THE AGRICULTURAL CLIMATE OF THE HYDERABAD REGION IN RELATION TO CROP PLANNING*

(A SAMPLE ANALYSIS)

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Farming Systems Research Program

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THE AGRICULTURAL CLIMATE OF THE HYDERABAD REGION WITH REFERENCE TO CROP PLANNING

1. INTRODUCTION:

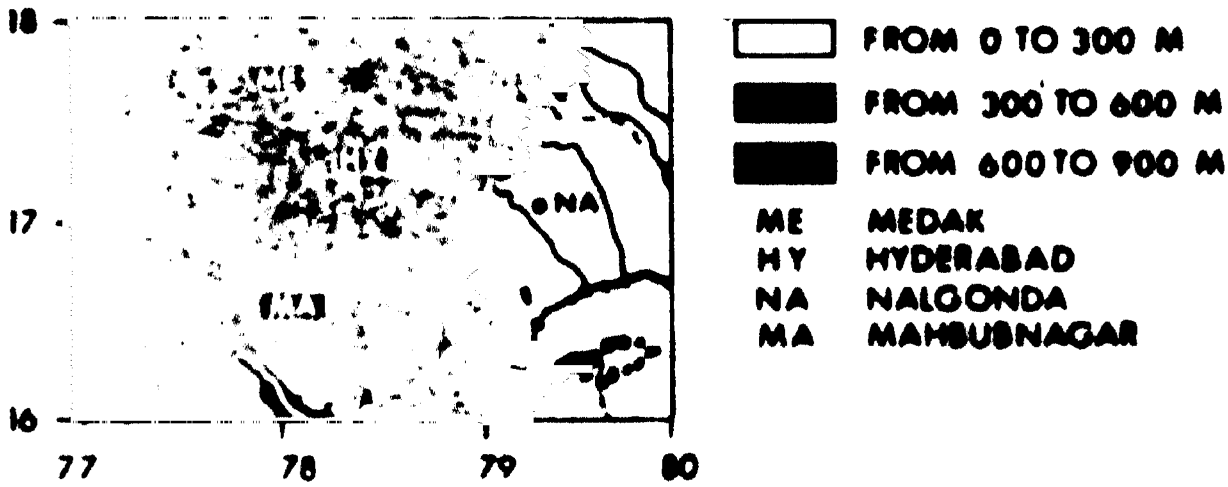
This paper has been prepared to provide essential criteria based on climatic and soil data for further planning of research in crop improvement and farming systems. The Hyderabad region is used as an example for analysis. In common with all semi-arid climates, the characteristics of rainfall and soil types are of primary importance in limiting agricultural production in this area. These two production factors largely determien the land use potential and it is therefore important that their effects in relation to determining the environment for crop growth be given as quantitative an appraisal as possible.

Besides efforts aimed at varietal improvement, better cropping systems and improved crop management, the current research emphasis in rainfed agriculture both in the Indian Council of Agricultural Research (ICAR) and at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is on profile moisture conservation and the use of runoff. A pragmatic approach to crop planning resulting in the optimum utilisation of available moisture and the additional water resources generated by way of adopting moisture conservation measures for improving and stabilising crop production, is yet to be evolved. Historically, the dryland farming research schemes of the ICAR which operated at some locations in the forties, failed to result in substantial increases in yields and production stability at the farmers' level because whatever improvement in soil moisture status was obtained by following better land and water management techniques largely remains unutilized because of a failure to develop cropping patterns which were sufficiently versatile to adjust to variable soil moisture conditions. The semi-arid areas of India are in addition characterised by such constraints as a high land - man ratio, lack of adequate capital resources and farm power and also by quite small farm sizes and fragmented holdings compared to the SAT areas elsewhere.

The climate-soil situation in the Hyderabad region is such that it does not appear to have any close homoclime in agriculturally developed areas so that experience generated there, could be applied to this situation. Therefore, this report has been prepared in three sections: the first is aiming to present a generalised description of the land and the environment; the second is giving a quantitative amount of the primary climatic elements influencing plant growth; and the last is aiming to interpret these analyses in terms of plant growth and land use potential.

II. GENERALISED LAND AND ENVIRONMENTAL FEATURES:

(a) Hypsometry: The Hyderabad region (Figure 1) is located between 77°-79° longitude and around 17° latitude at a height of 300-600 m above the mean sea level. The areas in the east are of somewhat lower elevation. A hill range located southwest of Hyderabad and extending to the northwest (dark area) has an elevation varying between 600-720 m. Around Hyderabad the height of some of the hills is about 715 meters but decreases to 680 m further west. The elevation of Hyderabad at the Begumpet observatory (airport) is 545 m above mean sea level.



* Figure 1: Hypsometry of the Hyderabad area.

(b) Geology and Lithology: Figure 2 shows that the area is characterised by the archean gneissic complex of geological formations. The Deccan trap (basaltes trapeens) type of lithology is a predominant feature west and north-west of 78° S and 17° N. Algonkian shale and limestone geological formations are found in a relatively small area.

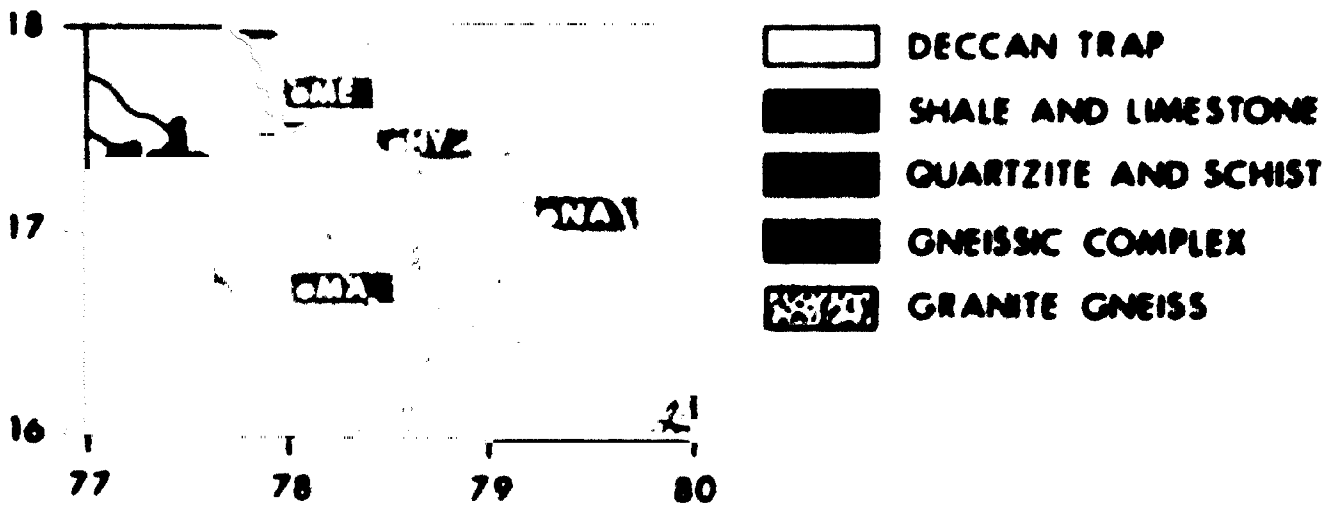


Figure 2: Geology and Lithology of the Hyderabad region.

