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8 An environmental physiologists approach to screening for drought resistance in sorghum with particular reference to Sub-Saharan Africa*

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Abstract Sorghum *Sorghum bicolor* (L.) Moench is an important food crop of the semi-arid regions of Sub-Saharan Africa but under drought conditions yields have fallen from a long term average of around 1000 kg/ha to below 100 kg/ha.

In view of the range of environments in Sub-Saharan Africa and the different patterns of drought which occur in these regions, breeding for drought resistance in sorghum is a complex problem. A careful analysis of the environment is combined with the identification of appropriate physiological traits for developing drought resistant and higher yielding sorghum.

Historical rainfall data for the sorghum growing locations were analysed for delineation of the average dates of the beginning and end of the rains, the length of the rainy season, and the probabilities of receiving a defined amount of rainfall during the crop growing season. From the computed date of sowing, the duration of drought at various probability levels were assessed on a 10-day interval for the growing season. This information was used to group locations that have similar probabilities of drought in different growth stages of the sorghum crop. Three important growth stages are recognised viz. seedling establishment, mid season growth, and the grain-filling period.

The approach taken to the systematic development of a practical drought screening program is illustrated using data from a mid-season drought situation although it is emphasised that the approach for all three stages is essentially the same.

Initially, a sample of genotypes were selected from the sorghum genetic resources accessions at the ICRISAT Center to represent material collected from many countries over a range of altitudes (0 to 2000 m) and mean annual rainfall (250 to 2500 mm) covering most of the taxonomic groups.

The sample of lines were screened under severe drought conditions at ICRISAT Center, Patancheru, India in the relatively rain-free summer seasons from 1983 to 1986.

Considerable genetic variation was shown in the response and survival of these genotypes to mid season drought and high temperature. Visually observed differences in 'resistant' and 'susceptible' genotypes in terms of desiccation tolerance and recovery ability were shown to be based on measurable physiological responses.

In conclusion, it is argued that although the 'environmental physiology' approach has enabled sorghum scientists to focus their screening efforts on specific drought problems, it is vital that more emphasis is put on developing those types of climatic analysis which better describe the various droughts of Sub-Saharan Africa.

Introduction

Sub-Saharan Africa (SSA) is the only part of the developing world in which the index of per capita food production has declined during the last two decades (33). Of all the sub regions of SSA, West Africa has shown the slowest growth rate for total food production. Sorghum (*Sorghum bicolor* (L.) Moench), is grown on over 10 million ha in West Africa where it is one of the most important rainfed food crops. In Burkina Faso, for example, 56% of the total calorific food intake comes from sorghum. Despite this the annual-growth rate of sorghum from 1969-71 to 1980-82 in SSA was 2.1% which was lower than the population growth rate of about 2.5% during the same period.

The present sorghum cultivation practices in SSA are vulnerable to the ravages of drought; while average yields of sorghum are around 1000 kg/ha, under drought conditions these have fallen below 100 kg/ha.

It is therefore important to limit yield losses from adverse variations in the environment. As Jordan and Sullivan 1982 stated, "the problem of crop performance under drought conditions resolves into two basic components: the first a genetic component and the second, a management component". There are complex interactions between the two and our efforts to cope with drought must aim at a thorough understanding of the entire production system including environment, management and genotype.

In this paper we emphasize the need to bring our present knowledge of two of the components of this production system, the environment and the genotype together in what is termed an "environmental physiology" approach. The physiological and genetic aspects of crop improvement in response to drought and the associated high temperature stress have been comprehensively reviewed in recent years and will not be repeated here. However, these reviews indicate that ample genetic variation for physiological components of drought resistance exists in sorghum.

An objective of this paper is to emphasise the need for appropriate descriptions of drought environments. Simple methods of rainfall analyses with suitable examples from SSA are described. A further objective is to demonstrate that these analyses provide the physiologists and breeders with sufficient information to focus their screening on a specific drought problem.

Such an approach should also aid in the identification of appropriate genetic variation and physiological traits for developing more drought resistant and higher yielding sorghums for the semi-arid regions of Sub-Saharan Africa.

The environmental physiologists approach

Drought is a complex problem and scientists have made little progress in developing material that is more stable than the local farmers' landraces. We believe that there is a very good reason for this; many of our crop improvement programs have been trying to develop 'improved' material with little or no idea about their real customers or the environment they live in. Initially the most important component to define (rather than drought itself) is the needs of the customer and the environment that he has to grow the sorghum crop in.

We think that the approach is simple and systematic, it has six components which are summarised briefly below under the following headings:

Customer; Environment; Growth stages; Germplasm; Traits; Collaboration.

All components are important but the most important is a clear understanding of the environment where the key person, the customer, is trying to produce food.

Customer

The customer's needs are very important. Researchers often forget that apart from feeding the children the farmer has cattle to feed, food to cook and roofs to cover. The failure of many high yielding varieties (HYVs) has been because these important uses have been ignored.

Environment

It is impossible to develop a crop improvement program for drought prone areas without a clear understanding of the climatic conditions of the area. If we are to focus our research on the type of sorghum genotypes and traits required for any particular customer, it is essential to establish whether the problem our customer has is one of seedling drought stress, mid season or terminal stress or a combination of any two or three. This can only be done through a detailed analysis of the customer's environment.

Growth stages

It is vital that the selection procedure set up will discriminate resistant and susceptible material under stress conditions for the three phenologically distinct growth stages; viz. (i) emergence to about floral initiation (GS1) (ii) floral initiation to flowering (GS2) (iii) flowering to physiological maturity (GS3).

Germplasm

It is essential that the material used has a wide a genetic base as possible. Therefore by germplasm we include both landrace and breeding material. We should also point out that the success of this approach relies more on the use of the landrace material than of breeding material.

Traits

The first part of this component is to visually identify a character or trait which imparts resistance at any one of the phenological growth stages. Many examples could be given but some are good seedling emergence, lack of leaf desiccation during mid-season stress and absence of lodging at the time of terminal stress. All these traits should be easily identifiable. The success of the overall approach depends on selecting both highly resistant and susceptible material.

The second part of this component deals with the physiological measurements on the resistant and susceptible material. As physiologists we should understand the principles that determine why that seedling or plant survived the harsh environmental conditions. Successful development of stable drought resistant material requires good science, coupled perhaps with a bit of luck.

Collaboration

Finally, but not least, is the collaboration component and evaluation of identified traits. As we said earlier, breeding for drought resistance is a complex problem which up to the present has not been solved. It never will be if we work in isolation from our colleagues, not just within ICRISAT, but those working outside of ICRISAT. The collaboration should be international and must include both basic and applied research and evaluation of the important traits and material.

Sub-Saharan Africa (SSA) – the drought problem

In brief, what is important is that we are able to solve our customers drought problems in SSA. Obviously this poses an enormous problem in itself as there are so many different climatic zones and variable rainfall patterns.

Among the environmental factors that are most relevant for a discussion on drought are rainfall, temperature, radiation and soils. Seasonal variation in temperature and radiation at a given site are the most predictable. The most variable factor however is the amount and distribution of rainfall. This, in combination with the variation in the depth and physical characteristics of soils between locations, leads to droughts of varying intensities and durations during the growing season. The first requirement in the analysis of the environment then, as Turner 1982 points out, is the characterization of droughts experienced and expected at different locations.

Unfortunately, in spite of a wealth of information on weather, interpretation of this information in terms of plant response has relied strongly on extensive yield testing. Priority zones for sorghum research continue to be identified on the basis of mean annual rainfall while drought-prone regions continue to exhibit considerable variability in rainfall from year to year and large variations in spatial distribution are common. For example, the variation in mean annual rainfall at Banfora in Burkina Faso (Fig. 1) over the last 64 years is about 25%. Although the mean annual rainfall here is 1148 mm (as represented by the horizontal line), from 1968 onwards the rainfall has been below average and in 1983 it was only 480 mm.

