Agroclimatic Aspects in Planning for Improved Productivity of Alfisols

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Abstract

Crop yields on Alfisols the most abundant soils in the semi arid tropics have remained low and unstable due to aberrant weather and soil related constraints With suitable examples from India and West Africa variations in the amount and distribution of rainfall as well as its intensity were described However crop planning on Alfisols should take into account the length of the growing period involving an assessment of rainfall as well as potential evapotranspiration The role of soil constraints such as depth soil water storage capacity particle size distribution and soil moisture release characteristics in making water available for crop growth on Alfisols was illustrated At soil depths below 30 cm in Alfisols the recharge and depletion of soil water occurred on an annual basis whereas in the upper 30 cm the process occurred repeatedly with a periodicity determined by the depth amount and frequency of rainfall In the upper 30 cm soil layers with decreasing capillary potential there was a large decrease in the water content while in the lower layers this decrease was considerably less The effect of short term intraseasonal droughts on crop moisture status was shown to differ depending on soil depth The timing and intensity of water stress is an important factor in assessing the crop response to drought on Alfisols Studies conducted at ICRISAT Center showed that crop water-use efficiency on Alfisols could be improved through appropriate management practices including the selection of suitable genotypes crops and cropping systems

Introduction

Alfisols are the third most important soil order in the world covering 13 1% of the world area (Buringh 1982) Compared with Vertisols (which have been the major focus of attention at ICRISAT's Farming Systems Research Program) Alfisols cover a much larger area of potentially arable and grazeable land These soils are most abundant in the semi-arid tropics (SAT) (Kampen and Burford 1980)

Due to aberrant weather and soil-related constraints to production, crop yields on Alfisols have remained low and unstable Experimental evidence from research however shows that these soils are capable of producing more food with appropriate soil and water-management systems Since successful crop production depends heavily on environmental factors the combined influence of climate and soil on plant growth must be considered before land use is planned In order to take advantage of the advances made in science and technology, Kanwar (1982) advocated that soil scientists should work with agroclimatologists to predict more accurately the interactions between the weather, the soil, and the plant

About 62% of the Alfisols in the SAT are located in West Africa and India The agroclimatic aspects that need to be considered in planning for improved productivity of Alfisols are illustrated in this paper, with suitable examples from India and West Africa

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Rainfall

Rainfall amounts

In SAT countries, Alfisols are distributed over a wide range of rainfall regimes The annual rainfall, for instance, varies from less than 500 mm in Botswana to more than 1400 mm in Nigeria In West Africa, which accounts for 36% of the global area under Alfisols, the mean annual rainfall varies from 400 to 1250 mm The rainfall isohyets run parallel to the equator, and the farther south the location of bands or zones, the more is the rainfall (Cocheme and Franquin 1967) Kowal and Knabe (1972) have shown that annual rainfall for the northern states of Nigeria decreases by 119 mm for every degree of latitude

In peninsular India, which accounts for a major portion of the area under Alfisols in India, the annual rainfall varies from 500 mm in a narrow zone that covers southwestern Andhra Pradesh and eastern Karnataka, to over 1000 mm in southwestern Tamil Nadu and Kerala The rainfall is also over 1000 mm a^{-1} in the Alfisol area of eastern Madhya Pradesh and western Orissa

To provide a description of the rainfall characteristics, we have chosen 24 stations in 5 different rainfall zones in India and Africa (Table 1) for which long-term rainfall data are available on tape from the Agroclimatology unit of ICRISAT Annual rainfall statistics for these stations are given in Table 2 The coefficient of variation of annual rainfall varies from 9 to 45%, with the largest variation at Mahalapye, which has the lowest rainfall

Rainfall distribution and probabilities

In most Alfisol regions of West Africa and India, rainfall is restricted to a short growing season (in the northern hemisphere summer) In West Africa, the rainfall increases gradually from the beginning of the rainy season (in late spring or early summer), to reach a maximum in the rainy season Seasonal distribution of rainfall for different stations in the Alfisol areas of India and Africa is shown in Table 3 Over 80% of the annual rainfall occurs in the rainy season It is recognized, however, that the amount of rainy-season rainfall cannot by itself provide a good index of productivity, because the potential evapotranspiration, or water loss and the soil's water-holding capacity, dictate the amount of rainfall available for crop growth

More important than the quantity of rainfall in a given season, is the question of persistency in receiving a specified amount of rainfall over a short interval (for instance, 1 week) In the case of Alfisols, which are known to dry rapidly and develop a surface crust, information on rainfall probabilities is important for agricultural planning The probability of receiving 10 mm of rainfall, and the weekly rainfall amount, for three locations in the peninsular Indian Alfisol zones are shown in Figure 1 Although there is little difference in the amount of annual rainfall at Hyderabad and Bangalore, the rainy season rainfall at Bangalore extends over a much longer period, albeit at a lower probability than at Hyderabad Coimbatore—located farther south in peninsular India—has a bimodal rainfall distribution with the two rainfall peaks separated by an 8-week dry period

The rainfall probabilities for Yeliman (Mali) Gaya (Niger) and Gaoua (Burkina Faso) in Africa are shown in Figure 2 These weekly rainfall probabilities as well as the amounts, are more sharply defined than those relevant to Alfisol locations in India In the higher-rainfall locations of Gaya and Gaoua, the cropping opportunities appear more promising For Lilongwe (Malawi) and Mahalapye (Botswana) the peak probabilities (Fig 3) occur in December and January At Mahalapye, the rainy season is short and the probabilities are low

Rainfall intensities

It is known that Alfisols, because of their poor structural stability at the surface, are susceptible to erosion In spite of this recognition, rainfall intensities

Table 1. List of stations in different rainfall zones used in the description of climatic aspects