* Source: Figures 1 - 5: ICAR (1963)

(c) <u>Soils</u>: A general description of the soils of the Hyderabad region is shown in Figure 3. Tropical red and black soils are predominant. A brief description of these is given below:

Black soils (order Vertisols and Inceptisols, sub-group - Chromusterts, Pellusterts, and Tropovertépts) are very dark, gray brown to dark gray brown calcareous soils. These vary in depth and may be medium (1 - 1.5 m) or deep black soils (> 2 m). The red soils (association of Entisols, Inceptisols and Alfisols - sub-groups Ustorthents, Ustocrepts and Rhodustalfs) are light reddish brown soils derived from granites. These soils are shallow to moderately deep (varying from 25 to 150 cm).

The black soils have a high clay content (40-60%), are calcareous and have a fairly high cation exchange capacity (CEC 25-30 me/100 g). Calcium and magnesium predominate in the exchange complex. The soils are characterised by a montomorillonitic type of clay mineral. The water holding capacity is fairly high (wilting point about 20%, field capacity 30-35%). Sardar Singh & Krantz* (1976) reported moisture equivalents of these soils in the range of 25-37%. The surface soils show lower values and the moisture equivalent increases with depth. In general, the total "available" water storage (assuming a root profile, providing for full extraction in a shallow

* A detailed discussion of the soils of the semi-arid tropics is reported by Virmani, S.M., Sardar Singh & Krantz, B.A. (1976).

black soil is about 100 mm and in the medium to deep black soils this value ranges between 150 to 200 mm per meter soil depth. These soils are usually poor in available nitrogen and phosphorus.

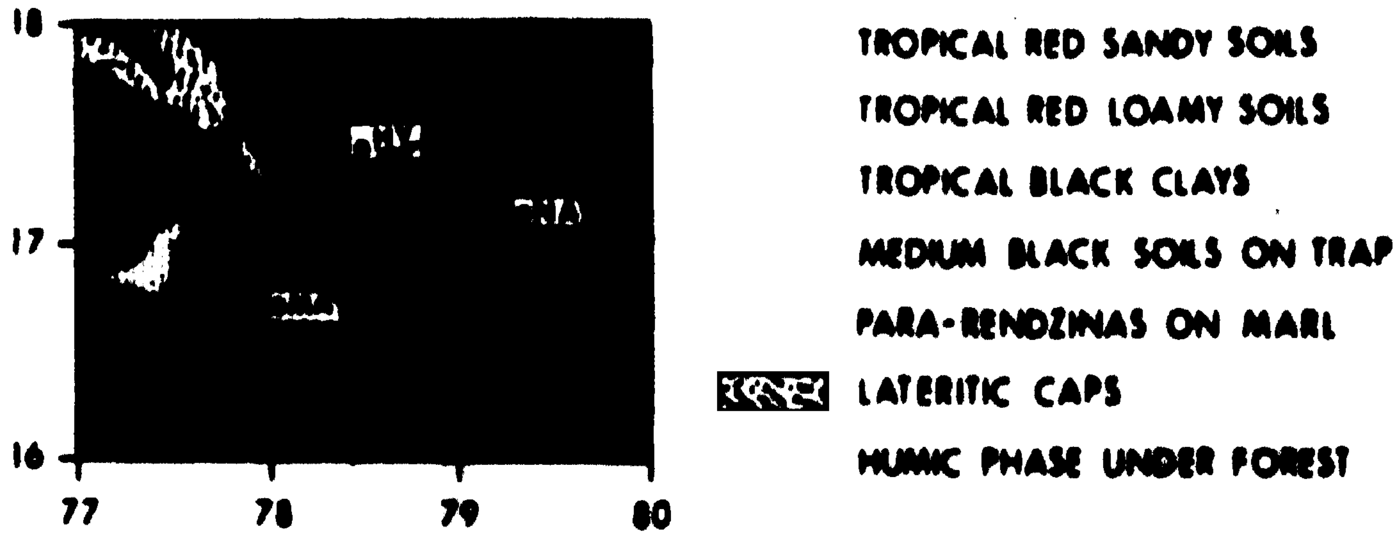


Figure 3: A generalised soil map of the Hyderabad area.
(ME = Medak; HY = Hyderabad, MA = Mahboobnagar; NA = Nalgonda districts)

The red soils are of a variable texture and may range from loamy sand to sandy loam at the surface to loam and loamy clay at the sub-surface. The clay is predominantly kaolinitic. Calcium carbonate is generally absent and the pH is about 6 (1 : 2.5 soil water ratio). The soils are relatively poor in exchange capacity. Sardar Singh and Krantz (ibid) reported moisture equivalents of two typical profiles at the ICRISAT site to vary between 11 and 23%. The values of moisture equivalents increased with depth. In general, the shallow red soils have an available moisture storage of about 50 mm in the root profile and for deep red soils this value may be around 150 mm. These soils are highly erodable and are poor in almost all nutrients; they respond well to fertil'zation.

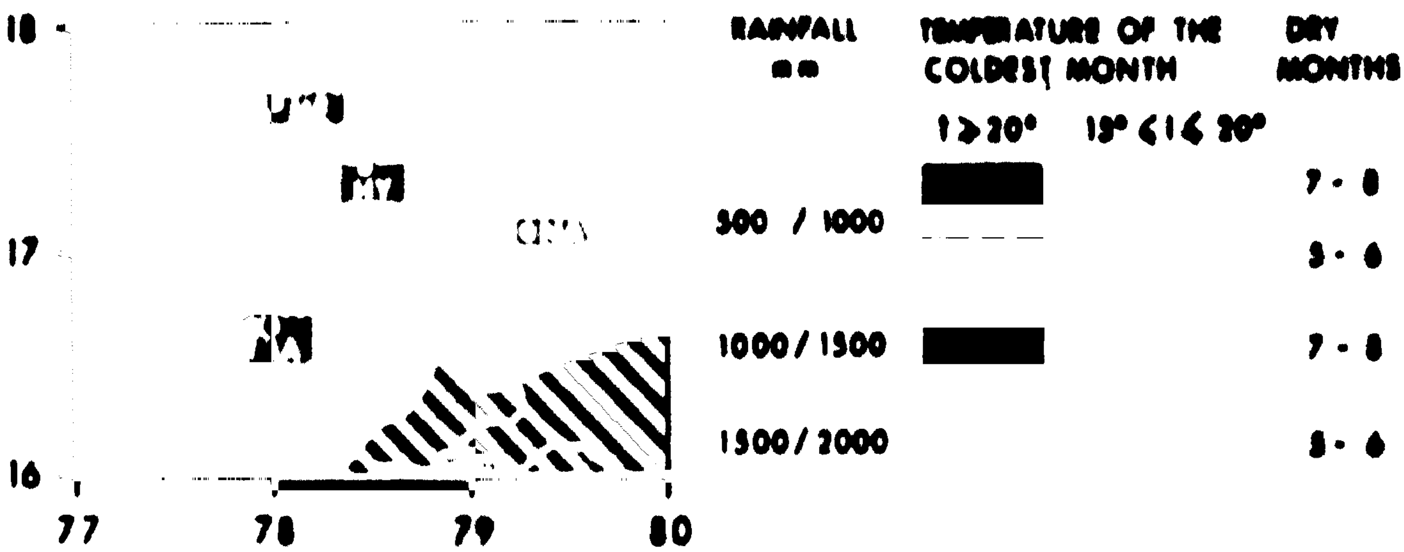


Figure 4: Bioclimate of the Hyderabad area.

