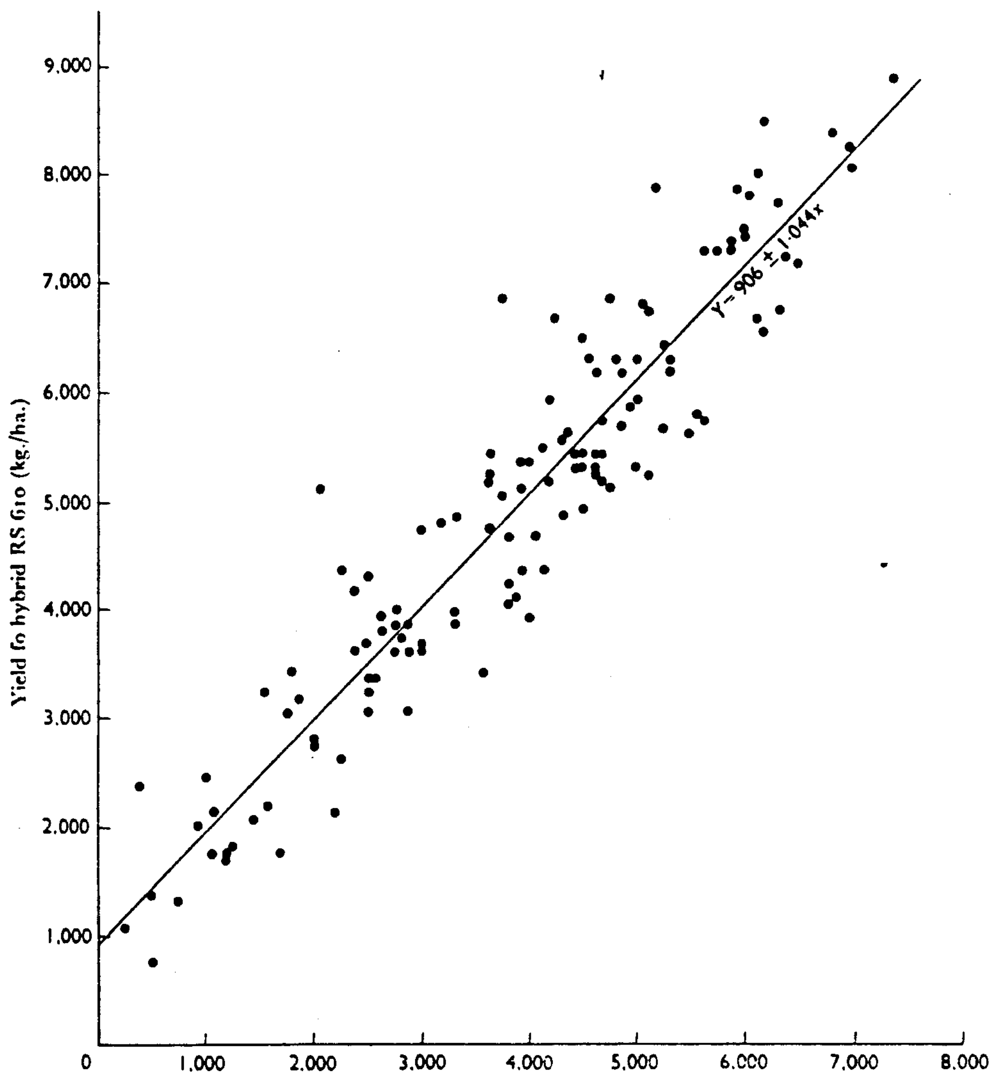

Fig. 1. Grain yield of the hybrid RS 610 plotted against the yield of variety Martin in the U.S.A. (based on data from Texas, Kansas, Nebraska, Illinois and Arizona in 1955, 1956, 1957, 1958, 1959, 1964 and 1965).

Table 2. The relationship between Sorghum Hybrid and variety grain yields(kg./ha.)