Rainfall zone (mm a^{-1})	Station	Country	Latitude °	Longitude °'	Elevation (m)
<500	Mahalapye	Botswana	23 04	26 48	
500-600	Anantapur	India	14 41	77 37	350
	Birni N'Konni	Niger	13 48	05 15	272
	Coimbatore	India	11 00	76 58	709
	Mourdiah	Mali	14 28	07 28	314
	Yeliman	Mali	15 07	10 34	97
600-800	Diema	Mali	14 33	09 11	252
	Cuddapah	India	14 29	78 50	130
	Fatick	Senegal	14 20	16 24	6
	Hyderabad	India	17 27	78 28	545
	Kayes	Mali	14 26	11 26	46
	Kurnool	India	15 50	78 04	281
	Kaya	Burkina Faso	13 06	01 05	313
800-1000	Bangalore	India	12 58	77 35	921
	Foundiaugne	Senegal	14 07	16 28	6
	Gaya	Niger	11 59	03 30	160
	Kolokani	Mali	13 35	08 02	399
	Lilongwe	Malawi	13 57	33 48	1029
	Madurai	India	09 55	78 07	133
	Salem	India	11 39	78 10	278
>1000	Bougouni	Mali	11 25	07 30	350
	Gaoua	Burkina Faso	10 20	03 11	333
	Bamako	Mali	12 38	08 02	332
	Raipur	India	22 14	81 39	296

Table 2. Annual rainfall (mm) for different stations in Alfisol areas of India and Africa

Station	Mean annual rainfall	CV (%)	Maximum rainfall	Minimum rainfall	Range (mm)
Mahalapye	494	45	1765	191	1574
Anantapur	591	26	866	259	607
Birni N Konni	565	26	990	289	701
Coimbatore	602	31	1047	238	809
Mourdiah	545	21	814	337	477
Yeliman	572	24	976	316	660
Diema	652	20	962	424	538
Cuddapah	751	28	1226	299	927
Fatick	775	27	1220	295	925
Hyderabad	784	27	1431	457	974
Kayes	723	22	1136	361	775
Kurnool	630	27	1065	281	784
Kaya	704	20	1008	184	824
Bangalore	831	18	1282	588	694
Foundiaugne	835	26	1427	416	1011
Gaya	836	17	1108	451	657
Kolokani	813	24	1226	352	874
Lincongeue	880	26	1260	198	1062
Madurai	883	25	1443	411	1032
Salem	955	24	1496	534	962
Bougouni	1090	12	1309	844	465
Gaoua	1259	29	2359	440	1919
Bamako	1022	9	1297	942	355
Raipur	1337	20	2175	714	1461

Table 3 Seasonal distribution of rainfall (mm) for different stations in Alfisol areas of India and Africa

Station	Prerainy season	Rainy season	Postrainy season	Dry season	Annual rainfall
Mahalapye	38	395	68	3	494
Anantapur	34	502	33	22	591
Birni N'Konni	30	507	10	18	565
Coimbatore	18	197	64	323	602
Mourdiah	32	461	27	25	545
Yeliman	15	516	24	17	572
Diema	19	584	31	18	652
Cuddapah	57	634	37	23	752
Fatick	32	709	25	9	775
Hyderabad	51	631	65	37	784
Kayes	16	667	26	14	723
Kurnool	47	517	34	32	630
Kaya	31	626	15	32	704
Bangalore	22	755	27	27	831
Foundiaugne	46	752	24	13	835
Gaya	32	768	15	21	836
Kolokani	24	745	18	26	813
Lilongwe	32	785	45	18	880
Madurai	213	590	46	34	883
Salem	24	865	34	32	955
Bougouni	0	1047	17	26	1090
Gaoua	60	1152	20	27	1259
Bamako	32	933	32	25	1022
Raipur	111	1174	33	19	1337

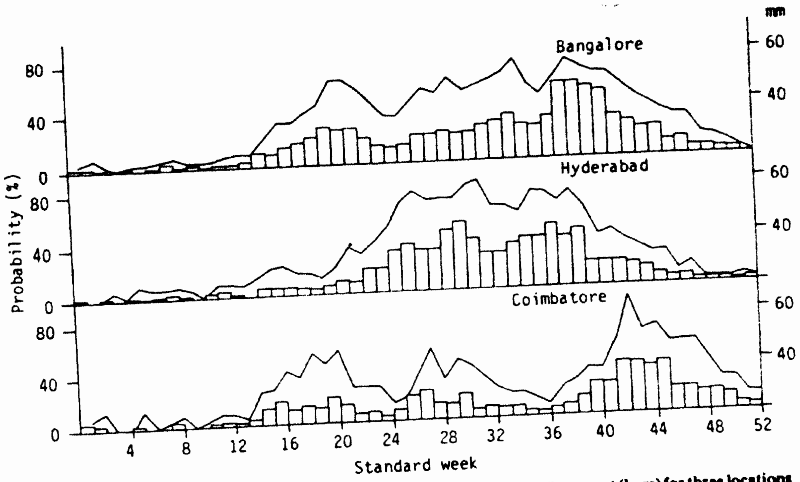

Figure 1. Weekly probability of receiving 10 mm of rainfall (line) and rainfall amount (bars) for three locations in Alfisol areas in peninsular India.