Like most areas in SSA the rainfall in West Africa is variable not only from year to year but also from month to month within the same year. An example of this can be seen in Fig. 2 which depicts the daily mean rainfall at Niamey, Niger, during three years. The mean annual rainfall at Niamey is 560 mm. From this criterion, 1964 was an above-average year, 1968 an average year, and 1972 a year with below average rainfall. However the rains terminated by early September in both 1964 and 1968 while in 1972 it rained till 18 October.

The variations described above cause instability in the traditional methods of crop production and open to question the utility of employing average rainfall data in evolving 'drought strategies'. A rainfall record can provide a wealth of guiding information for agriculturalists but only if the information generated can be used in solving operational problems. Obviously careful analysis of the long term rainfall data is called for. Some of the more meaningful questions that could be asked are:

a) What is the average date of the beginning of the rainy season and what is the variability associated with it?

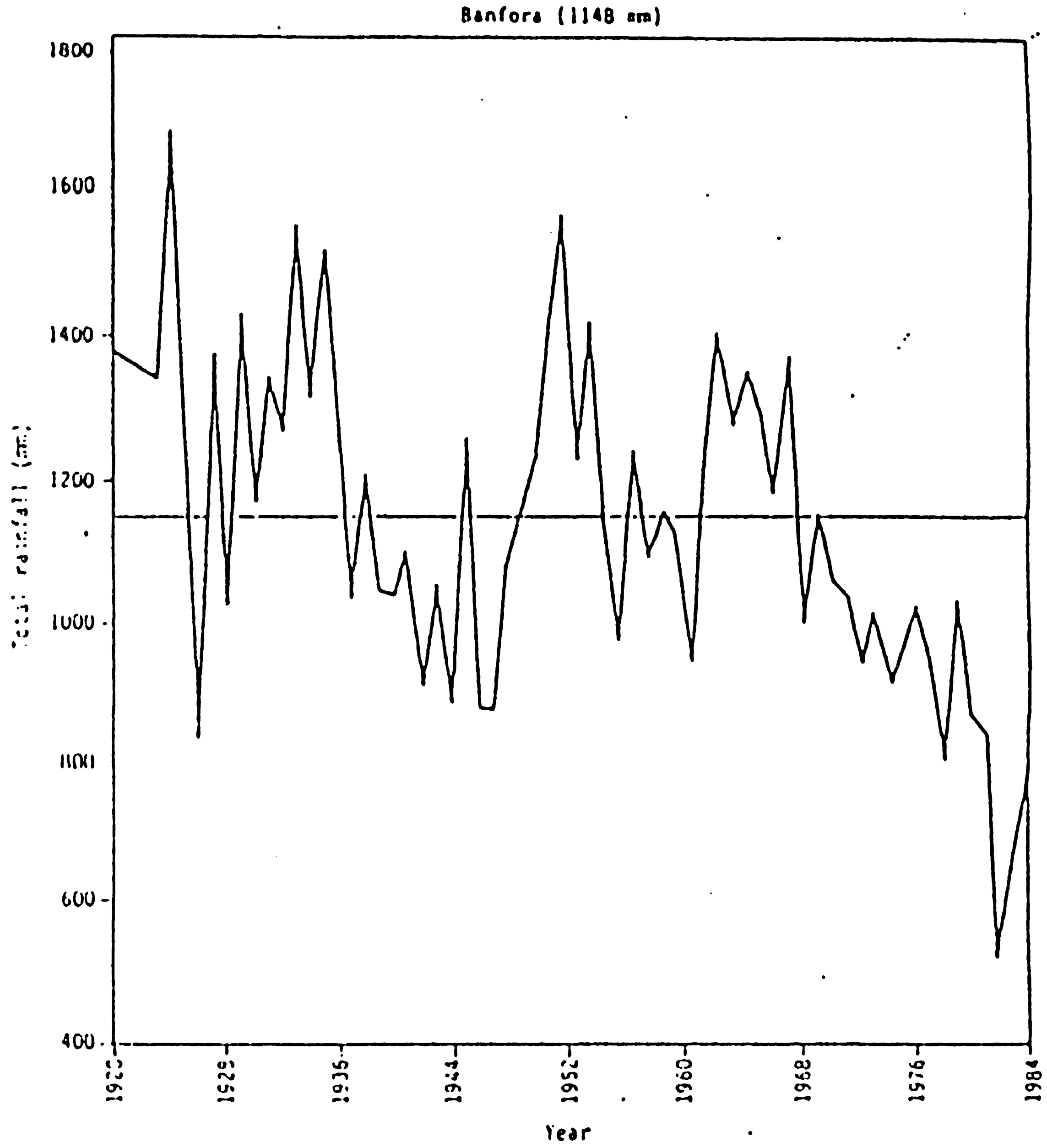

Figure 1 Annual rainfall variation at Banfora, Burkina Faso (Mean annual rainfall = 1148 mm).

b) When do the rains stop and what is the variability of the date when the rains end?

c) What is the average length of the growing season for a particular crop in a given location and what is the variability of this period?

d) Considering the above, what are the criteria to be used in the choice of a variety appropriate to this location?

e) In order to devise strategies for overcoming the effects of drought what are the probable periods of drought stress endured by a given variety?

Rainfall analysis: An example from Sub-Saharan Africa

To illustrate the application of agroclimatic information to answer the above questions, we have chosen five locations in SSA. These are Mopti (Mali) and Niamey (Niger) in the Sahelian climatic zone, Kaolack (Senegal) and