(d) Bioclimate: A bioclimatic map of the Hyderabad region is shown in Figure 4. According to Labroue et al (1965) the bioclimate of the Hyderabad region can be classified as Tropical - Thermoxerochionen with a physiologically dry period of 7 to 8 months. The rainfall average ranges between 500 to 1000 mm. The average temperature of the coldest month is around 20°C; however, the diurnal variation is large during the cool season.

(e) Vegetation types: With 160-230 physiologically dry days, the Hyderabad region is characterised by the Anogeissus - terminalia - tectona series of natural vegetation. Below 17°

latitude, the Hardwickia - pterocarpus - Auogerissus series of vegetation predominates (Figure 5). Savana woodlands are the general dry vegetation types under natural conditions.

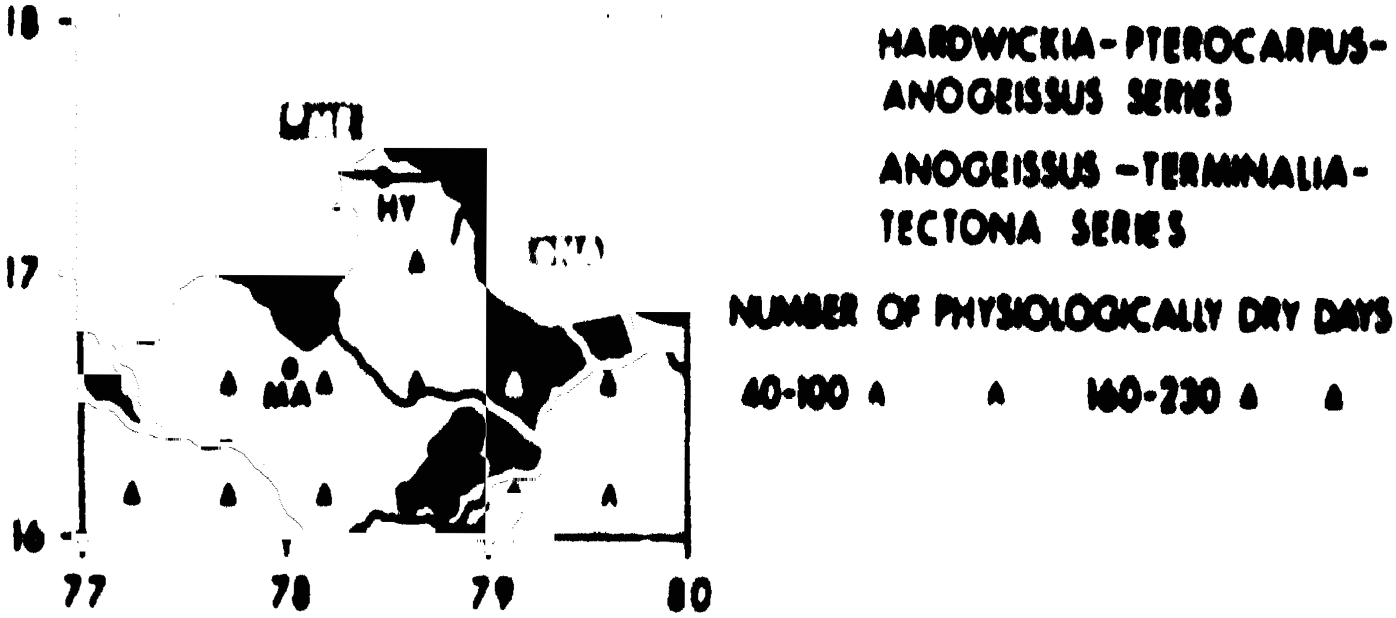


Figure 5: Vegetation types in the Hyderabad area.

(f) <u>Land use</u>: The land use pattern in the Hyderabad region according to Gausen et al (1963) is as follows:

Cultivated area	: 25 - 50%
Forests	: 15 - 25%
Cultivable land	: 15 - 25%
Uncultivable land	: 15 - 50%

III. PRIMARY CLIMATIC DATA

A meteorological observatory has been functioning at Begumpet, Hyderabad, since 1891. The climatic data used in this report relate to the observations recorded at this station. Rain data on a single day basis for 70 years (1901-70) have been used for detailed rainfall analyses. Normals of other climatic parameters on a monthly basis and the extremes observed are also reported.

(a) Temperature, relative humidity and vapour pressure: Normal daily maximum and minimum monthly mean temperatures, dry and wet bulb readings for the mornings at 0830 hrs, and for the afternoons at 1430 hrs, their extremes and normals of the relative humidity and vapour pressure are shown in Table 1. The temperatures remain fairly uniform from July to October, the daily maximum being around 30°C and the minimum around 21°C. There is a slight decreasing trend in mean monthly daily maximum temperatures after October until December. The mean minimum temperatures, however, drop sharply to about 16°C in November and to around 13°C in December. From January onwards temperatures starts ascending. May is the hottest month with a normal daily maximum temperature of 38.7°C. It sometimes is extremely hot and the highest temperature recorded is 44.4°C for May 28, 1935.

In the winter months from October to February, the dry bulb temperatures are around 4°C higher than the wet bulb readings recorded in the forenoon; the difference is around 7°C during the summer months of March to May and the difference narrows down to 2 to 3°C in the monsoon months from June to September. The variations in the dry and wet bulb readings recorded in the afternoon mostly follow the trend of the relative humidity; they are quite near to each other in the months showing a relatively high relative

TABLE 1

Monthly Air Temperatures (C°), Relative Humidity (%) and Vapour Pressure (mb) at Hyderabad