	COUNTRY					
	A	B	C	D	E	F
	East Africa[1]	U.S.A.[2]	Rhodesia[3]	Rhodesia[3]	East Africa[1]	India[4]
a. Hybrid	H × 58	RS 610	NK300	NK300	H × 57	CSH – 1
b. Variety	Serena (pollinator parent)	Martin	Framida	Red Swazi	SB65 (pollinator parent)	Local check varieties
c. Mean variety yield	2095	3820	3925	3560	1475	1835
d. Lowest variety yield	475	250	180	940	370	120
e. Highest variety yield	5715	7400	9320	6860	4250	5330
f. Mean hybrid yield	2590	4895	5740	5740	2185	2460
g. Regression for yield of hybrid on variety, b=	1·034±0·086	1·044±0·034	1·036±0·118	0·926±0·297	1·253±0·082	0·663±0·108
h. Mean yield increase for hybrid over variety	495	1075	1815	2180	710	625
i. Number of trials in sample	42	128	32	32	81	76

1. Data from 'Record of Research', *Ann. Rep. E. Afr. Agric. & For. Res. Org.*, Kikuyu, Kenya, 1964 to 1966.
2. From trial reports available at Serere from Kansas, Illinois, Texas, Nebraska and Arizona, 1956 to 1965.
3. From *Ann. Rep. Matopos Res. Sta.*, Rhodesia, 1961–1966.
4. From *Progress Reports Accelerated Hybrid Sorghum Project*, 1961–62, 1962–63, 1963–64 (Indian Council of Agricultural Research and Cooperating Agencies).

It will be seen that even in East Africa and India 15 years ago, hybrids showed a constant yield advantage of 495, 710, and 625 kg/ha either over one parent or over a widely grown variety. In the U.S.A. and Zimbabwe, the yield advantage was greater, but so was the whole level of inputs and management. This deserves more study: the right hybrid might have a useful contribution to make towards yields in drought areas. Certainly the U.S.A. has gone over to hybrids, although much of the crop receives some irrigation (Doggett 1969).

The problem of hybrids in Africa is seed production, distribution, and sale to farmers, coupled with the need to educate the farmer to buy new seed every year. When I started the ICRISAT sorghum program in 1973, I chose the route of population improvement. The sorghum material from the populations would provide excellent hybrid parents, and when the national programs were in a position to develop such hybrids, they would also be in a position to undertake the necessary seed production and distribution without which hybrids could never be adopted. Meanwhile, farmers could use the varieties and synthetic varieties developed from the populations. ICRISAT is putting a lot of effort into this population improvement breeding in sorghum.

OTHER CROPS FOR DROUGHT AREAS IN AFRICA

Cowpea is a valuable crop for dry areas: again, a short duration of growth may be one valuable factor, although crop durations vary from 60 to over 140 days according to variety. There is a strong tap root, a well developed rootsystem, and excellent nitrogen fixation capacity. Tepary beans are also useful in very dry areas. Pigeon pea is grown in dry areas of eastern Africa, but has not yet caught on in West Africa. Its roots are able to follow the receding water table.

Cotton can be another valuable crop, but it is important to use a cultivar which can be so managed that the early flowering period of the crop coincides with low moisture stress.

Sesame (Simsim) is a drought-tolerant crop, once it has been established in the field. There may be scope for growing this crop more widely in the northern Sudan zone.

Groundnuts can produce well under moderately dry regimes, but WUE is lower than for maize.

Castor and safflower can crop under difficult conditions on rather deep soils, with good water-holding capacity. Their roots are able to follow the water table down. There is probably scope to use these more widely in some of the flood plain and fadama areas.

POLICY ISSUES

The most important factor determining the type and abundance of vegetation in Africa is the amount and distribution of rainfall. Table 3 shows the grain yield potentials of various rainfall zones in the tropics, assuming moderate phosphate and nitrogen fertilizers, and no serious yield loss from pests and diseases.

