Some strategies to cope with drought in the Sahelian zone

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Per capita food production in the Sahelian zone of West Africa over the last two decades was negative. Substantial progress is needed during the next decade. Efforts to cope with drought must aim at understanding the entire production system—climate, management, genotypes. Droughts in the Sahel are characterized by extreme variability in time and space, persistence, and variable lengths of growing season. Aspects of current management systems and genotype selection that directly or indirectly aggravate effects of rainfall deficits are highlighted. Strategies to cope with drought, starting with an analysis of climate data, are illustrated. Simple management techniques, such as tillage, application of fertilizer, and intercropping, are an effective short-term strategy. A long-term strategy is to breed stable, high-yielding, drought-resistant cultivars.

The food production crisis in sub-Saharan Africa has been the focus of intense discussion in many national and international forums because the geographical regions and the populations involved are large and the time scale for solving the crisis is short. Thirty million people in Africa were affected by drought in 1985 (Timberlake 1985). Food deficits in sub-Saharan Africa alone are projected to be 27-34 million t by 1990 (IFPRI 1977).

About 90% of the population in sub-Saharan Africa depend on subsistence agriculture for survival, and agriculture is the main contributor to the gross domestic product (GDP) (Mudahar 1986). In the sorghum- and millet-growing countries of West Africa, the average population growth rate from 1970 to 1982 was 2.8%, while per capita food production was negative. Substantial progress in agricultural production needs to be made rapidly if the negative trends are to be reversed.

This paper reviews some strategies for coping with drought in the Sahelian zone. Pearl millet is used as the specific example because this important cereal crop is grown all over the Sahelian zone, from the extreme desert in Mauritania on the edge of the Sahara to higher rainfall regions in Burkina Faso and Nigeria.

Complexity of drought

Drought, often cited as the constraint to increasing the agricultural productivity in the Sahelian zone, is believed to result from lack of rainfall. This, at best, is an extremely simplistic view of a complex problem. In a recent report, Farmer and

Wigley (1985) said, "Although many of the meteorological features associated with drought conditions are now well-documented, the underlying causes of both the present drought and earlier droughts are unknown. It is clear that the causes of drought in Africa are complex and almost certainly not attributable to any single factor."

Drought is not a single constraint, but a complex of constraints. Crop performance in drought conditions has a genetic component and a management component (Jordan and Sullivan 1982), with complex interactions between the two components. A thorough understanding of the entire production system, including climate, management, and genotype, is a prerequisite to effective management of crop production systems in drought conditions. Insufficient rainfall creates conditions wherein crop growth suffers, but other important aspects of the current management system and genotype selection directly or indirectly aggravate the negative effects of rainfall deficiency.

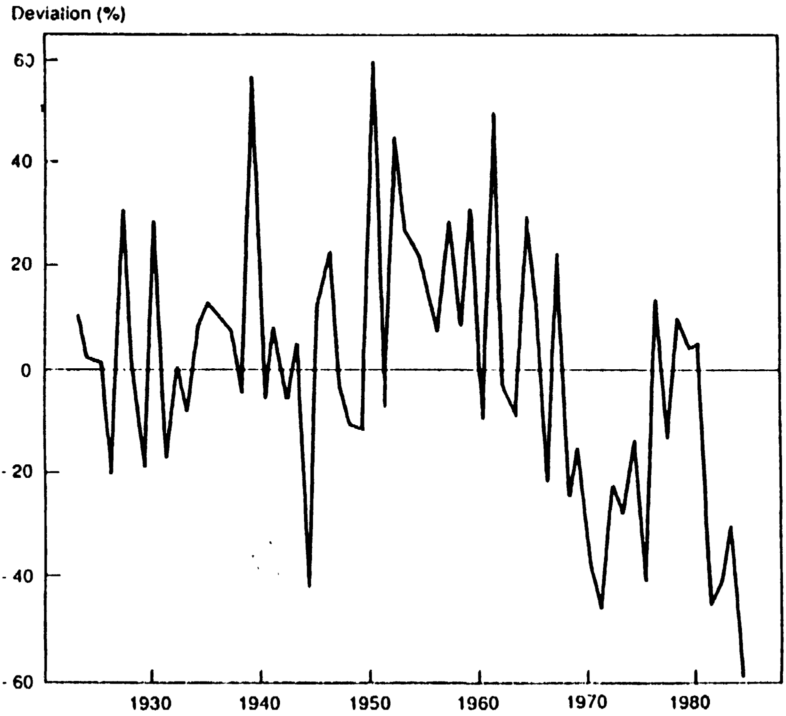
Climatic causes of drought

Extreme rainfall variability. In the Sahelian zone, droughts are set off by rainfall deviations that fall far below already low and undependable rainfall. Temporal and spatial variations in rainfall are large, and in the marginal areas, agricultural systems are vulnerable to large deviations. The impact of temporal variations depends on the scale at which they are considered (these variations increase as one moves from an annual to a daily scale). Examples of temporal variation on different scales have been described in detail (Sivakumar 1987a). Spatial variability in rainfall is equally important where large variations in rainfall occur over short distances and at critical stages of crop growth.