Month		Temperature (normal)				Temperature Extremes						Normal	
		Dry Bulb	Wet Bulb	Daily Max.	Daily Min.	Highest in the month	Lowest in the month	Highest	Date & year	Lowest	Date & year	Relative Humidity	Vapour Pressure
January	I*	19.6	16.3	28.6	14.6	31.9	10.7	35.0	17	6.1	8	79	16.3
	II	26.9	18.0						1929		1946	36	14.5
February	I	21.5	17.0	31.2	16.7	35.3	12.9	37.2	25	8.9	3	64	16.1
	II	30.0	18.9						1951		1911	35	14.5
March	I	25.4	18.8	34.8	20.0	38.5	16.5	42.2	29	13.2	6	54	17.4
	II	32.2	20.1						1892		1957	30	14.8
April	I	28.8	21.4	36.9	23.7	40.8	20.0	43.3	30	16.1	9	51	20.6
	II	34.9	21.8						1941		1917	31	17.8
May	I	30.4	22.2	38.7	26.2	42.4	22.5	44.4	28	19.4	17	50	21.7
	II	35.7	23.1						1935		1917	33	19.9
June	I	27.0	22.7	34.1	24.1	39.9	21.2	43.9	9	17.8	12	71	25.4
	II	31.7	23.7						1931		1922	54	23.8
July	I	24.7	22.2	29.8	22.3	34.0	21.0	37.2	13	19.4	14	83	25.9
	II	27.7	23.2						1918		1931	69	25.6
August	I	24.6	22.0	29.5	22.1	33.0	20.9	36.1	24	19.4	26	82	25.3
	II	27.5	23.2						1950		1955	70	25.1
September	I	24.7	22.2	29.7	21.6	32.8	20.3	36.1	15	17.8	30	82	25.4
	II	27.1	23.0						1927		1942	71	25.2
October	I	25.1	21.3	30.3	19.8	33.3	15.8	36.7	6	12.2	31	73	23.2
	II	27.7	21.7						1896		1952	58	22.0
November	I	22.7	18.4	28.7	16.0	31.5	11.8	33.9	2	7.8	25	68	18.6
	II	26.3	18.5						1909		1939	48	17.1
December	I	19.3	15.7	27.8	13.4	30.6	9.9	33.3	10	7.2	12	71	15.9
	II	25.7	17.2						1930		1945	42	13.8
Annual	I	24.5	20.0	31.7	20.0	42.4	9.1	44.4		6.1		69	21.0
	II	29.5	21.0									48	19.5
No. of years	I	30	30	30	30	30	30	70		70		30	30
	II	23	23									23	23

Source: Climatological Tables of Observatories in India (1931-60) - India Meteorological Department pp: 255.

humidity. The vapour pressure readings remain almost constant around 25 mb during the period of June to September, these are approximately 15 mb during the cooler months of the year and show a rising trend from April to June. The mean annual average is 21.0 mb of vapor pressure.

(b) Rainfall at Hyderabad[1/] Some generalised rainfall characteristics of Hyderabad are given in Table 2. It can be seen that an average rainfall at 761 mm is received annually. About 86% of this rainfall is received during the period June to October - during the monsoon season (Table 2). An average of 53 mm of pre-monsoon showers are received during the months of April and May. Generally the post-monsoon period is relatively dry.

The annual rainfall varies greatly (Table 2). In 20% of the years, it could be ≤ 628 mm, and in 40% of the years ≤ 726 mm. The 30 year records further reveal that 40% of the years would receive ≥ 800 mm annual precipitation. The wettest year on record during the period 1901-70, received 1431 mm rainfall, while the driest year accumulated a total of 457 mm. (Precipitation in 1972 amounted to 379 mm). The coefficient of variation (CV) for annual rainfall at Hyderabad is 26%. The standard deviation is 205 mm over a mean annual rainfall of 761 mm. The monthly rainfall amounts show great variation from year to year, as is evident from the CV and the standard deviation values (Table 2). In general, the lower the mean rainfall, the higher is the amount of variation.

(c) Dependable Precipitation: Dependable precipitation is defined as the precipitation that has a specified minimum probability of occurrence based on the analysis of long term records of rainfall. For agricultural decision purposes, a seventy or seventy-five percent probability is generally accepted as a reasonable risk value for most conditions. For drought sensitive

1/ A statement on rainfall in the Indian sub-continent is given in Appendix I.

Table 2

Some generalised rainfall characteristics of Hyderabad

Characteristics		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Datum Period
Frequency	0	0	0	0	0	0	29	41	26	61	2	0	0	481	
Groups of	I	0	0	0	4	5	54	115	77	87	24	0	0	628	
Precipitation	II	0	0	1	12	14	78	143	119	107	52	1	0	726	1931-60
(mm)*	III	0	3	5	22	34	100	176	144	163	87	15	0	800	
	IV	0	21	28	32	46	154	224	195	257	110	40	3	886	
	V	26	96	114	163	116	324	313	334	362	269	229	69	1158	
Average precipitation (mm)*		2	10	13	23	30	107	165	147	163	71	25	5	761	1931-60
No. of days with* precipitation > 1 mm		0.2	1.1	1.4	2.9	3.9	9.0	15.5	13.0	12.3	5.8	2.6	0.6	68.3	1931-60
<u>Extremes</u>:															
Wettest**		132	96	114	163	116	324	393	400	498	355	229	94	1431	1901-70
Driest**		0	0	0	0	0	17	30	25	32	0	0	0	457	65
Heaviest rain in 24 hrs**		95	43	103	61	65	123	109	190	153	117	96	44		65
S.D.		20	18	25	30	28	59	76	75	99	72	43	16	205	1901-70
CV%		315	202	197	124	95	57	45	52	56	93	166	247	26	1901-70
Median		0	0	2	14	22	90	158	127	158	63	8	0	772	1901-70

* Source: WMO (1971): Frequency groups of precipitation I-V refer to quintiles. The 0 group contains the lowest value and V group the highest.

**Source: IMD Climatological Tables of Observatories in India (1931-60).

or high value crops, or for periods of critical crop phenological stages, a higher probability level may be more appropriate. Conversely, for drought hardy crops or at relatively less water stress sensitive crop growth stages, a lower probability may be acceptable.

Rainfall amounts of given probabilities, based on 1901-70 data for Hyderabad for 4-week periods are presented in Table 3. The dependable precipitation at 75% probability for the early monsoon period of June 18 to July 15 is 85 mm, for the mid-monsoon period commencing July 16 and ending August 12, it is 95 mm; it is 81 mm for the period commencing August 13 to September 9 and 72 mm for the period September 10 to October 8. The amount of dependable precipitation in the post-monsoon is very small and also in the summer months of March, until late May. The total annual dependable precitation that will, on the long term, occur during three out of four years is 648 mm against a mean annual rainfall of 789 mm (Table 3).

TABLE 3

PRECIPITATION FOR GIVEN PROBABILITIES USING A GAMMA DISTRIBUTION (IN MM)
Station: Hyderabad Datum Period: 1901-70

4-week period	Commencing	Probability 90	75	50	25	10	Mean
1	Jan 1	0	0	0.3	3.8	15.6	5.2
2	Jan 29	0	0	0.7	7.6	27.9	9.2
3	Feb 26	0	0	1.1	10.0	34.5	11.4
4	Mar 26	0.1	1.3	7.6	25.4	55.6	19.8
5	Apr 23	0.2	1.5	8.5	28.2	61.8	22.1
6	May 21	7.6	18.7	41.6	79.1	127.4	57.2
7	Jun 18	59.7	85.5	122.1	168.0	217.8	132.2
8	Jul 16	63.9	95.1	140.8	199.2	263.6	154.7
9	Aug 13	51.2	80.6	125.2	184.1	250.5	140.7
10	Sep 10	41.2	72.4	123.5	194.9	278.3	145.4
11	Oct 8	0.7	5.4	27.0	84.0	177.7	64.5
12	Nov 5	0	0	2.5	19.4	62.1	20.5
13	Dec 3	0	0	0.4	4.5	17.6	5.9
	Annual:	549	648	772	912	1050	789

(d) Potential Evapotranspiration (PE): Daily, weekly and monthly PE, calculated from long-term climatic parameters according to the modified Penman's formula (Rao et al 1971) are given in Table 4. The data show that the monthly PE is about 200 mm or more during the summer months and in the pre-monsoon season and that the daily values of PE are invariably > 6 mm/day. In the monsoon season commencing in July, the PE values drop to around 4 mm/day, the monthly total range between 120-140 mm. During the post-monsoon season from October through early February, the PE values range between 3 and 4 mm/day and the monthly values are about 100 to 110 mm. Towards the end of the post-monsoon, the PE values show a rapidly increasing trend (Table 4).