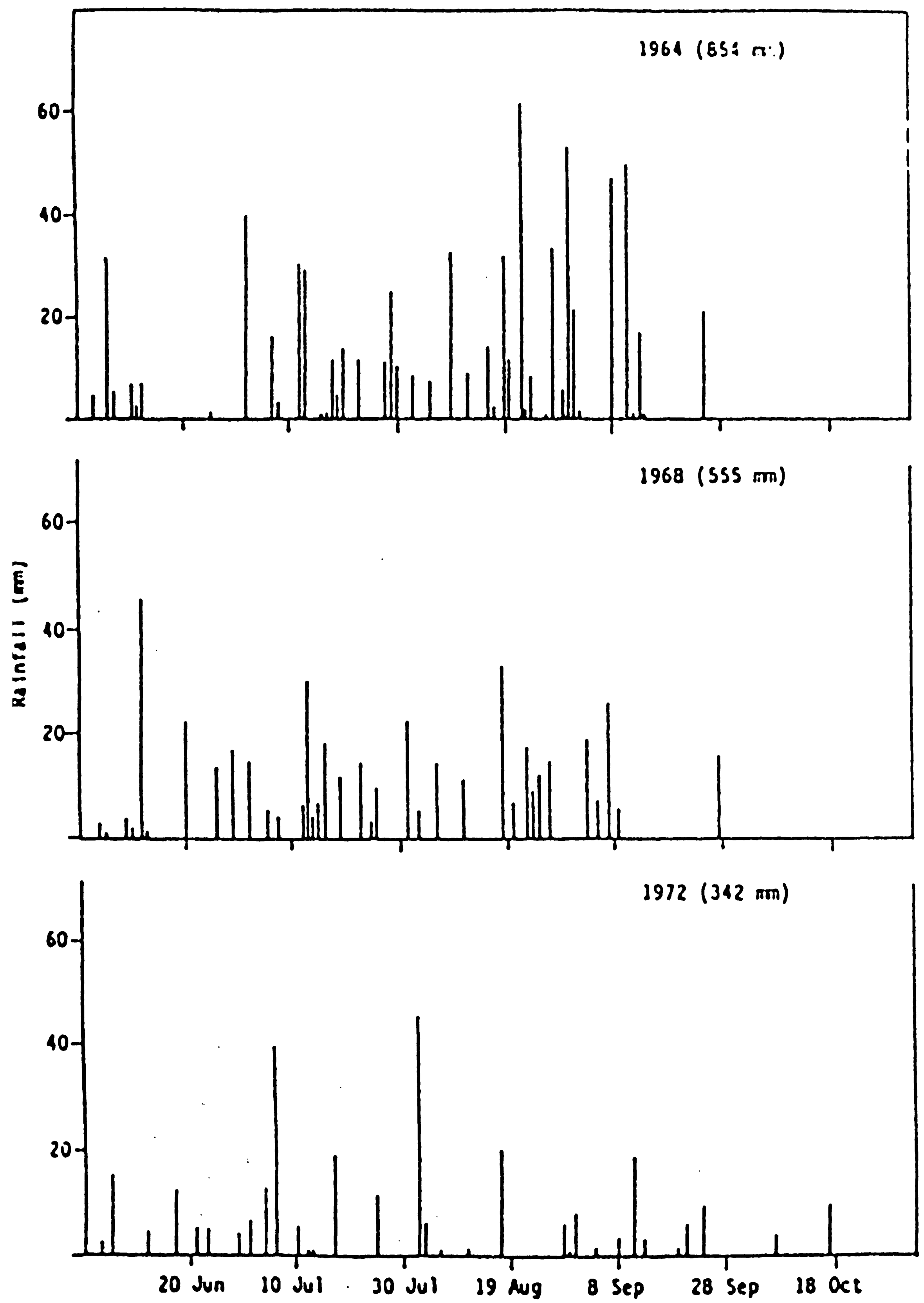

Figure 2 Daily rainfall variation at Niamey, Niger.

Ougadougou (Burkina Faso) in the Sudanian zone and Sikasso (Mali) in the northern Guinean zone.

Monthly and annual rainfall

The simplest analysis of rainfall is usually the calculation of means and variability. Monthly and annual rainfall statistics along with the data base for these five locations are given in Table 1. Mopti and Niamey with a low mean annual rainfall exhibit higher coefficients of variation (CV) than the other locations in SSA, specially in May and October. In general CVs during the rainy months of June to September range from 24 to 9 52% at different locations and the CV for annual rainfall ranges from 17 to 26%.

Considering the high variability associated with the monthly and annual rainfall it is imperative that strategic planning for the drought-prone regions must consider periods shorter than a month. Use of monthly averages to describe seasonal regimes is often suspect not only because moisture availability over a short period of even 10 days is critical but also the onset and the end of the season – either on average or for individual years – do not coincide with calendar months. Hence we have analyzed the daily rainfall data available over a period exceeding 50 years for these locations.

Beginning and end of rains

The date of the beginning of the rains is an important criterion in planning agricultural operations, particularly sowing. Various definitions of the beginning of rains are available. The criterion used here is that of receiving 20 mm of rainfall totalled over 3 consecutive days after 1 May with no period without rain longer than 7 days within the next 30 days. Experience with both sorghum and millet crops in West Africa suggests that this sowing criterion could give satisfactory emergence and plant stand. The date of ending of rains has been taken as the day after 1 September following which no rain occurs over a period of two decades (a decade is a 10 days period). The length of the rainy reason is the difference in days between the dates of the beginning and end of the rains, as defined above.

Table 1 Monthly and annual rainfall (mm) statistics at selected locations

Location	Data base	May		Jun		Jul		Aug		Sep		Oct		Annual	
	(yrs)	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Mopti (Mali)	58	26	100	60	52	146	40	183	39	93	45	19	96	534	23
Niamey (Niger)	78	35	93	76	52	143	37	193	40	90	51	16	100	563	25
Kaolack (Senegal)	56	5	232	60	70	157	49	293	40	211	44	63	76	796	27
Ouagadougou (Burkina Faso)	57	73	67	111	43	181	28	253	35	145	37	35	93	827	24
Sikasso (Mali)	65	113	52	165	32	268	29	334	24	242	37	98	60	1306	17

CV = Coefficient of variation (%)

Using these criteria we computed the dates of beginning and end of the rains and the length of the rainy season for each year of the data base for the five locations in SSA. Computations for each year have been used to calculate standard deviations associated with these dates. Results of this analysis, presented in Table 2, bring out more clearly the following important features of the daily rainfall at the selected locations (Table 1):

a) Rains at the drier Sahelian locations (Mopti and Niamey) begin 20-31 days later and end 25 days earlier as compared to the higher rainfall locations. The standard deviation of the beginning of the rains here is also higher. Hence in dry years the length of rainy season could be considerably shorter in the Sahel.
b) The end of rains is less variable than the start at the five locations in SSA as reflected by the lower standard deviations.
c) At Sikasso, the high rainfall location, the length of the rainy season is 46-52 days longer than at Niamey and Mopti and 13 days longer than at Ouagadougou.
d) Koalack, which has a mean annual rainfall nearly similar to that for Ouagadougou and falls in the Sudanian zone by that criterion, is like the Sahelian locations. The rainy season starts later at Kaolack indicating that much of the rains received earlier in the season are undependable for sowing. The length of rainy season at Kaolack is similar to that at Niamey.
e) The standard deviation of the length of rainy season at Mopti (26 days) and at Niamey (20 days) show that in dry years the length of the rainy season could be very short, viz. 62-74 days, showing thereby the reasons for crop failure in dry years.

Rainfall probabilities

Decadal precipitation totals for a long period of time are available for many of the drought-prone regions in SSA. These data can be analyzed by fitting the most appropriate mathematical function to the rainfall data and computing the probabilities of receiving a certain amount of rainfall, e.g. 10, 20, 30 mm, etc. We have used the Markov chain model for precipitation analysis which was introduced by Gabriel and Neumann 1962 and has been used widely. The application of these models in agricultural planning has been discussed by Stern and Coe 1982. Rainfall probabilities can be effectively used to sow the seasonal progression of rainfall dependability thereby providing a useful means to differentiate locations. This point can be amply illustrated for Kaolack and Ouagadougou which have the same mean annual rainfall. The probabilities of receiving 10 mm or more of rainfall during each decade at Ouagadougou and Kaolack are shown in Fig. 3. At Ouagadougou the rainfall probabilities by decade 12 are 35% but increase to 78% by decade 15 and stay above the dependable probability level of 70% (indicated by the horizontal line) till decade 27. At Kaolack the rains start late (Table 2) and so the probabilities do not reach the dependable level until decade 19 and stay below those at Ouagadougou until decade 21 but thereafter probabilities at Kaolack are higher.

Rainfall probabilities for Mopti and Niamey (Fig. 4) also show a slight advantage for Niamey where the probabilities reach the dependable level by decade 17 in contrast to decade 19 for Mopti. This initial advantage is reflected in the beginning of rains by 7 days and in the length of the growing season by 6 days for Niamey (Table 2). At Sikasso the dependable probabilities are attained by decade 14 and continue until deacade 29.

Figure 3 Probability of receiving 10 mm or more of rainfall during each decade at two locations in the Sudanian zone.