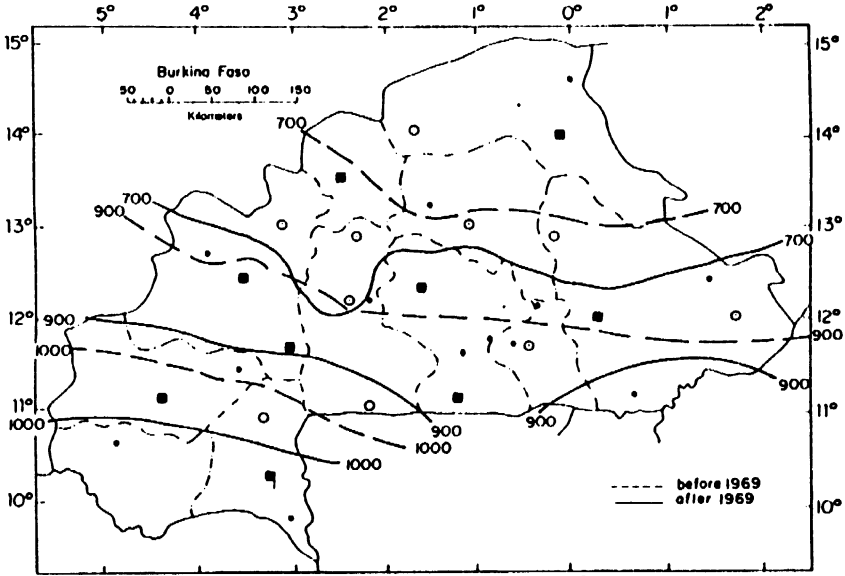
Persistence of deficiencies. An important feature of Sahelian rainfall is the magnitude and extent of the rainfall deviations. Below-normal rainfall can persist for 10-20 yr. At Tillabery, Niger, the period between 1966 and 1984 has been consistently dry; the rainfall deviation in 1984 was 58% below the mean (Fig. 1). Rainfall fluctuations also are associated with a preferred geographic pattern. In Burkina Faso reduction in mean annual rainfall after 1969 (Fig. 2) (Sivakumar 1987a) was the geographical mean pattern. Rainfall isohyets were displaced farther south after 1969, showing the geographical extent of the drought.

Erratic growing seasons. Potential evapotranspiration (PET), or water demand, is usually high in the Sahel due to consistently high air temperatures and radiation load. Hence, the length of growing season, which is a balance between the water supply and demand, depends on the rainfall. But rainfall is erratic. Length of growing season for Niamey, computed for an 80-yr rainfall record, is shown in Figure 3. The average is 94 d. But rainfall below average since 1969 has resulted in far below average growing-season lengths. In poor-rainfall years with short growing seasons, crop failures result from a mismatch between water availability and crop phenology.

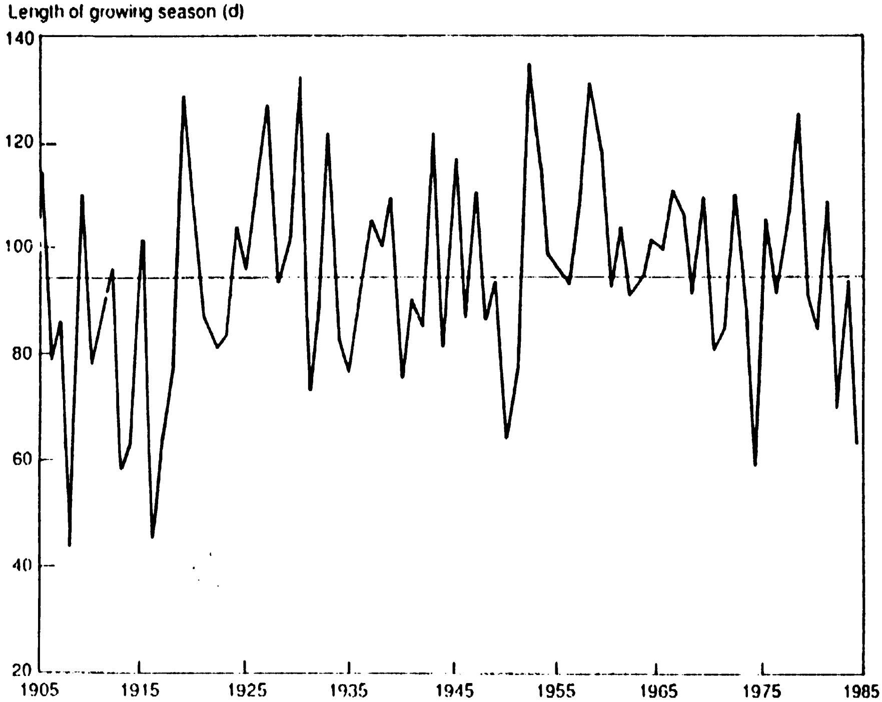
High soil temperatures. Environmental conditions during crop establishment are usually harsh, because the sowing rains follow a long, hot dry season. Although one or two showers facilitate sowing, soil moisture evaporates quickly. If a period of dry, clear weather follows, soil surface temperatures increase rapidly, up to 55 °C. Under these conditions, pearl millet seedling death is common, leading to plant