Table 4

Daily, weekly and monthly potential evapotranspiration* at Hyderabad

Week	Date	Evapotranspiration (mm)		
		Daily	Weekly	Monthly
			Pre-monsoon	
18	Apr 30 - 6	6.95	48.6	
19	May 7 - 13	7.05	49.3	220
20	May 14 - 20	7.00	49.0	
21	May 21 - 27	6.90	48.3	
22	May 28 - 3	6.80	47.[illegible]	
23	Jun 4 - 10	6.65	46.5	196
24	Jun 11 - 17	6.40	44.8	
			Monsoon	
25	Jun 18 - 24	5.90	41.3	
26	Jun 25 - 1	5.40	37.8	
27	Jul 2 - 8	4.90	34.3	140
28	Jul 9 - 15	4.60	32.2	
29	Jul 16 - 22	4.45	31.1	
30	Jul 23 - 29	4.45	31.3	
31	Jul 30 - 5	4.45	31.1	
32	Aug 6 - 12	4.40	30.8	135
33	Aug 13 - 19	4.30	30.1	
34	Aug 20 - 26	4.25	29.7	
35	Aug 27 - 2	4.15	29.0	
36	Sep 3 - 9	4.05	28.0	119
37	Sep 10 - 16	4.00	28.0	
38	Sep 17 - 23	4.00	28.0	
39	Sep 24 - 30	4.00	28.0	
40	Oct 1 - 7	4.00	28.0	124
41	Oct 8 - 14	4.00	28.0	

Table Contd.

			Post-monsoon	
42	Oct 15 - 21	3.90	27.3	
43	Oct 22 - 28	3.80	26.6	
44	Oct 29 - 4	3.70	25.9	
45	Nov 5 - 11	3.60	25.2	104
46	Nov 12 - 18	3.45	24.1	
47	Nov 19 - 25	3.40	23.8	
48	Nov 26 - 2	3.30	23.1	
49	Dec 3 - 9	3.26	22.8	99
50	Dec 10 - 16	3.20	22.4	
51	Dec 17 - 23	3.40	23.8	
52	Dec 24 - 31	3.40	27.2	
1	Jan 1 - 7	3.50	24.5	110
2	Jan 8 - 14	3.60	25.2	
3	Jan 15 - 21	3.70	25.9	
4	Jan 22 - 28	3.95	27.6	
5	Jan 29 - 4	4.20	29.4	
6	Feb 5 - 11	4.50	31.5	129
7	Feb 12 - 18	4.75	33.2	
8	Feb 19 - 25	5.10	35.7	
9	Feb 26 - 4	5.40	37.8	
10	Mar 5 - 11	5.70	39.9	181
			Summer	
11	Mar 12 - 18	5.95	41.6	
12	Mar 19 - 25	6.10	42.7	
13	Mar 26 - 1	6.30	44.1	
14	Apr 2 - 8	6.40	44.8	198
15	Apr 9 - 15	6.60	46.2	
16	Apr 16 - 22	6.70	46.9	
17	Apr 23 - 29	6.82	47.7	

* According to the modified Penman's formula Rao et al (1971). Daily and weekly values are obtained from monthly values reported by Rao, George and Rama Sastri (ibid).

(e) Moisture Availability Index (MAI): Hargreaves (1975) defines the MAI as the ratio of dependable precipitation = 75% probability and potential evapotranspiration. This results in a more realistic climatic water balance. The data show that during the monsoon period, commencing with week 25 (June 18) and lasting to week 40 (October 7) different periods have a MAI of about 0.60 or more (Table 5). The rest of the year is characterised by very low moisture availability index values.

Table 5

[illegible]

Week	Period	MAI	Climate Classification*	Productivity classification
Pre-monsoon:				
17-20	Apr 23 - May 20	# 0		
21-24	May 21 - Jun 17	0.10		
Monsoon:				
25-28	Jun 18 - Jul 15	0.59	Semi-arid (three or four months with a MAI of 0.34 or above)	Production possible for crops requiring a 3 to 4 months growing season
29-32	Jul 16 - Aug 12	0.77		
33-36	Aug 13 - Sep 9	0.69		
37-40	Sep 10 - Oct 7	0.64		
Post-monsoon:				
41-44	Oct 8 - Nov 4	0.05		
45-48	Nov 5 - Dec 2	0		
49-52	Dec 3 - Dec 31	0		
1-4	Jan 1 - Jan 28	0		
5-8	Jan 29 - Feb 25	0		
Summer:				
9-12	Feb 26 - Mar 25	# 0		
13-16	Mar 26 - Apr 22	# 0		

*After Hargreaves, G.H. [1975]

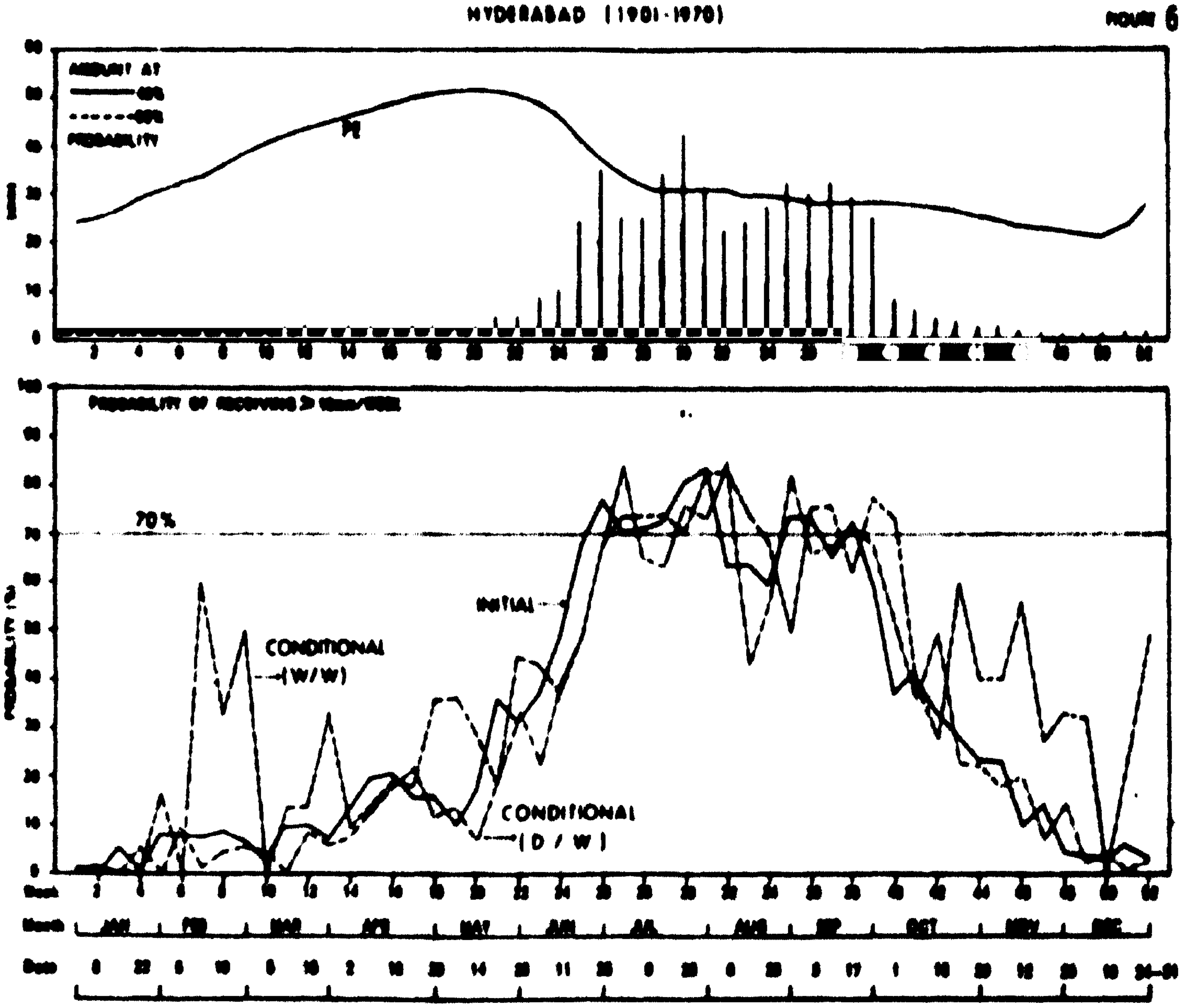
According to Hargreaves (1975), the Hyderabad area can be classified as a semi-arid climate as it has 3 or 4 months with a MAI of 0.34 or above. Production of crops requiring a 3 to 4 months growing season is possible. A more detailed analysis of climate in relation to agriculture is given in section 3 (p.20).