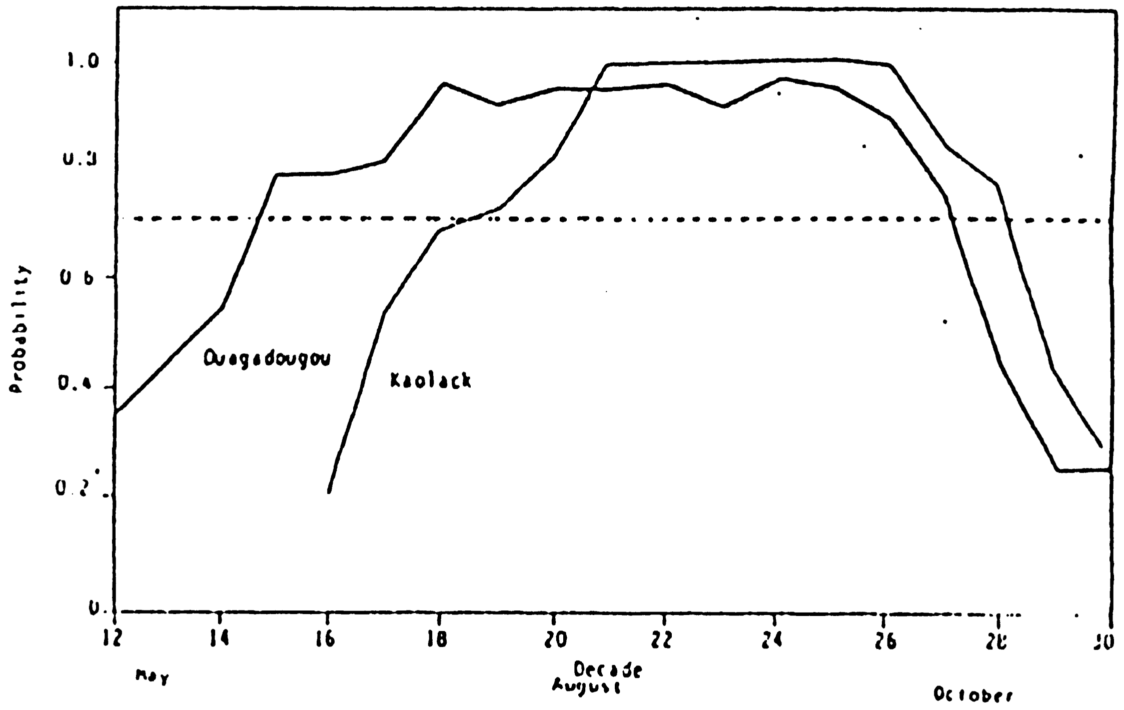

Table 2 Average dates of beginning and end of rains and length of rainy season at selected locations

Location	Beginning of rains		End of rains		Length of season	
	Date	s.d.	Date	s.d.	Days	s.d.
Mopti	19 June	21	15 Sep	11	88	26
Niamey	12 June	17	14 Sep	9	94	20
Kaolack	23 June	14	27 Sep	12	97	18
Ouagadougou	31 May	16	24 Sep	12	117	21
Sikasso	23 May	12	10 Oct	14	140	18

Drought probabilities

The analysis described so far provides useful information about a location but is still insufficient to supply answers to the specific question of probabilities of dry spells since there are occasions when dry spell frequency is more important regardless of rainfall totals. For example, in the case of sorghum it will be useful to have information on the relative susceptibility of the crop to drought spells during the GS1, GS2 and GS3 phases.

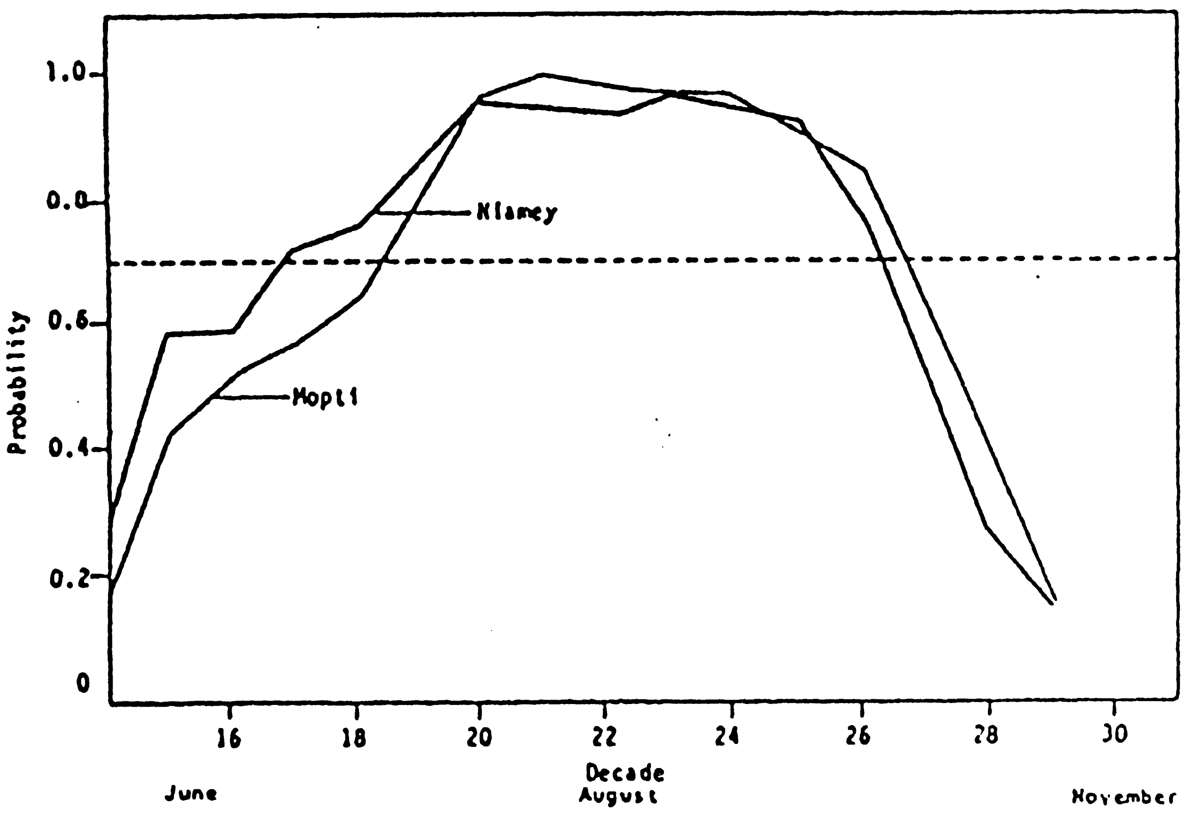

Figure 4 Probability of receiving 10 mm or more of rainfall during each decade at two locations in the Sahelian zone.