1. Rainfall deviation at Tillabery, Niger, 1923-84.



2. Deplacement of rainfall isohyets in Burkina Faso before and after 1969.



3. Variation in the length of the growing season at Niamey, Niger, 1905-85.

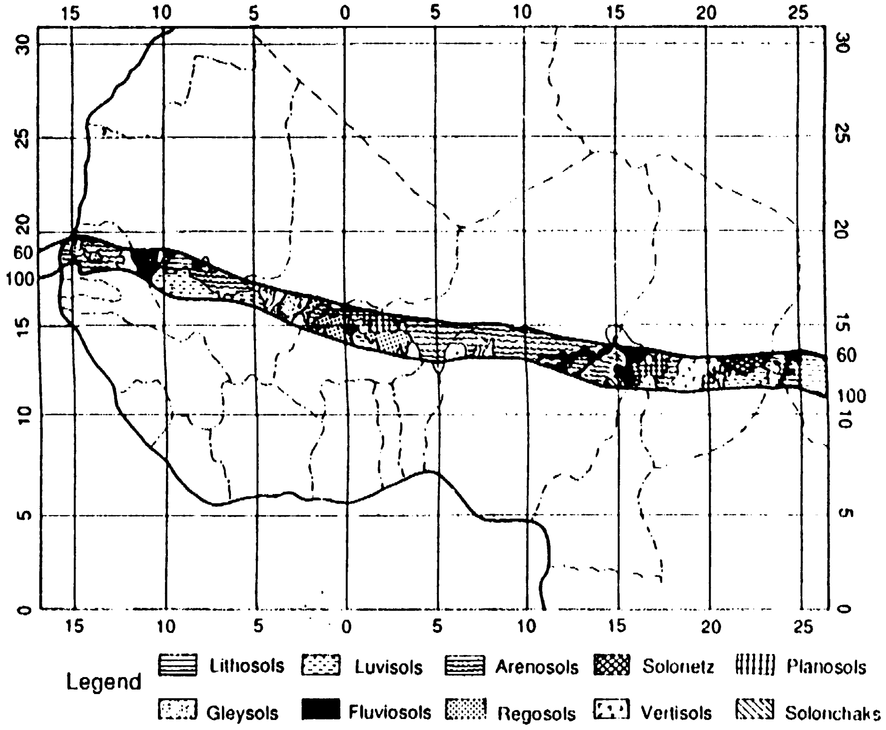
stands much below the recommended 10,000 hills/ha. In field surveys in the Niamey district, hill populations declined from a mean of 4,900/ha at 5 d after sowing (DAS) to 2,300/ha at 12 DAS, with stands failing completely in nearly half of the fields (Soman et al 1986). In those fields, soil temperatures exceeded 50 °C at midday. Such conditions often force the farmers to replant their fields 2-3 times a year.

Nonclimatic causes of drought

Limited, untimely cultural practices. Two soil types in the Sahelian zone occupy 40.2 million ha, 61% of the total area (Fig. 4) (Sivakumar 1986).

Arenosols are coarse-textured soils containing more than 65% sand and less than 18% clay (Swindale 1982). They have low moisture-holding capacity, which imposes a severe drought risk when extended dry periods occur during the crop season.

Luvisols are characterized by clay content and bulk densities that increase with depth, with low cation exchange capacities, hydraulic conductivities, infiltration rates, and available moisture (Perrier 1986). During the rainy season, the soil surface forms a hard crust. Reduced infiltration and increased runoff cause substantial moisture losses. Charreau (1972) showed that as much as 32% of the annual rainfall could be lost as runoff on a cultivated, well-tilled soil, and as high as 60% could be lost on bare soil. Perrier (1986) estimates surface runoff losses from any given area in the Sahel to vary from 40 to 80% of annual rainfall.