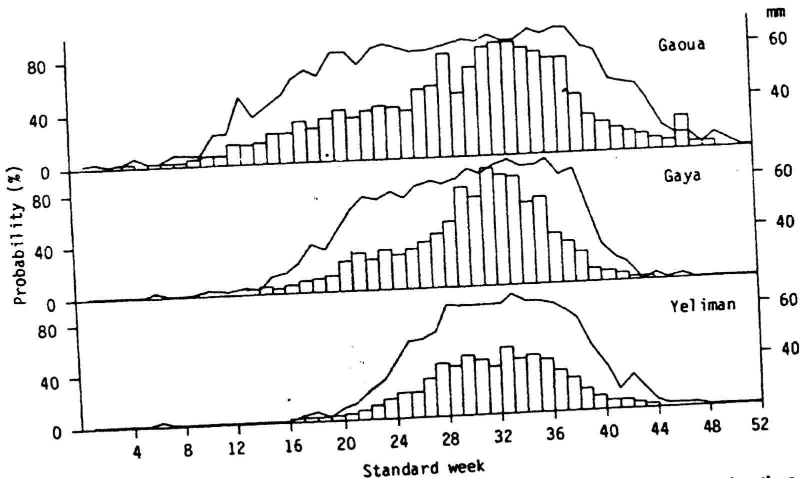

Figure 2. Weekly probability of receiving 10 mm of rainfall (line) and rainfall amount (bars) for three locations in Alfisol areas of Africa.

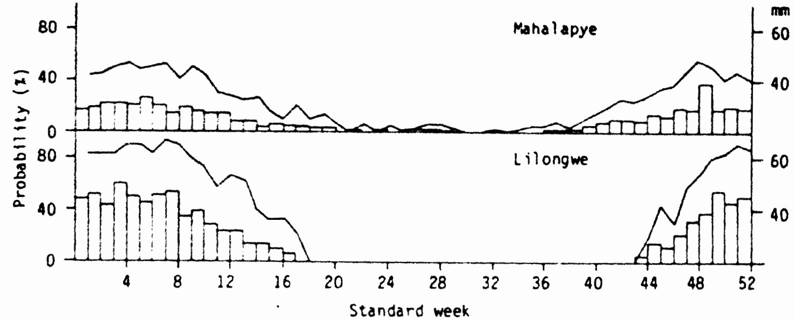

Figure 3. Weekly probability of receiving 10 mm of rainfall (line) and amount of rainfall (bars) for Mahalapye (Botswana) and Lilongwe (Malawi).

in Alfisol areas are seldom measured. At Bambey (Senegal), Charreau and Nicou (1971) reported that 75% of the total volume of rainfall had an intensity distribution of 8.6 mm h^{-1}, and 25% recorded intensities less than 52 mm h^{-1}.

Hoogmoed (1981) reported that, at Niono (Mali), 75% of the rainfall received had intensities of 10 mm h^{-1} or lower, while 25% had intensities of 58 mm h^{-1} or more (Fig. 4). Peak intensities in 1977, 1978, and 1979 were reported to be 190, 230, and 300 mm h^{-1} respectively.

At ICRISAT Center, the rainfall intensities are lower than those reported for Africa. Rainfall intensities at ICRISAT Center for 1975 are shown in

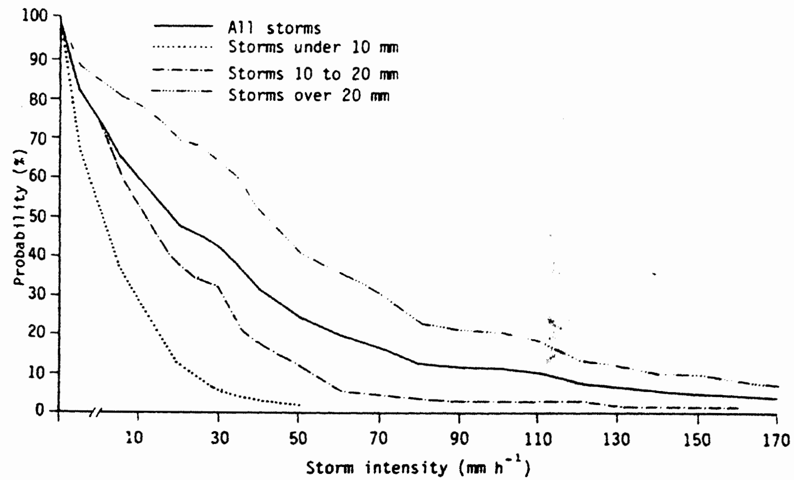

Figure 4. Distribution of storm intensities in different storm sizes at Niono, Mali (Hoogmoed 1981).

Figure 5. Peak intensities in 1974, 1975, 1976, and 1977 were reported to be 134, 155, 92, and 57 mm h^{-1} respectively (Hoogmoed 1981).

Length of the Growing Period

Plans for improved productivity on Alfisols should take into account the period available for crop growth. Using different average rainfall potential evapotranspiration (PE) ratios, Cochème and Franquin (1967) evolved a procedure to determine the beginning and end of the growing period as well as its length. We have used the average rainfall and PE for different stations in the Alfisol areas to determine the average dates of the beginning, end, and the length of the growing period. It should be understood that this analysis provides only approximate data, because in the SAT the variability in these dates could be large. As shown in Table 4, the beginning and end of the growing period show a wide fluctuation across the different rainfall zones, reflecting thereby the need to consider different management strategies. Kowal and Kassam (1973) showed that in the Sudanian and Northern Guinean zones of Nigeria, due to abnormality in the amount and distribution of rainfall, the start of the rainy season of 1973 was delayed, and the delay was most accentuated north of 11°N latitude. The length of the growing period was reduced from 120 days at 11.2°N latitude, and to 70 days at 12.3°N latitude. The minimum reduction in groundnut yield was estimated to vary from 0% at 11.2° latitude to 56% at 12.3° latitude.

Temperature

Air temperature

The air temperatures in Alfisol areas in India and Africa are consistently high, and can be considered above optimum for most crops (Table 5); in low-rainfall zones, the temperatures can exceed 40°C. Information on the probabilities of occurrence of lethal and stress-inducing temperatures would be useful in planning alternative cropping strategies for Alfisols; but the long-term records on air temperature recorded at shorter intervals are insufficient. Table 6 shows, as an example, the probability of the temperatures rising to the point of becoming lethal and stress-inducing in Kayes, Mali. High temperatures are known to effect germination and establishment, leaf-area development, stem growth, tillering, root growth, panicle initiation, photosynthesis, and respiration (Peacock 1982).