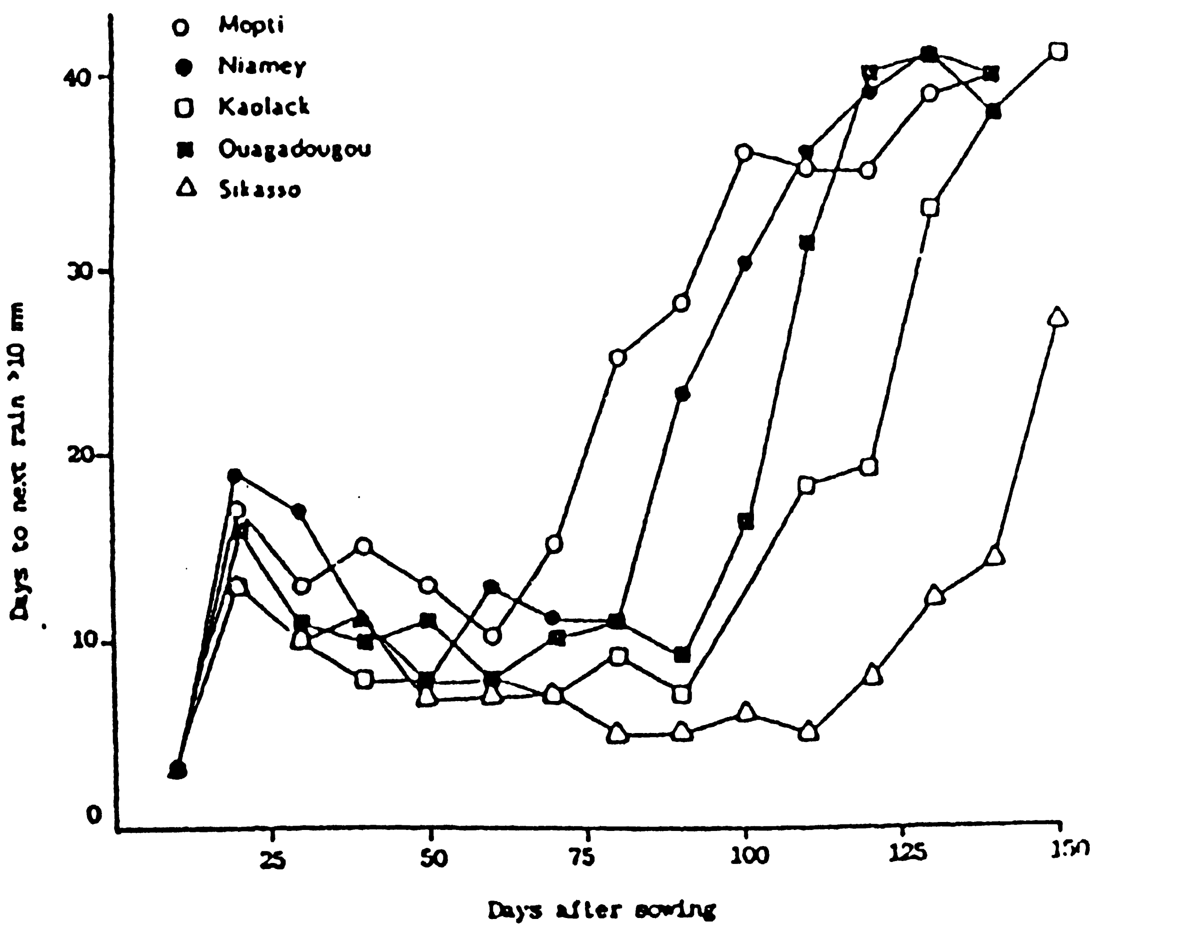

Figure 5 Number of days until the next rainfall greater than 10 mm at 90% [illegible] level at 5 selected locations

Assuming the computed date of beginning of rains in each year (defined previously) as the date of sowing, the length of dry spell (or days until next day with rainfall greater than a threshold value) at different probability levels can be computed for consecutive 10 day periods from sowing. Results of this analysis for the selected locations at a 90% probability level shown in Fig. 5 emphasise the following important points:

a) The dry spells during GS1 are more probable than those during GS2, specially at the low rainfall locations Mopti and Niamey.
b) At Mopti the length of dry spells is progressively longer during GS3 from 80 DAS and at Niamey from 90 DAS.
c) Kaolack and Ouagadougou with nearly similar mean annual rainfall show important differences in the length of dry spells as in the case of rainfall probabilities (Fig. 3). At Kaolack the length of dry spell is progressively longer form 100 DAS while at Ouagadougou this happens from 120 DAS.

Since the dry spell analysis shown in Fig. 5 is based on the computed date of sowing for each year of available rainfall data, these data could be used as a guide for the various maturity durations of varieties to breed for in different locations. At Mopti and Niamey breeding strategies should be oriented towards maturity durations of 80-90 days, for Kaolack 100 days, for Ouagadougou 110-120 dyas and for Sikasso 140 days. So far in this chapter we have attempted to better define some of the environments of SSA, but how can the physiologists use this information to solve the drought problems in Mopti, Niamey, Kaolack etc.

These data and the conclusions listed above provide essential information for the physiologists and the breeders for developing more stable yielding varieties for these five locations. Clearly physiologists and breeders from these locations should now concentrate on screening the sorghum material for those traits which will impart resistance during GS1 and GS3. However although many other locations in SSA have similar drought distributions to the five locations described, there are those such as the central region of Tanzania where there are mid season or GS2 droughts.

The next step in this paper is to describe those stages, of the components of the 'environmental physiologists' approach, that lead to the development of more stable and higher yielding lines for GS1, GS2 and GS3 stress environments. Although screening methods have been developed by ICRIAT scientists for all three stress environments it will not be possible to describe more than one in this paper. Our aim is to also demonstrate that the overall approach, irrespective of the particular growth stage (ie. GS1, GS2 or GS3) at which the stress occurs, is similar.

Screening methods for identifying good crop establishment traits in both sorghum and millet have been published and these are also described by Soman *et al.* 1986 in these proceedings. Similarly the important traits associated with GS3 were extensively reviewed in 1983 at the Bellagio workshop in 1984. Consequently we will concentrate on a mid-season stress situation, and go systematically through our approach for a location in India.

The environmental physiologist's approach – an example from India

Customer

Farmers at Anantapur who grow sorghum for food and fodder.

Environment

The mean annual rainfall at Anantapur is 590.2 mm, very similar to Mopti and Niamey but the distribution is very different. Fig. 6 shows that the drought problem is one of mid season stress.

As a result of the distance from Patancheru and the poor resources available at Anantapur it is impossible to conduct all the research at that location. Some of the more detailed research had to be undertaken at Patancheru.

Unfortunately the normal growing season at Patancheru, in the absence of a "rain-out" shelter, does not enable us to do this and therefore it was necessary to simulate mid-season stress conditions 'out of season'. This was done, by growing material in the summer season (i.e. March to the onset of rains in June).

Growth stage

The growth stage is GS2 and is usually associated with the growth from about the time of floral initiation to that of anthesis or 50% flowering. However, the onset of the stress may occur before initiation, particularly with late maturing varieties.

Germplasm

It would be extremely difficult to systematically screen the 26000 accessions of sorghum that have been collected so far. Thus, a representative sample was selected. In 1983, a total of 700 selected germplasm accessions and

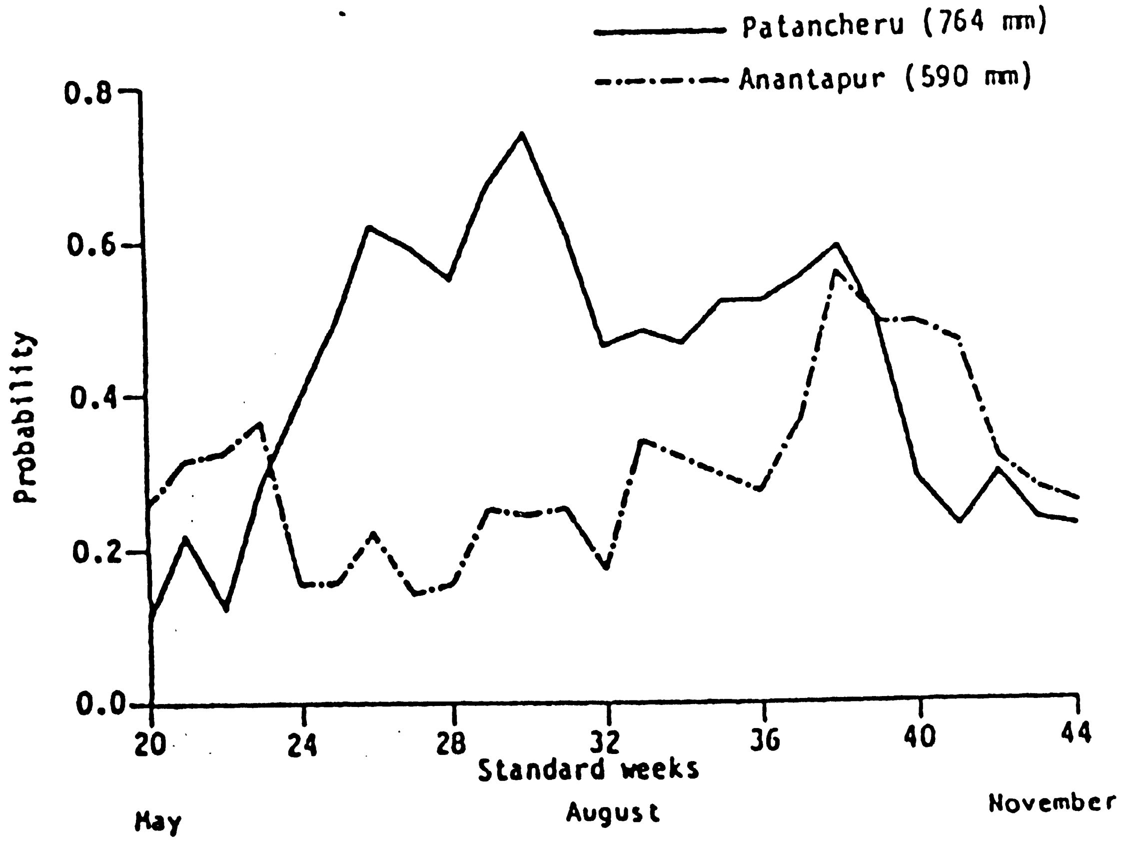

Figure 6 Probability of receiving 20 mm or more of rainfall during each standard week at two locations in India.

advanced breeding lines were screened during the summer (March-June) at ICRISAT Center. The material was divided into three groups; the first two comprised germplasm lines selected from a wide range of taxonomic groups (e.g. durra, caudatum, etc.), geographical locations (countries where sorghum was collected), and climates (range of altitudes and mean annual rainfall). The third group included both germplasm and 70 advanced breeding lines developed at ICRISAT or by national programs. The material was sown in mid March and established with irrigation for 15 to 18 days. Irrigation was then discontinued and the midseason stress imposed.