4. Major soil types in the southern Sahelian zone of West Africa.

It should be obvious that appropriate soil and water management practices are crucial for efficient use of the limited and variable rainfall. However, soil management practices are virtually unknown at the farm level. Traditionally, human labor has been the major source of power, and tillage was minimal. In a major part of the millet-growing region of the Sahel, animal traction is not used for preparatory cultivation, and the soils are seldom plowed (Spencer and Sivakumar 1987). Matlon (1985) estimates that less than 15% of the farmers use animal traction and less than 5% of the sorghum/millet area is plowed before planting. On soils that are hard and crusty, no tillage results in low infiltration rates and high runoff.

Other prevailing farm practices for millet production also are not conducive to efficient water use. Millet is sown in hills spaced 45 X 45 cm to 100 X 100 cm apart. Spacings of 100 X 200 cm or even 200 X 200 cm are not uncommon. Traditionally, farmers sow at low densities—about 5,000 hills/ha. Under these conditions, water-use efficiencies are low: a large proportion of the water is lost through evaporation from the soil.

Poor soil fertility management. Arenosols in the Sahelian zone are low in organic matter, nitrogen, and phosphorus. Soils in Niger are very sandy, with the sand fraction usually exceeding 92% (Table 1). Organic matter and cation exchange capacity are low and the soils are acidic.

Table 1. Physical and chemical characteristics of sandy soils in four villages of Niger.

Characteristic	Hamdalaye	Tounga	Mai Gamji	Magaria
Sand (%)	94.5	92.0	94.7	96.6
Silt (%)	0.6	1.4	1.3	0.6
Clay (%)	4.7	6.1	3.6	2.2
pH	5.9	6.6	5.6	6.2
Organic matter (%)	0.22	0.51	0.11	0.33
Cation exchange capacity (meq/100 g)	1.0	2.2	1.5	1.3

Source: Dr. A. Bationo, ICRISAT Sahelian Center, Niamey, Niger, pers. comm.

Traditional soil management was based on alternating arable and fallow phases to allow nutrient replenishment and organic matter buildup. Because the crops grown had low yield potential, dry matter yields and nutrient uptake were also low. Such yields could be sustained for substantial period. When crop yields declined to unacceptable levels, overcropped fields were abandoned and new ones opened (shifting cultivation), leaving fields under natural fallow to restore their soil fertility. This was possible because of the low populations.

Increasing population pressure has reduced land availability, reducing the ratios of length of fallows to cropping years to the point where shifting cultivation is losing its effectiveness. As a result, soil fertility is decreasing in many areas (Sanchez and Buol 1975). Without added manure or fertilizers, crop yields have declined (Sivakumar, this volume).

Use of fertilizers in the sorghum- and millet-growing regions during 1979-81 averaged only 5 kg/ha and was virtually negligible in some countries (Table 2). Where the fertilizer was used, it was applied mostly on export crops (Mudahar 1986).

The absence of a system of crop rotations or regular and optimum fertilizer applications to restore soil fertility led Penning de Vries and Djiteye (1982) to conclude that poor soil fertility rather than water supply is the major constraint to increased production.

Lack of early crop varieties. Lack of improved, suitable varieties is recognized as a major biological constraint (Matlon 1985, Spencer 1985, Stoop et al 1982). Given the rainfall variability and short growing season, it is apparent that short-duration cultivars are to be preferred. Short duration offers several farm management options (intercropping, relay cropping) that would reduce the risk of drought in late planting.

The choice of currently available improved pearl millet varieties is limited. In Burkina Faso, a promising variety IRAT S-10 was recommended for the dry northern zone (Labeyrie 1977). But it was not adopted by farmers because it had a long duration (Stoop et al 1982).

Lack of pest and disease management strategies. One constraint that limits realization of the potential of existing millet varieties and land races is the lack of

Table 2. Average fertilizer use (1979-81) in sorghum- and millet-producing countries of West Africa.[a]

Country	Fertilizer use (kg/ha)
Benin	1.3
Burkina Faso	2.9
Cameroon	5.3
Chad	0.5
Gambia	15.2
Ghana	7.4
Guinea	1.1
Guinea Bissau	0.8
Ivory Coast	13.3
Mali	5.7
Mauritania	7.2
Niger	0.8
Nigeria	5.4
Senegal	4.6
Togo	2.5
Av	5.0

[a] Compiled from various sources by Mudahar (1986).

effective pest and disease management. No effective control measures are available for the two major insect pests of pearl millet in the region: stem borer (*Acigona ignefusalis*, Hmps.) and earhead caterpillar (*Raghuva albipunctella* De Joannis). These two pests are not known to exist elsewhere (ICRISAT 1984). Downy mildew, ergot, and smut, major diseases that cause significant economic losses, have not received much research attention so far.