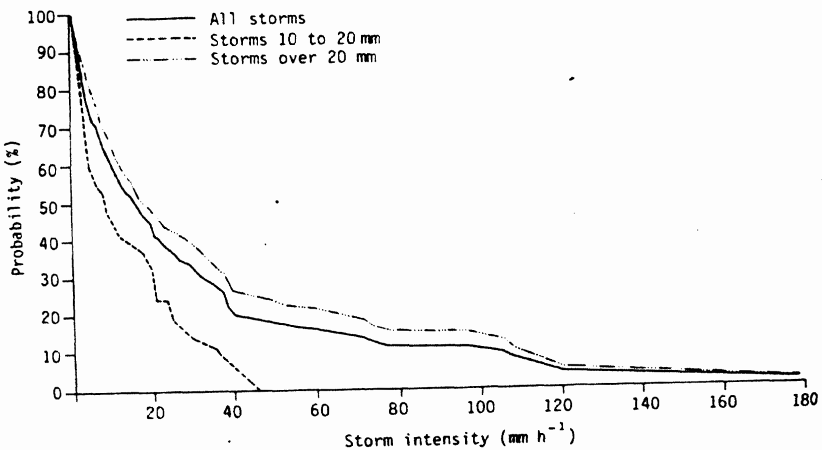

Figure 5. Distribution of storm intensities in different storm sizes at ICRISAT Center, 1975 (Hoogmoed 1981).

Table 4. Dates of beginning and end of the period and length of the growing period for different stations in Alfisol areas of India and Africa.

Station	Growing period: Date of beginning	Date of ending	Length (days)
Mahalapye	13 Nov	17 Apr	155
Anantapur	09 May	24 Nov	199
Birni N'Konni	01 Jun	07 Oct	128
Coimbatore	24 Aug	23 Dec	121
Mourdiah	07 Jun	10 Oct	125
Yeliman	07 Jun	13 Oct	128
Diema	05 Jun	15 Oct	132
Cuddapah	16 May	13 Dec	211
Fatick	13 Jun	30 Oct	139
Hyderabad	26 May	15 Nov	173
Kayes	01 Jun	22 Oct	143
Kurnool	23 May	12 Nov	173
Kaya	18 May	12 Oct	147
Bangalore	12 Apr	08 Dec	240
Foundiaugne	13 Jun	29 Oct	138
Gaya	08 May	12 Oct	157
Kolokani	21 May	21 Oct	153
Lilongwe	02 Nov	28 Apr	177
Madurai	03 Jul	08 Jan	189
Salem	09 Apr	20 Dec	255
Bougouni	19 Apr	04 Nov	199
Gaoua	25 Mar	11 Nov	231
Bamako	08 May	08 Nov	184
Raipur	23 May	05 Nov	166

Table 5. Average monthly air temperature (°C) for different stations in Alfisol areas of India and Africa.

Station	Jun / Nov[1]	Jul / Dec	Aug / Jan	Sep / Feb	Oct / Mar	Nov / Apr
Anantapur	29.7	28.0	27.9	27.8	26.9	24.7
Birni N'Konni	31.2	28.2	26.8	27.7	29.5	27.3
Coimbatore	26.5	25.5	26.0	26.3	26.2	25.2
Cuddapah	31.9	30.0	29.7	29.1	28.2	25.8
Hyderabad	29.1	26.0	25.8	25.6	25.0	22.3
Kayes	31.6	28.3	27.2	27.5	28.7	28.2
Kurnool	30.3	28.1	27.8	27.6	27.4	25.1
Bangalore	24.3	23.2	23.2	23.2	23.2	21.7
Lilongwe	15.5	15.0	16.5	19.4	22.3	23.4
Madurai	31.5	30.7	30.2	29.9	28.5	26.8
Salem	29.6	28.5	28.3	28.2	27.3	25.8
Bougouni	27.2	25.6	25.2	25.7	26.6	26.5
Gaoua	26.8	25.5	25.5	25.7	27.2	27.8
Bamako	28.5	26.6	26.0	26.3	27.3	26.7
Raipur	32.1	27.2	27.1	27.5	26.3	22.5

1. Months in the lower row refer to Lilongwe which is south of the equator.

Table 6. Statistical analysis of maximum air temperatures for Kayes, Mali.

Month	Mean max. temp. (°C)	SD	CV (%)	Probability of exceeding max. temp. (°C) >25	>30	>35	>40	>45
Jan	33.8	1.6	5	100	100	26	0	0
Feb	36.6	1.5	4	100	100	85	3	0
Mar	39.6	1.2	3	100	100	100	33	0
Apr	41.7	0.9	2	100	100	100	100	0
May	42.0	1.0	2	100	100	100	100	3
Jun	38.1	1.3	3	100	100	98	3	0
Jul	33.5	1.0	3	100	100	10	0	0
Aug	31.8	1.1	3	100	100	3	0	0
Sep	32.9	0.8	3	100	100	0	0	0
Oct	35.9	1.3	4	100	100	73	0	0
Nov	36.7	1.0	3	100	100	90	0	0
Dec	33.7	1.1	3	100	100	13	0	0
Annual	36.3	0.5	1	-	-	-	-	-

Soil temperature

Soil temperatures, particularly the extremes, adversely influence germination of seed, functional activity of roots, the rate and duration of plant growth, and the occurrence and severity of plant diseases (Chang 1968). The soil temperatures observed at any given location depend (Monteith 1979) on:

a. The rate at which radiant energy is absorbed;
b. the fraction of energy that is available for heating the soil and atmosphere (sensible heat), i.e., the fraction not used for evaporation (latent heat); and
c. the partitioning of sensible heat between soil and the atmosphere.