Traits

Many physiological traits that affect crop adaptation to drought and high temperatures have been identified and a "physiological approach" to breeding for drought resistance has been described by Morgan 1980, Bidinger 1980 and Steponkus *et al.* 1980. However, in the early stages of our screening program it was essential to examine only those traits that could be visually recognised. The two traits examined were:

1. Desiccation tolerance, i.e. a measure of the amount of leaf area that remained unscorched or "fired'. We scored leaf firing at regular intervals during the stress period on a 1 to 5 scale, where 1 = less than 20% of leaf-area fired, and 5 = over 80% leaf-area fired.
2. Recovery ability, i.e. ability of a previously stressed line to produce new leaves and grain after rain. We scored recovery ability on a 1 to 5 scale where 1 = over 80% of the plants in a row recovered, and 5 = less than 20% recovered.

We examined the results of the 1983 screening and retained lines that had a leaf firing score of less than 3 (most resistant) and those having more than 4 (most susceptible). Fig. 7 shows the effects of stresses due to heat and lack of water on a typically 'resistant' and 'susceptible' line. We selected 266 lines for further screening in 1984.

These selected lines were sown on 16 March 1984 in an Alfisol at ICRISAT Center with four replications. The crop was established with irrigation (soil brought to field capacity) and midseason stress imposed by witholding irrigation from 20 DAS. All the lines experienced stresses from heat and lack of water for a period of 66 days. During the stress period only 4.5 mm of rain fell, and the mean maximum temperatures were close to 40°C. The stress ended at 91 DAS, following 21.6 mm of rain. We scored the material for leaf firing at 48, 61, 70 and 83 (DAS), for recovery ability at 89, 94, 102, and 117 (DAS), and for grain yield when the lines reached physiological maturity.

The visual screenings in 1983 and 1984 clearly demonstrated that there were marked differences in the response of these sorghum genotypes to high temperature and water deficit. It was argued that our screening approach could be simplified even further, if the underlying mechanisms associated with these striking differences (Fig. 7) were understood.

Survival (maintenance of membrane integrity) is ultimately determined by the plants' ability to maintain an internal water status which will allow it to sustain a minimum of essential metabolic processes such as photosynthesis and respiration, and to facilitate transpirational cooling of leaves. The apparent failure of some of the genotypes in the earlier screenings were a consequence of one or more of the following:

Figure 7 Effects of stresses due to heat and lack of water on two sorghum cultivars. IS 22327 (left), a resistant line from Botswana, and IS 12741 (right), a susceptible line from China, ICRISAT Center, 1984. (Source ICRISAT Annual Report 1984).

1. An inadequate root system, which was unable to extract water to sustain atmospheric demand.
2. Stomatal behaviour which is over sensitive to plant water deficit and high evaporative demand.
3. The cell and leaf tissue is unable to survive at temperatures above 40°C.

From the 266 lines sown in 1984 only 157 flowered by the end of the recovery period. Of these we selected five 'susceptible' lines (FS) and four 'resistant' lines (FR) (Table 3) for a detailed experiment, to examine the physiological bases of resistance to mid-season heat and drought stress.

Instrumentation was installed in two replicates of each of five genotypes in stress and control treatments. The lines measured are marked with an asterisk in Table 3 and represent an early and a late maturing 'susceptible' line and two early and one late maturing 'resistant' lines. Full details of this instrumentation and the physiological measurements are given by ICRISAT 1986 and Peacock *et al.* 1985.

In brief, the following measurements were made on the youngest fully expanded leaf: relative leaf water content (RLWC – defined as the ratio of leaf water content at sampling to that at full turgor), leaf water potential (ψl – as measured with a pressure chamber) and stomatal conductance (gl – measured with a diffusion porometer). Measurements of light incident on the leaves, (Si), and the leaf temperature, (tl), at the time and site of measurement of conductance were made with a quantum sensor and an infrared thermometer, respectively.

Measurements of ψl, gl, Si, and tl were made on the same leaves. Immediately after the measurements of gl, Si, and tl, the leaf was excised and returned to a field laboratory for measurements of ψl and RLWC. Soil water content was measured in these plots, using a neutron probe. Detailed measurements continued until the onset of the rains at 84 DAS after which only dry matter production and grain yield were measured.

The purpose of this paper was not to examine in detail the data from these physiological experiments but to illustrate that it is possible to systematically screen the germplasm and breeding lines. Also, by setting the correct 'selection pressure', it was possible to rapidly identify material from which it may be possible to obtain drought 'resistance' genes. We selected three sets of data.

Results shown in Fig. 8a and 8b clearly demonstrate that, after a critical level of stress is reached (56 DAS), the 'resistant' lines have a very different

Table 3 Sorghum lines used in detailed physiology experiment at ICRISAT Center, summer 1985.

Sorghum line	Origin	Elevation (m)	Annual Rainfall (mm)	Taxonomic group	Time to 50% flowering
Susceptible 1					
*IS 17605	Yemen	1970	600	Durra	131
*IS 12739	China	-1	-	Caudatum bicolor	50
IS 12744	Taiwan	-	-	Guinea caudatum	53
IS 21436	Malawi	75	800	Durra	56
IS 22253	Botswana	1250	514	Kafir	52
Resistant (FR)					
*IS 20969	Kenya	1100	1500	Caudatum	115
*IS 1347	Egypt	-	-	Caudatum bicolor	48
*IS 13441	Zimbabwe	-	-	Caudatum	60
IS 22380	Sudan	600	450	Caudatum	85