Some strategies to cope with drought

The crises that droughts create in the Sahel could be avoided with accurate forecasting. In a report on climatic trends for tropical Africa, Farmer and Wigley (1985) concede that forecasting is difficult at present. Still, they predict a continuation of the low rainfall levels of the 1970s and 1980s as more likely than a return to the wetter conditions of earlier decades. A range of strategies are needed to deal with this situation.

Reducing risk

Exploiting the environment. Effective and stable soil and crop management practices in the drought-prone Sahel can only be developed with an understanding of the environment and its variability.

In a recent analysis (Sivakumar 1987b), we reported a highly significant relationship between the date of the onset of rains and the length of the growing season for several sites in the southern Sahelian zone. This analysis points to possibilities for assessing the potential length of the growing season from the date of the onset of rains.

In field tests at the ICRISAT Sahelian Center, Sivakumar (1989) showed that by tailoring management tactics to weather conditions in years with early onset of rains in the Sahelian zone, it is possible to establish a second crop of cowpea for hay after a first crop of millet. If the rains are delayed 10 d beyond the calculated average date of onset, short-duration cultivars that will mature early may be grown. The objective is to minimize the effects of drought by making efficient use of scarce rainfall in a drought year, but to maximize production in good years by exploiting the longer growing season. In disaster planning, delayed rains signal the need for early-maturing cultivars, since traditional and improved cultivars of medium season length are likely to give poor yields.

Stewart (1987) recommends using a combination of date of onset of rains and the first 30-day rainfall to make early season adjustments of plant populations and fertilizer rates. These recommendations need to be field-tested, but the concept appears promising given the already established relationship between onset of rains and length of growing season.

Intercropping. Another strategy adopted by farmers to reduce risks due to climatic variability is intercropping. Steiner (1984) estimates that 80% of the cultivated area in the West African tropics is intercropped. In the Sahelian zone, millet/cowpea is the most prevalent intercropping system. Recent reviews suggest that yields in traditional millet/cowpea intercropping could be increased by improved agronomic management (Fussell and Serafini 1985, Ntare et al 1987).

Planting and harvest schedules, crop densities and spacing, soil fertility, and varieties with different durations were found to be the important factors determining the performance of a millet/cowpea intercrop. Manipulation of one or more of these components led to substantial yield increases (Table 3). In traditional combinations,

Table 3. Reported yield advantage (%) by agronomic manipulation in intercropping.[a]

Component	Yield advantage (%)
Fertilizer	
40 kg N	49
Cultivars	
Local millet + local cowpea	28
Improved millet + local cowpea	38
Local millet + improved cowpea	40
Improved millet + improved cowpea	69
Date of planting of cowpea relative to millet	
Same day as millet	35
6 d after millet	24
25 d after millet	22
Time of harvesting of cowpea	
40 d after planting	102
60 d after planting	146
80 d after planting	94
End of season	35

[a] Compiled from Ntare et al (1987).

a local cultivar of millet is intercropped with a long-duration, photoperiod-sensitive, local cowpea that flowers at the end of the rains. When the rains end early, the local cowpea often produces little or no grain. Substituting an improved cultivar for either of the crops gave similar yield increases, but the maximum advantage was with improved cultivars for both crops.

Another management tool that can maximize intercropping advantages is to adjust the cowpea planting date relative to the development stage of millet and to the probable length of the rainy season (Ntare et al 1987). Early planting of cowpea with, or shortly after, millet gave good cowpea growth and maximized the advantages of the association. Competition between cowpea and millet for moisture and nutrients during early growth should be considered. When millet and cowpea were planted simultaneously, harvesting cowpea early for hay was another option that helped stabilize millet yields (Table 4).

Intercropping short- and long-duration cultivars is currently receiving increased attention in reducing drought risk.

Increasing water-use efficiency. In semiarid regions, efficient water use is the key to yield and yield stability. Regardless of our ability to forecast droughts, no one can dispute the need to maximize the use of rainwater. In a recent review on the water-use efficiency of crops in the semiarid tropics, Gregory (1987) defined water-use efficiency (WUE) as

$$\mathrm{WUE} = \frac{N/T}{1 + E/T} \qquad (1)$$

where N where N is dry matter yield,
T is transpiration, and
E is evaporation.