Moisture levels in the lowest rainfall zone shown in Table 3 impose an upper limit on yields. Perhaps we hope to make some progress in obtaining rather better yield stability by using drought-enduring or drought-avoiding crops: but even if a 20 percent mean yield increase were to be obtained by this means, that would be worth only 260 kg of grain per hectare. Further, such an improvement is likely to make little impact on the frequency of crop failures. Move to the next rainfall belt, and a 20 percent mean yield increase is worth 600 kg/ha of grain: that might well lead to a slight reduction in the frequency of crop failure. Taking the whole range of the table, an average yield increase of 20 percent in the lowest rainfall zone gives 260 kg/ha, with crop failure still in the order of one year in three. An increase of 20 percent in the highest rainfall zone is worth 1.6 t/ha, and crop failures are very rare. Clearly, the most profitable regions in which the invest the money available for the improvement of crop production lie in the higher rainfall zones. Larger increases in the amount of grain produced can be obtained more easily, and for lower research and development costs. Inputs will be better used and will very seldom be wasted through drought-induced crop failures.

A glance at a rainfall map of West Africa shows high, reliable rainfall in a belt along the Gulf of Guinea, and roughly parallel to it. The rainfall decreases in amount and duration as one moves northwards, until the desert is reached. The political map of Africa shows that many national boundaries run

Table 3. Grain yield potential for various rainfall zones.

Rainfall, mm/yr	Yield potential (t/ha)	Crop failure rate [a]
300- 500	1.3	1 in 3, or more frequently
500- 800	3.0	1 in 5
800-1,000	5.0	1 in 7
1,000-1,200	8.0	1 in 10 or less often

a "Failure" means less than 300 kg/ha of grain

Table 4. Present and projected populations compared with potential population supporting capacities in Africa.

Year	Population	People per hectare	Potential population supporting capacities - people per hectare		
			Low Inputs	Intermediate Inputs	High Inputs
1975	380	0.13	0.39	1.53	4.47
2000	780	0.27	0.44	1.56	4.47
2020	1542	0.54	?	?	?

East-West. The more northerly States may have no zone of ample, reliable rainfall; for example, Mauritannia, Mali and Niger. Most semi-arid countries in Africa have favoured rainfall zones or are adjacent to countries possessing such zones. The first need is the development of good communications between the two. In West Africa, that requires complete freedom of north-south movement for local produce and livestock. In all countries, better roads between wet and dry areas are essential.

Higgins and Kassam (1984) have calculated the potential population that can be supported in Africa based on three levels of inputs - low, medium and high, taking soils and climate into account. This is shown in Table 4.

This table is full of hope: but it does demand freedom of trade between all areas. It is based on rainfed agriculture, so irrigation may provide a bonus. Higgings and Kassam emphasize that for individual zones within a country attempting to attain food self-sufficiency from their own land resources, the situation is drastically different. Hope for the future lies in increased inputs only if there is freedom of trade in local produce. On a purely within-country level of food distribution, even with intermediate input levels, 12 countries totalling 110 million people would remain in a critical situation in 2000 A.D.

Kassam et al. (1978), in the FAO Agro-ecological Zones project, analyzed 10 crops. They estimated their potential yield range, and also suitable land areas for their cultivation, classified as very suitable, suitable and marginal. For each of these land classes, they estimated yield potential with low inputs and with high inputs. Averaging their estimates for 7 of the crops they chose (those belonging to the lowland tropics, but omitting cotton), the effect of high inputs was dramatic - a factor of approximately 5, regardless of the land-suitability class.

THE SAHEL ZONE

In the really dry areas with food crop failure rates of 1 in 3, the Sahel Zone, few people should be wholly dependent upon such crops. Crops should rather be regarded as supplementary food, or food for only a part of the population. The "crops" for the really dry and unreliable zones are grasses, legumes, and browse plants, grazed by livestock. The traditional African pastoralists have always known this - their main food resource was milk, or milk and blood from the living animal. Sorghum was grown by the African pastoralists in the lowlands, barley by the Galla. The young and able followed the livestock over their extensive grazing grounds and lived from them. The elderly and the younger children lived from the food crop harvests in the base camps. Increasing populations of people have resulted from better health care and lower mortality rates. Increasing cattle populations have resulted from disease control and the installation of increased numbers of watering points.