(f) Probability of Weekly Rainfall: Probabilities of weekly rainfall at various levels of precipitation viz., 1, 5, 10,[1/] 20 and 40 mm per week have been calculated using a first order Markov Chain Model and the data are presented in Appendix II, Tables 1.1 - 1.4. The data based on a probability of receiving at least 10 mm of weekly rainfall are shown in figure 6. The curves giving the initial probability of a week being wet, and curves for conditional probabilities of a wet week followed by a wet week and a dry week followed by a wet week are also shown (Fig.6).

The results (Appendix II and Fig.6) show that in the pre-monsoon season from April 30 to June 17, the initial probabilities of weekly rainfall increase from around 35% after June 4 at rainfall levels of at least 10 mm/week. A perusal of the data for higher levels of weekly rainfall shows (Appendix II Tables 1.3 and 1.4) that the relative probabilities reduce considerably with an increase in the threshold amount of rainfall. The dry/wet conditional probabilities even at ≥ 1 mm/weekly rainfall levels are not more than 57% in any of the weeks during this period, thus showing that these early rains are not at all dependable and would in frequent years be small in quantum. The wet/wet probabilities for the period after May 29 reveal that these early rains, once they commence, have a tendency to persist.

1/ Date for precipitation probabilities of atleast 10 mm/week is given in Fig.6.

PATTERN OF RAINFALL
HYDERABAD (1901-1970)



For the early monsoon period (June 18 - July 15), the initial wet/wet and dry/wet probabilities show a marked upward trend where weekly cumulative rainfall is taken as 10 to 20 mm. The heavier showers (>20mm/week) may occur around once every two years; and weekly rainfall exceeding 40 mm has a probability of occurrence of an average once every three years. If the land is not properly prepared in advance of the receipt of rains, the early monsoon rainfall is likely to produce runoff even before the soil profile is filled. Surface runoff may take place in red soils and deep drainage losses (through cracks) in black soils.

In the context of the semi-arid tropical rainfall situation, it is suggested that at least 10 mm of dependable weekly rainfall be adopted as a criterion for effective rainfall during the monsoon crop season. The reason for selecting this value is that potential evapotranspiration values range between 4 and 6 mm/day during this period and rise to around 8 - 10 mm/day in rainless periods. A weekly rainfall of 10 mm, even if it were to occur in any one day of the week, would be only a minimal contribution to soil moisture to support plant life. Again, as explained earlier (para c), around 70% probability can be taken as the lower threshold for dependable rainfall. Based on these two criteria, it is evident (from figure 6) that the rainfall in the monsoon period extending from week 26 - 39 (June 25 - September 30), is dependable both in the early part (late June and July) and the later part (late August and September). The period of August 6 - 26 is risky when a break in the continuity of the rains is likely to occur in at least 40% of the years. The dry/wet and wet/wet conditional probabilities also show a dip alongwith the initial probability of rainfall during this period. The period of dry weather can be long when it occurs early in August or may be of a shorter duration when it occurs after mid August.

Figure 6 also shows that some years have a marked tendency for the rains to extend from the normal date of recession (end of September) to the middle of October (about 1 in 2 years) or to early November (about 1 in 4 years). However, in general, once the recession of monsoon rains takes place, there is a high probability of the season to be dry in the post-monsoon period; this is evidenced by dry or dry/dry probabilities (Appendix II, Tables 1.1 - 1.4).

The post-monsoon season (mid-October to mid-February) is characterised as a relatively dry period with little rains. If it rains around the first week of February (Probability 1 in 10 years), the rainfall has a tendency to continue over the next 2-4 weeks as shown by the wet/wet probabilities (figure 6).

IV. CROPS AND CROPPING SYSTEMS IN RELATION TO SOILS & CLIMATE

The most significant features of the climate in relation to plant growth and production are those which affect the duration and the characteristics of the growing period. Differences in soils, specifically with regard to the the availability of soil moisture strongly influence plant growth. Because of the occurrence of a relatively high potential evapotranspiration demand during most of the growing season (Table 4), a favourable environmental humidity also seems necessary at critical plant growth stages (e.g. flowering). The balance between increments to the available water within the root zone of the soil caused by rainfall and the water loss resulting from evapotranspiration is thus of fundamental significance in relation to plant growth in semi-arid tropical areas.

Different crop species and varieties are known to react distinctively to a particular set of soil water (and environment water) conditions, and the availability of soil moisture to crops or pasture depends upon many interrelated climate, plant and soil factors. Also, the amount of precipitation actually entering the soil depends to a great extent upon the type, surface conditions and moisture status of the soils, the nature of the cover, the degree of slope and the intensity of the rainfall.

It is not feasible to give detailed consideration to all these factors at the scale of regional surveys and descriptions; only a generalised assessment of the climate and soils environment in relation to crop growth can be attempted at this level. Such an assessment can be made with the aid of idealised crop-water use models, which on the basis of experience and theoretical considerations, are appropriate for particular modes of land-use. In this report, a rather generalised model for a dryland crop situation has been used (for details see Appendix III). These models are location specific and cannot be expected to be valid under all circumstances. They do, however, give a more meaningful interpretation of climate than is possible from rainfall statistical summaries of the various elements alone, or from general studies based on assumptions relating to the use of water by crops.