We measured the soil temperature, at 10 cm depth, of a medium-deep Alfisol planted to a postrainy-season sorghum crop at ICRISAT Center. Three mositure regimes were imposed on the crop.

1. No drought stress (by irrigating the crop every 10 days).
2. Drought stress imposed 35 to 65 days after emergence (DAE) (by withholding irrigations during this period and irrigating thereafter every 10 days).
3. Drought stress imposed from 65 DAE (by withholding irrigation) to maturity.

Soil temperatures were also measured on a nonirrigated, bare soil. Maximum soil temperatures under different treatments are shown in Figure 6. Treatment 1 showed the lowest soil temperatures to range between 21° and 24°C, up to 95 DAE. Because all irrigations were withheld thereafter, the soil temperatures showed a sudden increase. Treatment 2, which was under stress up to 65 DAE, showed soil temperatures that were, on an average, about 4°C higher than in treatment 1. In treatment 3, the temperatures were high, occasionally approaching those for the bare fallow in treatment 4.

Van Wambeke (1982) computed the mean annual, mean summer, and mean winter soil temperatures for selected stations in Africa from the mean air temperatures (see Table 7). According to the USDA Soil Conservation service (1975), Alfisol regions can be classified as Hyperthermic or Isohyperthermic.

In crops, the shoot meristem has been indentified as the site of temperature perception (Kleinendorst and Brouwer 1970; Peacock 1975). At the start of the growing season, the meristem may be at or just below the surface, so that the rate of leaf expansion is determined by surface soil temperature (Monteith 1979). As the shoot extends, the meristem moves away from the soil surface but, if transpiration is fast enough, its temperature may still be modified by the temperature of the root system and, therefore, of the water the roots absorb.

In relating the response of a crop plant to soil (or air) temperature, Monteith (1979) advocates that it is essential to record the duration of each developmental stage. Several management practices (e.g., mulching) aimed at favorably altering the soil-temperature regimes of Alfisols will be discussed during the course of this workshop, and the forementioned suggestion of monitoring the duration of growth in addition to the rates is worth considering.

Soil Water

Soil water storage capacity

The above discussion on rainfall, PE, and the length of the growing season provides rough solutions to

Table 7. Computed soil temperatures and soil taxonomy definition of the temperature regime for different stations in Alfisol areas of Africa.

Rainfall zone (mm a⁻¹)	Station	Mean soil temperature (°C)			Temperature regime
		Annual	Summer	Winter	
<500	Mahalapye	23.0	25.7	18.5	Hyperthermic
500-600	Birni N'Konni	31.0	30.6	28.3	Isohyperthermic
600-800	Kayes	32.0	31.4	29.4	Isohyperthermic
800-1000	Lilongwe	22.4	23.6	19.3	Isohyperthermic
>1000	Bougouni	29.5	28.5	28.3	Isohyperthermic
>1000	Gaoua	30.0	28.3	30.2	Isohyperthermic

Source: van Wambeke 1982.

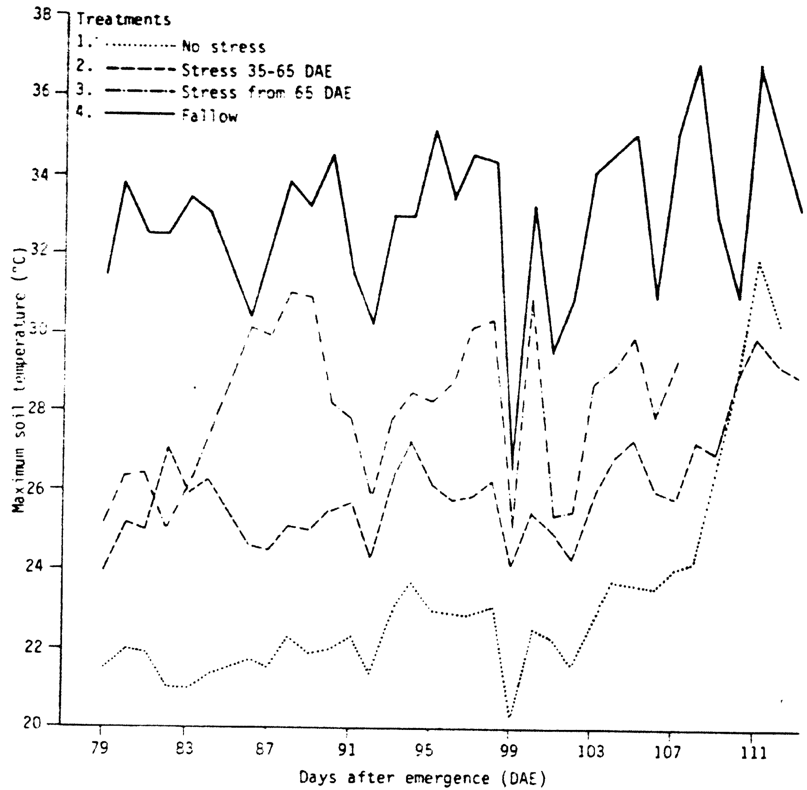

Figure 6. Seasonal variation in maximum soil temperature under different treatments in sorghum grown during the postrainy season at ICRISAT Center.

broad, region-specific problems in agricultural planning. But the soil characteristics of the region are by themselves very important since the soil serves as a storage reservoir when rainfall exceeds PE. Availability of stored water is crucial for the successful harvest of a crop in SAT Alfisols, where water deficits during the growing season are frequent.