Since runoff (R) and drainage (D) are also substantial components of total water balance in the semiarid regions, WUE was expressed as

$$\mathrm{WUE} = \frac{N/T}{1 + (E + R + D)/T} \qquad (2)$$

Because N/T is constant for a given saturation deficit and crop, Gregory (1987) concluded that to produce dry matter with the greatest WUE, either the total

Table 4. Effects of nitrogen, phosphorus, and potassium fertilizer on water use (WU), grain yield (Y), and water-use efficiency (WUE) for pearl millet grown at 3 sites in Niger during 1985 rainy season.

Site	Rainfall (mm)	Treatment	WU (mm)	Y (t/ha)	WUE (kg/ha per mm)
Sadore	543	Fertilizer	382	1.57	4.14
		No fertilizer	373	0.46	1.24
Dosso	583	Fertilizer	400	1.70	4.25
		No fertilizer	381	0.78	2.04
Bengou	711	Fertilizer	476	2.23	4.68
		No fertilizer	467	1.44	3.08

amount of water available to the crop should be increased or T should be maximized with respect to all other losses.

Research at the ICRISAT Sahelian Center (ISC) and by ICRISAT/SAFGRAD (Semi-Arid Food Grain Research and Development Project) in Burkina Faso over the last 4 yr showed that the denominator term in equation 2 could be manipulated by simple cultural practices to enhance WUE.

Tillage. The major soil types in the Sahelian zone (Fig. 4) have a high propensity to compaction and hardening during the dry season (Nicou and Charreau 1985). In these soils, which have limited water availability and poor fertility, deep root establishment is essential for plant growth. Cultivation promotes better crop establishment and root growth through increased porosity, reduced bulk density, improved infiltration, enhanced soil water availability, and water conservation (Klaij and Hoogmoed 1987, Nicou 1977). Chopart (1983) found that plowing doubled the dry weight of millet roots in the first 50 d of growth. Nicou and Charreau (1985) reported significant yield advantages due to tillage for several crops.

On the sandy soils at the ISC, the beneficial effects of cultivation have been attributed primarily to enhanced rooting (Klaij and Hoogmoed 1987). Interrow cultivation during the rainy season helps control weeds; at the end of the rainy season, it kills weeds – saving precious soil moisture for a subsequent crop (Dancette and Nicou 1974).

Different tillage methods have been tested in the Sahelian zone. For sandy soils, ridging has reduced wind erosion and increased effective plant populations (Klaij and Hoogmoed 1987). Tied ridges or microcatchment basins increase water storage on the surface and trap runoff, which increases water infiltration and storage in the soil profile (Boa 1966). Perrier (1986) showed significant yield advantages with tied ridging on Alfisols in Burkina Faso. On-farm trials in the central plateau region of Burkina Faso also confirmed significant yield increases (Ohm et al 1985).

Mulching. In the Sahelian zone, millet is traditionally grown in wide rows. Water loss through soil evaporation is a significant component of total evapotranspiration (ET). In recent investigation at ISC, evaporation losses were as high as 40% of total ET. Mulching is an effective means of reducing evaporation losses. It also improves infiltration by absorbing the impact of wind-driven rain, by increasing termite or biological activity, and by improving soil organic matter status. In trials in Burkina Faso, use of mulches in the traditional flat cultivation system was superior to in-place water harvesting methods such as tied ridges (Perrier 1986). Mulching with crop residues helped reduce the aluminum and hydrogen saturation of the exchange complex, a major problem on the acidic soils in the Sahelian region (Bationo et al 1987). Despite the much demonstrated beneficial effects of mulching, the availability of crop residues for mulching is often a problem, because of their use as cattle feed.

Interaction of ridging and mulching. On structurally poor soils, a combination of ridging and mulching has been reported to be an effective management strategy. Experimental results on Arenosols and Luvisols showed considerable yield advantages, because adding plant residues in the tied ridges improved infiltration and water storage capacity (Klaij and Hoogmoed 1987, Perrier 1986). In Burkina Faso, sorghum cultivar E 35-1 with tied ridges yielded 2.2 t/ha; with mulch added, yield improved to 3.3 t/ha (Perrier 1986).

Restore and maintain soil fertility

Several studies have shown that lack of phosphorus is a major constraint to crop growth in semiarid West Africa (Hauck 1966, Jones and Wild 1975, Pichot and Roche 1972). Applying as little as 8.8 kg P/ha can double millet yields. But even this small quantity of fertilizer may be expensive for the resource-poor farmers in the Sahelian zone. Direct application of ground indigenous phosphate rock is an alternative to using imported commercial phosphate fertilizers. In field trials in Niger, two sources of indigenous phosphate rock were compared with commercial single superphosphate (SSP). The less reactive PARC-W phosphate rock was 48% as agronomically effective as SSP, the more reactive Tahoua rock was 76% as effective as SSP (Bationo et al 1987).