1 = Data not available
* = Measurements taken

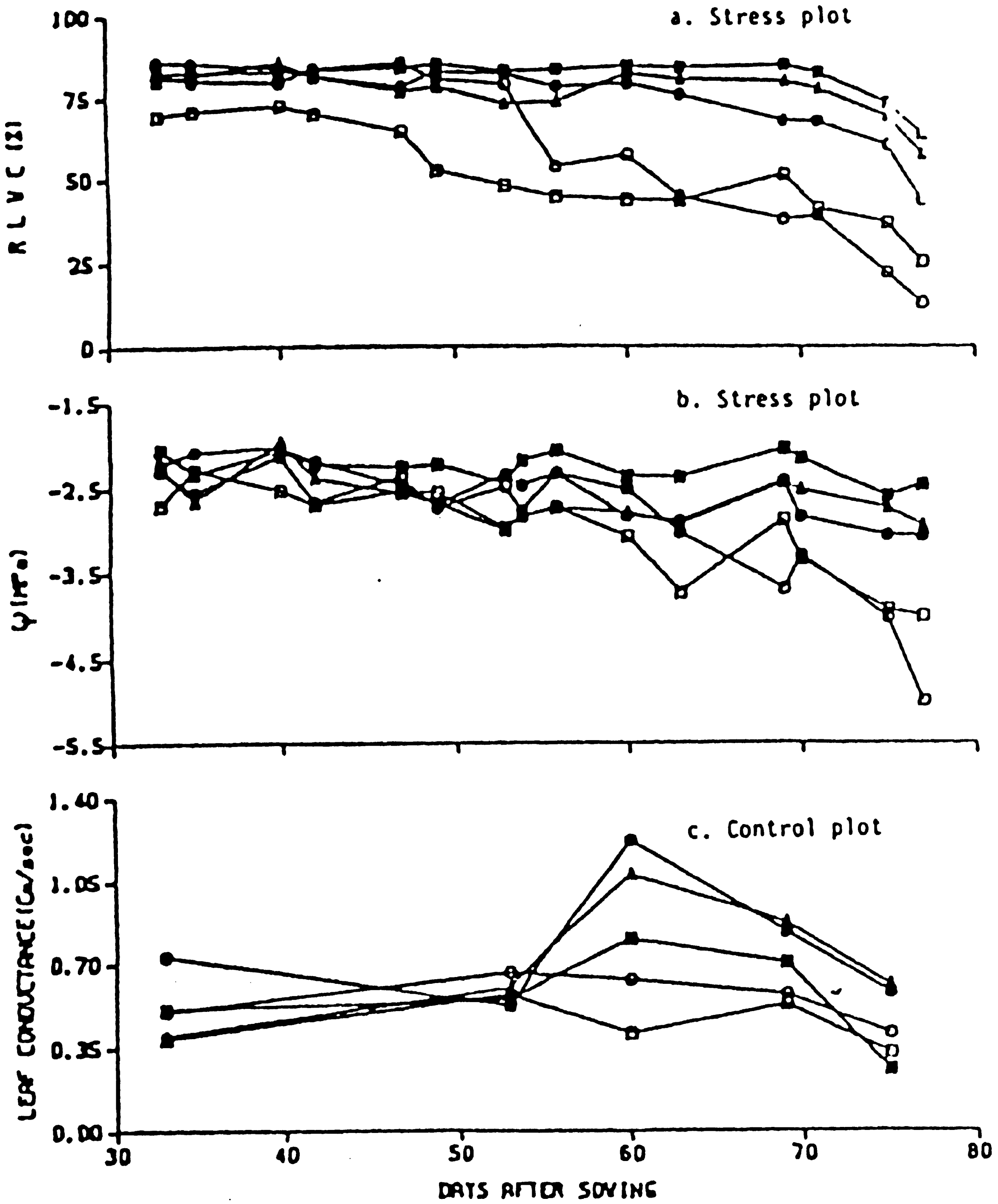

Figure 8 Measurements made at 12.30 h on the midportion of the youngest leaves in five sorghum lines IS 20969 (■), IS 13441 (▲), and IS 1347 (• (resistant), and IS 12739 (o) and IS 17605) (□) (susceptible) of (a) relative leaf water content (RLWC %) and (b) leaf water potential ψl MPa in the stress plots and (c) leaf conductance (gl cm sec−1) in the control plot, ICRISAT Center, summer 1985. [From Peacock *et al.* 1985.]

plant water status to the susceptible lines, in terms of RLWC and ψl under both soil and atmospheric water stress. Noticeably, the trend for both traits is the same. A similar response, under atmospheric water stress only is shown in Fig. 8c for stomatal behaviour in terms of individual leaf conductance, gl. The terminology requiring phrases such as 'resistant' and 'susceptible' was obviously subjective, based on the earlier visual scorings. Yet these data verify that these visual differences are based on measurable

physiological traits and could be used effectively in an improvement program to identify 'resistant' genes.

Collaboration

We have little information on the more basic characteristics of these constrasting lines. To date, most of the significant collaborative basic research has been done at the seedling stress stage or earlier. An example of this research is a Ministry of Overseas Development Project (R3801) being conducted at the Welsh Plant Breeding Station (WPBS), in the UK. Earlier, using techniques developed at ICRISAT Center we have shown considerable genetic variation in the ability of sorghum seedlings to emerge at high temperatures. The biochemists at the WPBS, working with the same genotypes, showed clearly that the differences in seedling emergence were closely related to the rates of embryo-protein synthesis. Such collaborative research has not only enabled us to jointly develop a more rapid screening method, but has led to an understanding of some of the underlying mechanisms influencing crop establishment at high temperatures. In the meantime in the area of mid-season stress collaborative research on the applied side has been going on with the Andhra Pradesh Agricultural University (APAU) at Anantapur where lines are evaluated under a typical mid-season stress. In 1985 we obtained excellent correspondence between results at Patancheru and Anantapur.

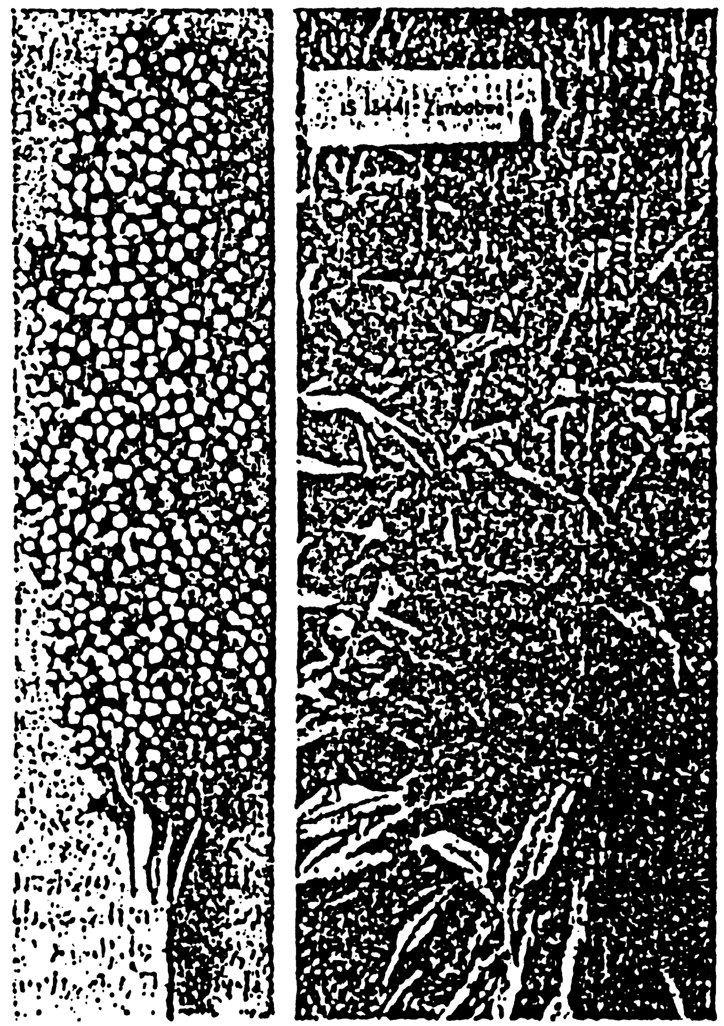

Figure 9 Sorghum cultivar IS 13441 from Zimbabwe with firing resistance and ability to recover from severe stress. This line has also produced good grain yields on large panicles (left). Source ICRISAT Annual Report 1984).

Conclusions

The approach described has enabled sorghum scientists at ICRISAT Center to focus their screening efforts on specific drought problems and identify important traits associated with that particular drought. This information is also useful in the rapid screening of environments for the choice of suitable testing sites for breeding material, thereby eliminating the present empirical, ad hoc methods of yield testing.

However, we are still some way from our goal as these identified traits have yet to be incorporated, by conventional breeding methods, into better agronomic backgrounds. However, some of the so called germplasm accessions, such as IS 13441 from Zimbabwe, (Fig. 9) are not only a source of these useful traits but also have relatively high yields. It is also encouraging to learn that one of the promising lines, IS 22380 from Sudan, is being used as a parent in Burkina Faso.

Looking to the future, regional programs like SAFGRAD, the national programs and international Centers engaged in agroclimatology should put more emphasis on developing those types of climatic analysis that can better describe the various climatic zones, soils and droughts of the SSA, and at the same time can be used by breeders and physiologists.

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References

Benoit, P. 1977. The start of the growing season in Northern Nigeria. *Agric. Meteorol.* 18:91.