In the following pages the analyses of the primary climatic elements presented in section 2 are related to the environment for plant growth in the two main cropping seasons at Hyderabad: the kharif, i.e. the monsoon rainy season and the rabi, when crops are raised on conserved profile moisture in the dry post-monsoon season. Based on the soil-climate analyses, some implications for agricultural research in the semi-arid tropics are also derived.

(1) Plant Growth and Water Balance in the Monsoon Season: The monsoon cropping season, as mentioned earlier, commences with the onset of the rainy season i.e. in end June or early July. The crops are planted around this time. The land, however, is prepared in advance, with the pre-monsoon rains. The time of the pre-planting tillage differs with the soil type. In case of the red soils, which are to some degree subject to wind erosion and which become extremely hard when dry, the initial land preparation is taken up in the period immediately preceding the onset of the monsoons; while the black soils, which resist wind erosion, can be cultivated earlier in the dry season and the seed-bed can be prepared well in advance. The black soils, of Hyderabad region have a

high clay content of the montmorillonite type and once these soils are wet, they take quite some time to come to a drier condition suitable for soil manipulation. At Hyderabad, as shown earlier, the dependability of occurrence of rainfall from the end of June to early August is quite high. The probabilities of a wet week followed by a wet week are invariably more than 70%. Obviously once the monsoon sets-in, land preparation and the planning of <u>kharif</u> crops in black soils is very difficult and therefore traditionally these soils have been monsoon fallowed. The ICRISAT's experience in seeding of some crops in a dry seed-bed in the case of deep black soils over the past 3 years has been encouraging and seems to be the only feasible proposition for the planting of monsoon season crops in these soils.

The climate bound decisions are:

i) When should the pre-planting seed-bed preparation be taken up?

ii) When should the planting of crops be done, so that the seedling survival is assured? and

iii) What are the variations in the growing season and what should be the characteristics of an optimum crop pattern or system for the location?

A brief description of the methodology to derive answers on these questions for the Hyderabad region is given in the following pages:

(a) <u>Pre-sowing cultivation</u>: The probabilities of rainfall during the pre-monsoon season (Fig.6) are quite low and consequently undependable. For cultivation operations on a black soil after initial land preparation has been completed earlier, the soil should be moist upto a depth of about 5 cm. A minimum of 20 mm of rainfall received in a one day or two day period is thus required. An analysis of 70 years (1901-70) single day rainfall data of Hyderabad for the months of March, April, May and June, showed the following results with respect to the probability of pre-planting rainfall sufficiently adequate to wet a black soil for tillage operations (Table 6).

Table 6

Probability of rainfall at Hyderabad for pre-planting cultivation on black soil

(a) Number of years when adequate rainfall to carry out at least one tillage operation was received in the month of:

March	: 13%
April	: 33%
May	: 43%
First 3 weeks of June	: 80%

(b) Number of times adequate rainfall was received during the period March-June 20 to carry-out pre-sowing tillage:

Once	: 95%
Twice	: 50%
At least Thrice	: 14%

The data (Table 6) show that the chances of carrying out pre-sowing tillage operations increase progressively from March to June. However, the number of opportunities available in any one year for seed-bed cultivation are highly undependable. In most of the years, only one or two cultivations may be possible. The analysis also shows that these one or two adequate rainfall events for cultivation are quite spread out during the summer months.1/

The Farming Systems Research Program recommendation of deep tillage just after the harvest of the crop in the preceding season in black soils 2/ is highly commendable in this context. The soil is thus left in an open and cloddy state and as and when adequate rainfall is received during the period from March onwards, the final seed-bed preparation can be carried out.

1/ Small intermittent showers are, however, helpful in breaking the clods in the case of black soils..

2/ Krantz, Kampen and Associates (1975)

In one out of two years (on an average) on black soils, that may be the only opportunity for final seed-bed preparation before seeding. If a further opportunity arises, the seed-bed should be refined and recultivated.

On the red soils, initial land preparation should be executed as and when sufficient moisture has been accumulated in the surface horizon (i.e. minimum of 20 mm of rainfall received in a one or two day periods. The soil should, however be left in an open and cloddy state so that wind erosion and runoff are minimised.

(b) Sowing rains: Sowing rains may be defined as the receipt of at least 20 mm of rainfall, received on not more than two consecutive days in a week having a dependable precipitation probability followed by a week with a similar or higher probability.[1/] On this basis, the date of the commencement of the sowing rains for Hyderabad for the monsoon season have been calculated and reported in Table 7.

Table 7

Commencement of sowing rains in the monsoon cropping season at Hyderabad (1901-70)

Probability	Date of Commencement
First Quartile	Jun 18 (week No.25
Median	Jun 25 (week No.26
Third Quartile	Jul 2 (week No.27
Mean	Jun 25 (week No.26
No. of years without sowing rains upto July 8	9 (13%)

The results (Table 7) show that because of a fairly good dependability of rainfall during the initial period of the monsoons at Hyderabad (Figure 6); the sowing period in 90% of the years would lie between June 18 to July 8.

Based on the rainfall analysis presented in Tables 6 and 7, a calendar of farm operations for seed-bed preparation and planting dates for the monsoon cropping season is presented in Table 8. As stated earlier, on black soils

1/ With ≥ 70% probability of receiving ≥ 10 mm rainfall.

the initial land preparation would commence immediately after the harvest of the last crop in the preceding season and only secondary tillage would be carried out in the pre-sowing period.

Table 8

Suggested calendar for seed-bed preparation and seeding during kharif at Hyderabad

Farm operation	Soil type*		
	Heavy black	Light black	Red
1. Preparatory tillage	Before Jun 18	Jun 4 - Jun 25	Jun 11 - Jun [illegible]
2. Seed-bed preparation	Before Jun 18	Before Jul 2	Before Jul 2
Seeding**	Dry-planting	Planting in moist seed-bed	
(i) Crops tolerant to drought at seedling stage1/	Jun 18	Jul 2	Jul 2
(ii) Crops sensitive to drought at seedling stage	Jun 25	Jul 2	Jul 2

* Heavy black soils are fine textured, while light black and red soils are relatively coarse textured.

** The planting dates should be advanced by a week if more than 10 mm weekly rainfall is received in week 23 (Jun 4-10) and/or week 24 (Jun 11-17).

(c) Length of the Monsoon Growing Season: A computerised water balance model 2/ was designed to give estimates of week-to-week changes in available moisture in relation to potential evaporation demands, using weekly rainfall as an input and estimated evapotranspiration as withdrawals; 70-years of weekly rainfall data were used. Through this simulation study the duration of the monsoon crop growing periods have been investigated in the Hyderabad

1/ A list of crops sensitive and tolerant to drought at seedling stage is given by Krantz, Kampen & Associates (1975).

2/ For details see Appendix III; the model may in certain cases over estimate the total available water because it does not allow for simulation of the effects of high intensity storms causing runoff.

area. The results are shown in Table 9.