Traditionally, the water-storage capacity of a soil profile is determined by using the limits of water extraction at field capacity and -15 bars (permanent wilting point). The lower limit used in this procedure has come under criticism of late, because the proportion of the soil profile tapped by the crop is difficult to ascertain (Hsiao et al. 1980). By growing sorghum, pigeonpea, and chickpea under good management during the postrainy season on water stored in the soil, generalized estimates of crop-extractable water in deep and medium-deep Alfisols at the ICRISAT Center were determined. (See Fig. 5, El-Swaify et al. 1987, in this volume).

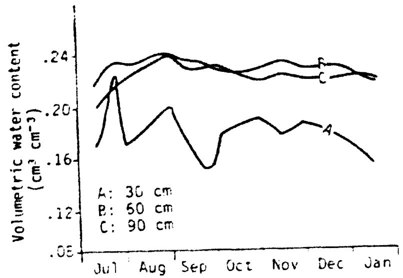

Figure 7. Seasonal changes in water content at three soil depths in an uncropped deep Alfisol.

Soil texture and soil moisture changes

The particle size distribution of selected Alfisols at ICRISAT Center are reported in El-Swaify et al. 1987 (in this volume).

Soil-moisture changes at depths of 30, 60, and 90 cm in an uncropped deep Alfisol (Fig. 7) clearly reflect the dynamic changes in profile-water recharge and depletion in the top 30 cm during the rainy and postrainy seasons. At depths below 30 cm, recharge and depletion occur annually, whereas in the upper 30 cm the periodicity of recharge and depletion is determined by depth and by the size and frequency of rainfall. The water regime of the upper 30 cm of the profile is highly dynamic, evaporation from the soil surface being the primary cause of depletion.

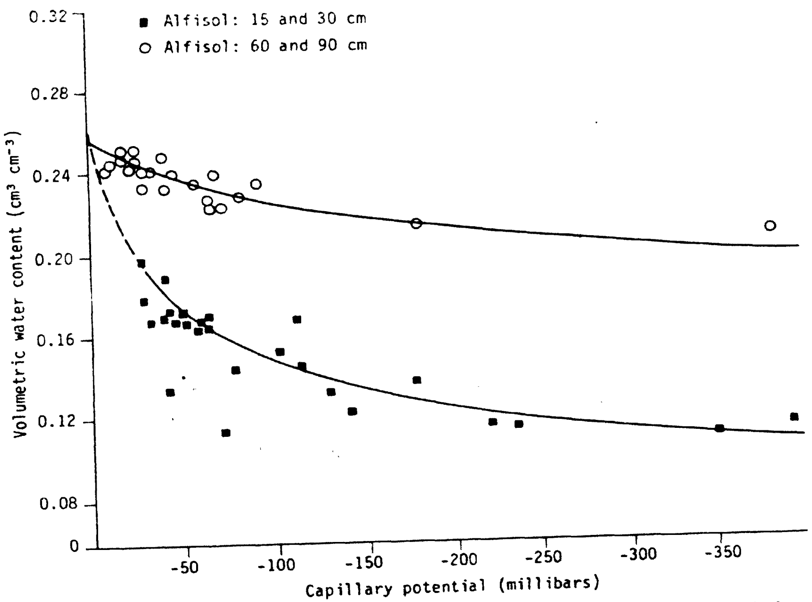

Figure 8. Moisture characteristic curves determined from in-situ field measurements on an Alfisol at ICRISAT Center.

Capillary potential: water cc relationships

One of the basic relationships used to describe and analyze the interactions of water with soils is the functional relationship between volumetric water content and capillary potential. From the tensiometric data and volumetric water contents measured at different depths on an Alfisol at ICRISAT Center, it was shown (Fig. 8) that with decreasing capillary potential there was a large decrease in the water content in the top 30-cm soil layer, while, in the lower layers, this decrease was considerably less. This reflects the large difference in texture between the soil layer at 0-30 cm and the deeper layers of Alfisols.

Water balance

Once the extractable water-holding capacity of an Alfisol is determined, water-budgeting or water-balance techniques can be used to determine the pattern of changes in profile moisture during the crop-growing season. The changes in profile moisture in deep and medium-deep Alfisols were estimated for five locations in Africa and India, using a simple water-balance model (Keig and McAlpine 1974). The results, shown in Figures 9a and 9b, indicate that, under identical rainfall conditions, the effect of short-term intraseasonal droughts on crop moisture status will differ with the depth of the Alfisols. The effect of changes in seeding dates, and the influence of different phenological characteristics on crop performance, could be assessed on a first-approximation basis using such analysis.

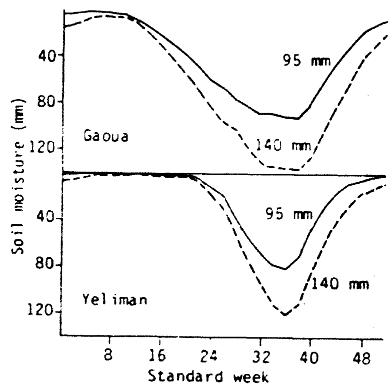

Figure 9a. Simulated profile moisture changes under two assumed available soil water storage capacities (95 and 140 mm) for two locations in Africa.

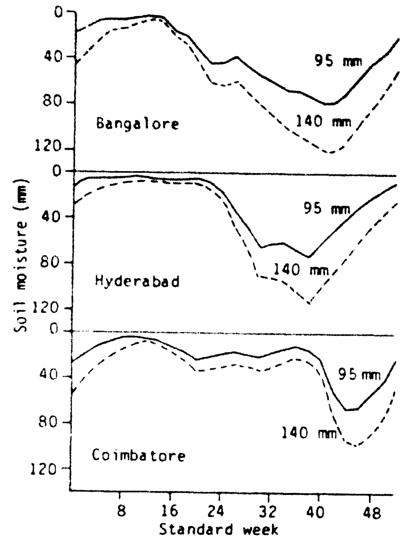

Figure 9b. Simulated profile moisture changes under two assumed available soil water storage capacities (95 and 140 mm) for three locations in India.