Another way to utilize unreactive phosphate rock is to increase available phosphorus by chemical conversion to a partially acidulated phosphate rock (PAPR). In field tests in Niger, PAPR acidulated to a level of 50% was agronomically as effective as triple superphosphate (Bationo et al 1987). Niger has phosphate reserves large enough to meet the country's phosphate requirement, with a positive, reasonably high internal rate of return (Mudahar 1986). Use of PAPR also confers an added advantage: it supplies sulfur, an important plant nutrient, and has a long-term residual effect.

Nitrogen, especially a split application, has also been shown to give substantial yield increases (Bationo et al 1985).

An important consequence of the use of fertilizers is increased water-use efficiency. Early vigorous growth builds up a larger canopy, which shades the ground early in the season when a significant proportion of the water is lost through soil evaporation, and helps in effective and efficient use of the scant rainfall. Studies at three sites in Niger showed substantial increases in WUE with the use of fertilizer (Table 4).

Fertilizer application also helps ensure better plant stands. Klaij and Hoogmoed (1987) showed that hill survival in fertilized plots was 74%, against 43% in control plots.

Combine technologies

The management strategies discussed demonstrate their individual value. There is accumulating evidence that a combination of these inputs offers much greater advantages in the Sahelian region. On sandy soils, tillage alone did not result in much yield increase, but a combination of tillage and fertilizer gave a 300% yield increase (Klaij and Hoogmoed 1987). Soil tillage combined with fertilizers and residues improved the long-term productivity despite rainfall variability in West Africa (Pieri 1985). This point merits consideration because cost-benefit analysis of the inputs is often done on the basis of field trials conducted over only 1-3 yr. The advantages of using these inputs to improve long-term productivity are often ignored.

Breed improved cultivars

Developing stable, high-yielding, drought-resistant cultivars for the Sahelian zone is a long-term, complex task, given the climatic and soil variability under which the cultivars are to be grown. Analysis of the long records of daily rainfall available for many sites could help us understand some aspects related to crop breeding. As much attention needs to be paid to variability as to the averages themselves (Table 5).

Too often in the past, "improved" varieties and genetic material were brought into the Sahelian region from other regions of the world, in hopes of achieving "quantum leaps" in crop yields. That has not happened, because the genetic material was not well adapted to the Sahelian environment. Improved varieties bred in situ have performed remarkably well. With adequate soil fertility at ISC, improved variety CIVT consistently outyielded the local variety for 4 yr (Table 6). Significantly, the maximum yield advantage (78%) was achieved in 1984, a year with the lowest annual rainfall on record. These data point to the advantages of increased varietal development and testing in the Sahelian region itself.

For varietal improvement in drought-prone regions, information on the probabilities of dry spells is often more important than rainfall totals. Knowledge of the relative susceptibility of millet to drought spells during the three important growth stages emergence to panicle initiation (GS1), panicle initiation to flowering (GS2), and flowering to physiological maturity (GS3) -- may provide breeders with useful criteria in breeding for drought resistance. Assuming the date of the beginning of rains each year as the date of sowing, we have computed the length of dry spells (or days to next day with rainfall greater than a threshold value) at different probability levels for consecutive 10-d periods. For two selected locations in the Sahelian zone (Fig. 5), dry spells in the GS1 phase were longer than those during GS2. At Hambori, the length of dry spells is progressively longer from 75 DAS and at Niamey, from 90 DAS. These data could be used as a guide for the growth durations of target

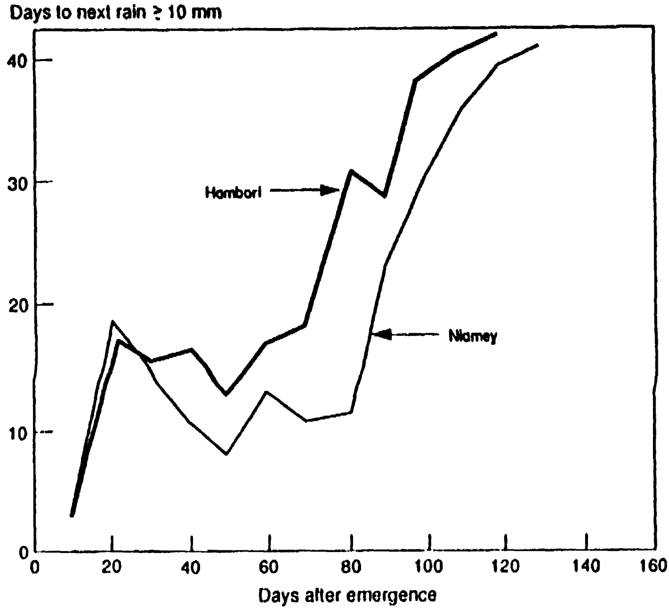
Table 5. Variability in annual rainfall and growing season characteristics pooled over 30 sites in the Sahelian zone.