Bidinger, F.R. 1980. Breeding for drought resistance. Pages 452-454 *in* N.C. Turner and P.J. Kramer, eds. Adaptation of plants to water and high temperature stress. Wiley Interscience, New York, NY 482 p.

Blum, A. 1983. Genetic and physiological relationships in plant breeding for drought resistance. *Agric. Water Manage., 7:195-205.*

Christiansen, M.N. and Lewis, C.F. 1982. Breeding plants for less favourable environments. *Wiley Interscience, New York, NY 459 p.*

CILSS (Comite Permanent Interetats de Lutte Contre la Secheresse dans le Sahel) 1984. Rapport Annual 1983, CILSS, Bamako, Mali.

Cocheme, J. and Franquin, P. 1967. An agroclimatological survey of a semi-arid area in Africa south of the Sahara. *WMO Tech. Notes No. 86.*

Davey, E.G., Mattei, F. and Solomon, S.I. 1976. An evaluation of Climate and water resources for the development of agriculture in the Sudano-Sahelian zone of West Africa. *WMO Special Environment Report No. 9.*

FAO (Food and Agriculture Organization of the United Nations). 1984. *Production year book 1983, pp. 119-120. FAO, Rome.*

Gabriel, K.R. and Neumann, J. 1962. A markov chain model for daily rainfall occurrence at Tel Aviv. *Quart. J. Roy. Met. Soc. 88:90.*

Hills, R.C. and Morgan, J.H.T. 1981. Rainfall Statistics: an interative approach to analysing rainfall records for agricultural purposes. *Expl. Agric. 17:1.*

House, L.R.1982. A look ahead into the 1980s. Pages 61-68. In: Sorghum in the eighties: *Proceedings of the International Symposium on Sorghum, 2-7 Nov. 1981, Patancheru, A.P., India: ICRISAT.*

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985. *Annual Report 1984. Patancheru, A.P. 502 324, India: ICRISAT, 376 p.*

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. *Annual Report 1985, ICRISAT, Patancheru, A.P., India.*

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Sorghum root and stalk rots, a critical review: *Proceedings of the consultative group discussion on research needs and strategies for control of sorghum root and stalk rot diseases, 27 Nov.-2 Dec. 1983, Bellagio, Italy, Patancheru, A.P. 502 324, India: ICRISAT.*

Jordan, W.R. and Sullivan, C.Y. 1982. Reaction and resistance of grain sorghum to heat and drought. Pages 131-142. In: Sorghum in the eighties: *Proceedings of the International Symposium on Sorghum, 2-7 Nov. 1981, Patancheru, A.P. India: ICRISAT.*

Morgan, J.M. 1980. Differences in adaptation to water stress within crop species. Pages 369-382 in N.C. Turner and P.J. Kramer, eds., *Adaptation of Plants to Water and Light Temperature Stress. Wiley Interscience, New York, NY 482 p.*

Mussell, H. and Staples, R.C. 1979. Stress physiology in crop plants. *Wiley Interscience, New York, NY 510 P.*

Ougham, H.J. and Stoddart, J.L. 1985. Development of a laboratory screening technique, based on embryo protein synthesis, for the assessment of high temperature susceptibility during germination of *Sorghum bicolor. Expl. Agric. 21:343-355.*

Paleg, L.G. and Aspinall, D.D. 1981. The physiology and biochemistry of drought resistance in plants. *Academic Press, New York, NY 492 p.*

Peacock, J.M. and Wilson, G.L. 1984. Sorghum. Pages 249-279 *in* P.R. Goldsworthy and N.M. Fisher, eds., *The physiology of tropical field crops. John Wiley & Sons, Chichester. 664 p.*

Peacock, J.M., Syed Azam Ali, and Matthews, R.B. 1985 In press. Effect of high temperature on the establishment and embryo protein synthesis of *Sorghum bicolor. Presented at the International Arid Lands Research and Development Conference "Arid Lands: Today and Tomorrow", 20-25 Oct. 1985, Tucson, Arizona, USA.*

Raper, C.D. Jr. and Kramer, P.J. 1983. Crop reactions to water and temperature stresses in humid temperature climate. West View Press, Boulder, Colorado. 373 p.

Shao, F.M. 1986. Agricultural research strategies to promote dryland agriculture in Tanzania (these proceedings).

Soman, P. and Peacock, J.M. 1985. A laboratory technique to screen seedling emergence of sorghum and pearl millet at high soil temperature. *Expl. Agric. 21:335-341.*

Soman, P., Stomph, T.J., Bidinger, F.R. and Fussell, L.K. 1986. Improvement in stand establishment in pearl millet (these proceedings).

Steponkus, P.L., Cuttler, J.M. and O'Toole, J.C. 1980. Adaptation to Water stress in rice. Pages 401-418 in N.C. Turner and P.J. Kramer, eds., Adaptation of plants to water and high temperature stress. *Wiley Interscience, New York, NY 482 p.*

Stern, R.D. and Coe, R. 1982. The use of rainfall models in agricultural planning. *Agric. Meteorol. 26:35.*

Stern, R.D., Dennett, M.D. and Garbutt, D.J. 1981. The start of the rains in West Africa. *J. Climatol. 1:59.*

Turner, N.C. 1982. Factors reducing sorghum yields Environmental stress. Pages 191-203. In: Sorghum in the eighties: *Proceedings of the International Symposium on Sorghum, 2-7 Nov. 1981, Patancheru, A.P. India: ICRISAT.*

Turner, N.C. and Kramer, P.J. Adaptation of plants to water and high temperature stress. *John Wiley & Sons, New York. 482 p.*

Walter, M.W. 1967. Length of the rainy season in Nigeria. *Niger. geogr. J.* 10:123.
Wilson, G.L., Raju, P.S. and Peacock, J.M. 1982. Effect of soil temperature on seedling emergence in sorghum. *Indian J. agric. Sci.* 52:848-851.
World Bank, 1984. Toward sustained development in Sub-Saharan Africa. *1818 H Street, NW, Washington, D.C. 20433, USA.*

9 Breeding Sorghum Hybrids for Irrigated and Rainfed Conditions in the Sudan

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Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is the most important food crop in the Sudan. With over one third of the crop land in the country devoted to sorghum, it ranks first in total tonnage of grain produced and total area cultivated. Every year some 75% of the total cereal production in the Sudan is generated from sorghum. In most years, the total area under sorghum is over 3 million hectares and over 2.5 million metric tons of sorghum grain is produced. In contrast the total production from all other cereals (millet, wheat, rice and maize) is less than one million tons. Following the 1984 drought, over 4 million hectares of sorghum were planted in the 1985 crop season and resulted in a large production surplus in the current 1985/86 marketing year.

In Sudan, sorghum is the main staff of life for millions of people. In many parts of the country, the crop is wholly utilized. The grain is used for making *kisra* (unleavened bread from fermented dough); a significant portion is also used as thick porridge, *asida*; as a popular beverage, *abreih* and as a local beer, *marisa*. The stalks are used as building material and the straw is used as animal feed or as fuel. Sorghum is thus the nutritional backbone of the country.

Rationale for Hybrid Sorghum Research

The decision to develop an expanded hybrid sorghum research program in Sudan was timely and important. In the Central Clay Plains, mechanized sorghum production on increasingly large farms created the demand for short, combinable, sorghum types. Work in the region by the Agricultural Research Corporation (ARC) over several years had clearly demonstrated that traditional local varieties were late, tall and unadapted to the large mechanized farming operations. As a result, there was a conscious effort by the ARC to undertake intensive selection for high yielding cultivars suitable for mechanized types within the otherwise good local land race varieties. In much of the rainlands seasonal precipitation is usually unpredictable and unreliable with the result that yield reductions and crop failures are common in some years. It has been widely demonstrated that sorghum hybrids have higher yield potential and greater stability under stress conditions than varieties. Hence from the outset it was believed that superior sorghum hybrids identified under local conditions in Sudan could rapidly increase and stabilize yield levels in the rainlands.