Crop Response to Drought Stress on Alfisols

Timing and intensity of drought stress

From the description of the climatic and soil characteristics of Alfisols, it is apparent that improved productivity on these soils would largely depend on the nature of the crops' response to drought. We

...ve conducted several studies on the effects of timing and intensity of drought stress on groundnut grown during the postrainy season on Alfisols at ICRISAT Center. The timing of stress on the crop was found to be much more important than the intensity of stress. This is reflected in the yields achieved, as shown in Figure 10. The final yields were greater from the crops that experienced drought stress during the preflowering stage.

It is worth noting the yield advantages obtained from early stress and considering whether or not this can be exploited. The merit of conditioning groundnuts to early stress to enable them to withstand a second stress has been demonstrated by Rao and Williams (1983), who found that the damage due to stress may be halved.

Water × nutrient interactions

Aborted and stunted groundnut seeds result from inadequate calcium uptake by the pod. Calcium deficiencies can develop in soils with low calcium-

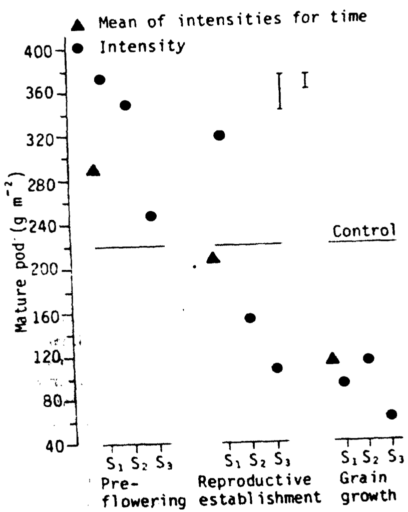

Figure 10. The effect of time and intensity of drought on groundnut yield (Robut 33-1). S_1 = mild stress; S_2 = intermediate stress; S_3 = severe stress.

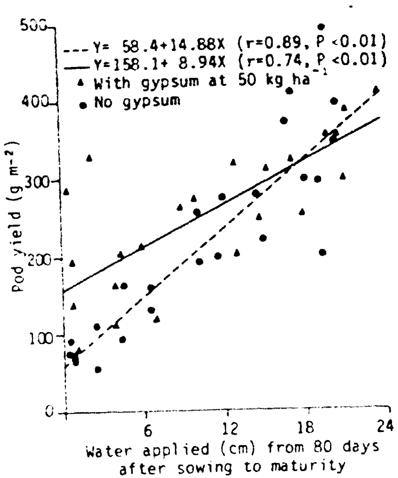

Figure 11. Effect of gypsum on the relationship between applied water and pod yield in groundnut (ICG 4601) at ICRISAT Center.

exchange capacity, or when drought restricts calcium movement in the soil solution. The effects of gypsum application on yields of different groundnut genotypes under varied intensities of drought stress on a medium-deep Alfisol were studied at ICRISAT Center. Although the Alfisols utilized would, normally, not be considered deficient in calcium, gypsum application did increase the yields under drought (Fig. 11).

Crop water-use efficiency on Alfisols

Since water is the most limiting factor for crop production on Alfisols, its efficient use is important. Water-use efficiency can be increased by decreasing evaporation from bare soils (E) between crop rows, and by increasing transpiration (T) and the transpiration efficiency of crops. Various soil and crop management practices employed for improving productivity on Alfisols (El-Swaify et al. 1987) can alter either or both the components of ET. The variation in the E and T components of sorghum and millet crops was studied under both irrigated and nonirri-

Table 8. Water balances for rainfed a[illegible]gated sorghum on an Alfisol during the rainy and postrainy seasons of 1977-78 at ICRISAT Center.

Dates	Days	P	Eo	M	L	E	Tm	E/Tm
				Rainy-season sorghum				
13 Jul to 18 Jul	5	50	37	29	21	10	11	0.91
18 Jul to 28 Jul	10	56	92	10	46	36	4	9.00
28 Jul to 04 Aug	07	16	37	-16	32	19	12	1.58
04 Aug to 16 Aug	12	97	54	6	91	10	27	0.37
16 Aug to 05 Sep	20	124	73	7	17	13	50	0.26
05 Sep to 12 Sep	7	0	38	-42	42	1	31	0.03
12 Sep to 26 Sep	14	0	83	-16	16	1	15	0.07
Total	75	343	364	-22	365	90	150	0.60
				Postrainy rainfed sorghum				
07 Nov to 16 Nov	9	5	53	-17	22	12	10	1.20
16 Nov to 01 Dec	15	28[1]	61	6	22	10	12	0.83
01 Dec to 28 Dec	27	2	125	-44	46	7	39	0.18
28 Dec to 18 Jan	21	17	90	-20	37	9	28	0.32
Total	72	52	329	-75	127	38	89	0.43
				Postrainy irrigated sorghum				
07 Nov to 16 Nov	9	5	53	-11	16	12	4	3.00
16 Nov to 01 Dec	15	28[1]	61	0	28	11	17	0.65
01 Dec to 15 Dec	14	41[2]	65	18	23	13	10	1.30
15 Dec to 23 Dec	8	0	37	-33	33	5	28	0.18
23 Dec to 04 Jan	12	34[3]	55	- 4	38	9	29	0.31
04 Jan to 18 Jan	14	35[4]	58	- 8	43	13	30	0.43
Total	72	143	329	-38	181	63	118	0.53

P = Rainfall (mm).
Eo = Open-pan evaporation (mm).
M = Change in water in 127 cm profile (mm).
L = Total water loss (mm).
E = Soil evaporaton (mm)
Tm = Transpiration by mass balance (mm).
1. = Including 22 mm irrigation.
2. = Including 39 mm irrigation.
3 = Including 34 mm irrigation.
4. = Including 18 mm irrigation

gated conditions on Alfisols in the rainy and postrainy seasons at ICRISAT Center. Data in Table 8 show that the E/Tm ratio was high in the early stages of sorghum growth in both the rainy and postrainy seasons. In the rainy season, evaporation accounted for 60% of the total transpiration, and about 24% of the total water loss.