Parameter	Av	Range	Av SD
Annual rainfall (mm)	480	330-640	125
Onset of rains	23 Jun	10 Jun-4 Jul	19 d
End of rains	12 Sep	6 Sep-16 Sep	9 d
Growing-season length (d)	82	66-99	22

Table 6. Yields of improved millet variety CIVT and local variety Sadore local (SL) grown at the ICRISAT Sahelian Center, Sadore, Niger, 1982-86.[a]

Year	Sowing date	Harvest date	Rainfall from sowing to harvest (mm)	Yield (t/ha)		Yield increase for CIVT (%)
				CIVT	SL	
1982	1 Jul	12 Oct	372	1.69	1.21	40
1984	1 Jun	14 Sep	213	1.12	0.63	78
1985	18 Jun	21 Sep	536	2.35	1.90	24
1986	29 May	10 Sep	499	2.26	1.95	16

[a] Source: Dr. K. Anand Kumar, ICRISAT Sahelian Center, Niamey, Niger, pers. comm.



5. Days to next rain ≥10 mm at 90% probability for two sites in the southern Sahelian zone.

varieties. At Hambori and Niamey, breeding strategies should be oriented toward growth durations of 80-90 d.

This information is important because many varieties presently available mature in 100-110 d and are exposed to drought risk during grain filling. Development of slightly earlier varieties would mean that the new lines could escape late-season drought. This is necessarily a long-term strategy, but some of the improved cultivars available from ISC now show promise and yield stability. ICRISAT's millet varieties (such as ITMV 8303) yielded more than 1.3 t/ha in 1984, which recorded the lowest rainfall in the century.

The ability of plants to withstand high temperatures is an important character, especially during germination, emergence, and plant establishment. Sivakumar (1987a) analyzed the frequency distribution of air temperatures and showed that mean maximum temperatures could exceed 40 °C at time of sowing and that absolute temperatures could be much higher. High soil temperatures at this time lead to poor plant stands. Research is under way at ISC to identify millet and sorghum genotypes that germinate and emerge under high soil temperatures (> 55 °C at the surface, 3 d after a rain).

Even with the limited rainfall in the Sahelian zone, millet cultivars can yield total dry matter of more than 8 t/ha. Low harvest index (usually less than 0.20) of existing cultivars is responsible for the low grain yields. A long-term research strategy is to alter the harvest index in favor of higher grain yields.

Incorporation of resistance to insect pests and diseases is a long-term research strategy that is likely to play a significant role in efforts to bring stability to present production systems.

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Climate vulnerability of sorghum and millet

M. V. K. Sivakumar

Sorghum and millet are the most important cereals for resource-poor farmers of West Africa. They are the only staple crops that can withstand the ravages of weather in that area. Temporal and spatial variations in rainfall and the persistence and patterns of rainfall shortages, especially since 1969, have contributed to low productivity over the last 2 decades. Increased yields can only be achieved through effective management of available resources, both physical and biological. Ongoing research in West Africa offers hope, but significant changes in present farming methods will be needed to reduce the climatic vulnerability of sorghum and millet.

Given the excellent analysis of the influence of climate on sorghum and millet production in India (Rao et al, this volume), I would like to focus on another region of the world—West Africa—where these crops are the most important cereal food for millions of resource-poor farmers. In northern Nigeria, sorghum contributes 73% of total calorie intake and 52% of per capita protein (Simmons 1976). Sorghum and millet play an important role in rural economies and are put to various uses: the grain is used to prepare a variety of local foods and drinks, the hay is used as animal feed, and the stalks are used to construct fences and thatched houses.

West Africa is the poorest region in the world, with the lowest gross national product per capita. About 90% of the population in this region live in villages and depend on subsistence agriculture for their survival. The population growth rate in the 1970s averaged 2.7% and is projected to remain about 3% across 1980-2000 (FAO 1981). This is the only region in the world where capita food production declined over the last two decades (World Bank 1984) and the ratio of food imports to total food increased.

Several factors are responsible for low agricultural productivity in West Africa. Some are climatic, principally low and highly variable rainfall and high demand for water imposed by the consistently high temperatures and radiation. In a large belt across West Africa, there were serious crop failures during 1968-73.

Rainfall variability

Rainfall in West Africa is low and variable. The scale of variability determines the magnitude of crop vulnerability and the extent of regional crop failures. Temporal