From the crop standpoint, priority goes to the improvement of pasture plants, and their management, in the 300-500 mm rainfall zone. Drought-tolerant crops, as generally understood, have a valuable part to play in this zone, but only as a supplementary food source. Cowpeas should receive more attention. Small irrigation schemes based on shallow wells and run by groups of farmers should be encouraged where appropriate.

The Northern Sudan Savanna (NSS), with a rainfall of around 600 mm, will repay more investment in millet and sorghum improvement, and this could result in a significant reduction in the crop failure rate. Hybrids may well pay off here. Millet should receive major attention. Cowpeas are important. The Sudan Savanna proper (SS, sometimes SSS for Southern Sudan Savanna), with a rainfall around 750 mm, should be the major focus of the sorghum work.

The Northern Guinea Savanna (NGS), rainfall around 1,000 mm, should be growing more maize. Root crops will also be important. Sorghum and millet will both still have a place, although using different genotypes from those further north.

The Southern Guinea Savanna (SGS), average rainfall about 1,100, should be growing maize, and root crops. Relay cropping should be explored, e.g. the short-term Katumani maize at the beginning of the rains, followed by another crop. Rice should receive attention. This is an area where multiple-cropping systems based on those developed in Asia need to be given support.
Evidently, there are no sharp boundaries, millet, sorghum, and maize will be found throughout the Sudan and Guinea zones.

SUMMARY

* The drought-prone areas of Africa should be producing livestock primarily, and the better rainfall areas crop products primarily. The first requirements to overcome the problems of feeding the growing population are greatly improved communications between dry and wet zones; improved trade and marketing systems; and unrestricted movement of local produce across national boundaries.

* Research inputs should be concentrated on the improvement of grasses, legumes and browse plants in the dry areas, with some emphasis on associated crop plants. The main emphasis should be on grazing management and livestock health. In the better rainfall zones, research inputs should concentrate on the most productive, paying crops: and on all aspects of multiple cropping.

* Plant breeding can do much to improve the yield stability of the crops in drier areas, by identifying drought-resistant strains and reducing their susceptibilities to pests, diseases and to Striga. Hybrids and synthetic varieties could provide a worth-while production increase. The most rewarding results from plant breeding will be obtained in the higher rainfall zones, both from improved varieties and hybrids, and from tailoring crops to match multiple-cropping systems.

* The biggest obstacle to the use of the improved varieties and hybrids in Africa is the absence of efficient, adequate seed multiplication systems - the seed industry is virtually non-existent for food crops.

* Greatly improved distribution and marketing systems, so that fertilizer and other inputs are available to farmers at the right places and the right time, are required.

REFERENCES

Blum, A. 1974. Genotypic responses in sorghum to drought stress 1. Response to soil moisture stress. Crop Sci 14, pp. 880.

Doggett, H. 1969. Yields of Hybrid Sorghums. Expl. Agric. 5, pp. 1-8.

Eastin, J.D., T.E. Dickinson, D.R. Krieg, and A. Bruce Maunder 1983. Crop Physiology in Dryland Agriculture. Dryland Agriculture, Agronomy Monograph No. 23, p. 333. ASA-CSSA-SSSA. Madison, U.S.A.

Elston, J., and A.H. Bunting 1980. Water relations of Legume Crops, in R.J. Summerfield, and A.H. Bunting (eds) Advances in Legume Science, p. 37. Royal Botanic Gardens, Kew, U.K.

Higgins, G.M., and A.H. Kassam 1984. Land, Food and Population in Africa, in Advancing Agricultural Production in Africa, ed. D.L. Hawksworth. p. 337 C.A.B., Farnham Royal.

Kassam, A.H., J.M. Kowal, and S. Sarraf 1978, in Report on the Agro-Ecological Zones Project, Vol. 1, Methodology and results for Africa. F.A.O. Rome.

Rai, K.N., and J.R. Witcombe 1985. Problems and methods in Pearl Millet Breeding. Fourth Regional Workshop on Sorghum and Millet Improvement in Eastern Africa. Soroti, Uganda, 22-26 July 1985. ICRISAT PO Patancheru A.P. 502 324 India.