In the postrainy season, for nonirrigated sorghum, the proportion of E to Tm was lower than that for the rainy season. Under irrigation, the E/Tm ratio increased to 0.53. Early-season losses in water due to evaporation were high during the postrainy season also, indicating the need to check evaporation in the early stages of plant growth. For pearl millet (Table 9), the E/Tm ratio, averaged over the season, was 0.25—considerably lower when compared with sorghum.

Early canopy growth and development of maximum leaf area increase the canopy demand for water through increased transpiration. For a postrainy-season groundnut crop grown on Alfisols, stress imposed from emergence to appearance of first pegs considerably reduced the canopy transpiration through reduction in leaf area index (LAI), but did not reduce the water-use efficiency (WUE) (Table 10). However, when stress was imposed after full

Table 9. Water balances for rainfed and irrigated pearl millet on an Alfisol during the postrainy seasons of 1977-78 at ICRISAT Center.

Dates	Days	P	Eo	M	L	E	Tm	E/Tm
			Rainfed pearl millet					
31 Oct to 10 Nov	10	18	52	-12	30	12	18	0.67
10 Nov to 25 Nov	15	10	67	-46	56	5	51	0.10
25 Nov to 05 Dec	10	2	42	- 5	7	1	6	0.17
05 Dec to 15 Dec	10	0	49	- 3	3	1	2	0.50
Total	45	30	210	-66	96	19	77	0.25
			Irrigated pearl millet					
31 Oct to 10 Nov	10	18	52	-15	33	12	21	0.57
14 Nov to 23 Nov	• 9	5	38	-42	47	6	41	0.15
25 Nov to 05 Dec	10	2	40	-29	31	9	22	0.41
12 Dec to 28 Dec	16	0	63	-30	30	3	27	0.11
28 Dec to 05 Jan	8	0	37	-14	14	1	13	0.08
Total	52	25	240	-130	155	31	124	0.25

P = Rainfall (mm).
Eo = Open-pan evaporation (mm).
M = Change in water in 127 cm profile (mm).
L = Total water loss (mm).
E = Soil evaporation (mm).
Tm = Transpiration by mass balance (mm).

Table 10. Effect of stage of growth at which drought stress is imposed on leaf growth and water-use efficiency of groundnut.

Stage of growth at which stress is imposed	LAI[1] before imposition of water stress	LAI[1] at maturity	Water-use efficiency (kg ha⁻¹ cm⁻¹)
1. Emergence to peg initiation	-	3.60	29.61
2. Flowering to last pod set	1.90	3.90	10.47
3. Pod filling to maturity	3.39	1.35	2.95
4. Continuous drought stress	-	1.42	1.73

1. LAI = leaf area index.

leaf-area development, the transpirational demand was very high; the moisture supply was inadequate and the WUE was low.

Selection of varieties that produce more yield for a given amount of water has been made at ICRISAT Center. It seems possible to increase groundnut yields under drought conditions on Alfisols utilizing appropriate genotypes (Fig. 12).

Because various cropping systems differ in their capacity to cover the ground quickly, and in their sensitivity to drought stress at different stages of growth, WUE also usually differs. The differences in the WUE of three sole crops and an intercrop grown on Alfisols at ICRISAT Center are shown in Table 11.

Conclusions

Planning for improved productivity of Alfisols should take into account the interactions between climate, soil, and plant in different areas of the world where these soils are situated. Information on the intensity, amount, and distribution of rainfall does help provide a general idea about the cropping potential and soil erosion, but this information should be combined with potential evapotranspir tion data to assess the available length of the gro ing period for crops. Air and soil temperature da for crop-growing seasons are equally important, view of the dynamic changes in soil moisture tl occur in the surface soil layers of Alfisols. The dep

Table 11. Water use and water-use efficiency of crops/cropping systems grown on Alfisols during the rainy season at ICRISAT Center.

Crop/cropping system	Water use (cm)	Yield (kg ha⁻¹)	Water use efficiency (kg ha⁻¹ cm⁻¹)	Reference
Sorghum	24.0	3700	154	ICRISAT (1978)
Pearl millet	15.9	2226	140	Reddy and Willey (1981)
Groundnut	19.6	1185	60	Reddy and Willey (1981)
Pearl millet/groundnut	22.8	1227/840	91	Reddy and Willey (1981)

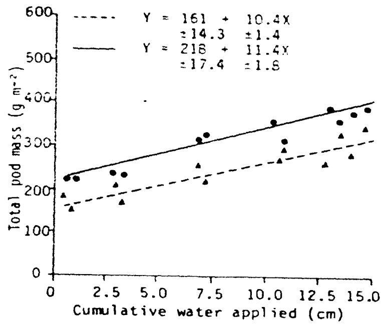

Figure 12. The response of pod yield to variations in applied water during pod set to pod filling for groundnut (ICG 4743), at ICRISAT Center.

of Alfisols being variable, various soil physical characteristics related to moisture storage and its release should be quantified. First-approximation information on profile water changes, employing simple models that use soil and climatic data, should prove useful in planning.

The crop's response to water shortages—so common on Alfisols—should be studied carefully, taking into account the timing and intensities of water stress. Water × nutrient interactions play an important role in drought responses. Crop WUE on Alfisols could be improved through appropriate management practices, selection of genotype, crops, and cropping systems.

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