Table 9

The length of the kharif growing period* in three soils having variable available water storage capacity (AWC) at Hyderabad

Probability		Available water storage capacity of the root profile**		
		Low	Medium	High
Mean		Jun 25 - Oct 28 (17 weeks)	Jun 2[illegible] - Nov 25 (21 weeks)	Jun 25 - Nov 25 (25 weeks)
First decile	(90%)	Jun 25 - Sep 30 (12 weeks)	Jun 25 - Oct 21 (16 weeks)	Jun 25 - Nov 18 (20 weeks)
First Quartile	(75%)	Jun 25 - Sep 30 (13 weeks)	Jun 25 - Nov 4 (18 weeks)	Jun 25 - Dec 2 (22 weeks)
Median	(50%)	Jun 25 - Oct 21 (16 weeks)	Jun 25 - Nov 18 (20 weeks)	Jun 25 - Dec 23 (25 weeks)
Third Quartile	(25%)	Jun 25 - Nov 11 (19 weeks)	Jun 25 - Dec 9 (23 weeks)	Jun 25 - Jan 14 (28 weeks)
Ninth Decile	(10%)	Jun 25 - Nov 25 (21 weeks)	Jun 25 - Dec 23 (25 weeks)	Jun 25 - Feb 4 (31 weeks)

From the commencement of sowing rains upto the week when availability of profile moisture reduces EA/PE to 0.5***.

** The shallow red soils examplify a low AWC situation; the deep red and medium deep black soils, a medium AWC situation and the deep black soils a high AWC situation.

*** EA stands for estimated available water and PE for potential evapotranspiration.

The data (Table 9) show that in the shallow red soils (low AWC) the length of the growing season fluctuates between 12 and 21 weeks; in medium AWC soils between 16 and 25 weeks; and between 20 to 31 weeks in soils characterised by a high AWC. According to these results a 16-week crop will have a 50% chance of successfully maturing in a shallow red soil, a 90% chance in a deep red or medium deep black soil, and a greater than 90% chance in deep black soil. The soil type, in a given rainfall situation, plays a dominant role in defining the growing periods in the SAT, as examplified by this Hyderabad analysis.

Such analyses of the growing periods give the upper limits of crop (and variety) durations, on the basis of given probabilities. They also aid in determining the relative area that should be assigned to different crops in a cropping pattern scheme, so as to distribute the risk. However, the selection of the crop and its genotype must also be made on the basis of an assessment of intra-seasonal water availability, the periods of water deficits in comparison to crop water needs and the probability of damage due to rainfall at the time of crop maturity.

(d) Variability of Available Profile Moisture in Three Soil Types: A reliable estimate of intra-seasonal probability of water deficits is provided by estimates of soil moisture variations occurring over the growing season. The median amount of available water present in the root profile of the three soil types - low AWC, medium AWC and high AWC made from water balance studies are shown in Figure 7. It can be seen that the amount of available moisture in the low AWC soils does not exceed 60 to 70 percent of the total available water capacity. There is a marked decrease in the amount of available water in the first half of August (to less than 25 mm). Since the evapotranspiration demand during the monsoon season exceeds 25 mm per week (Table 4), a break in the continuity of rains exceeding one week or so would be quite hazardous to crops in these low available water storage capacity soils.

These results emphasise the need for developing alternate water sources in case of failure of rainfall to break intra-seasonal droughts, to increase and stabilise crop production in such soil regions of Hyderabad. Since shallow red soil areas are mostly located in undulating uplands (Figures 1 and 3), they have poor potential for the development

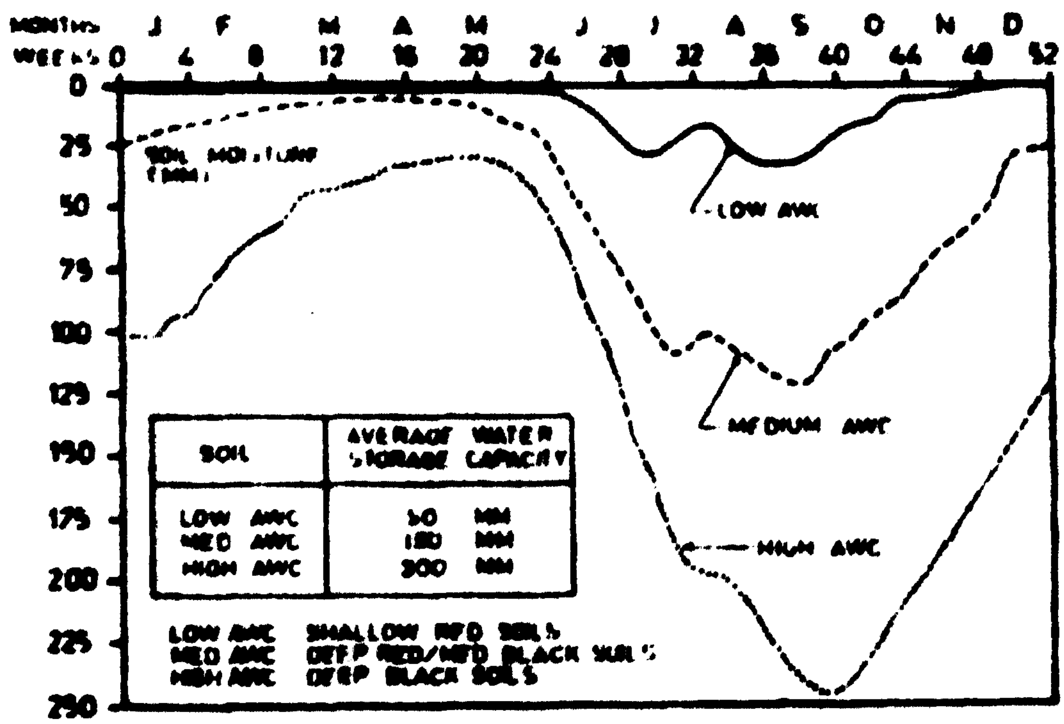


FIG. 7 WEEKLY SOIL MOISTURE STORAGE IN THREE SOILS (HYDERABAD 1901-70 DATA)

of large scale surface irrigation systems. The geology of the Hyderabad region does not permit ground water utilisation in the zones of recharge (that is where red shallow soils are mostly present). The only alternative for such soil areas is to collect runoff during periods of excess rainfall and to reuse the collected water through a farm water storage and application facility.[1]

The graphs of available water held in the soil profiles in the red or medium black and deep black soils (Figure 7) shows that except in the initial weeks after the commencement of monsoon rains, the available water capacity of these soils is almost filled for a substantial part of the growing season. It is only after the middle of September that the available water curves show an upward trend. This coincides with the general recession of the monsoon in the Hyderabad region (Figure 6), and the crops thereafter, primarily draw upon the soil moisture reservoir to meet their ET needs.

(e) Climatic Water Availability: In the SAT areas of India, the temperatures during the monsoon crop period are quite high; this can cause relatively high PE values. Since the availability of soil water for crop use is dependent on the potential evapotranspiration demand[2] (Denmead and Shaw, 1962), the climatic water availability assumes significance particularly at phenological crop stages when climatic water stress is critical.

1/ ICRISAT and AICRPDA are developing appropriate technologies in this direction. The application of small quantities of water should be made on the basis of probabilities of rainfall given in Appendix II, Tables 1.1 - 1.4.

2/ Daily PE values exceeding 10 mm are not uncommon during dry periods in the monsoon. Contrary to the situation in more temperate regions, the PE demand occurs during a relatively short period of time ($\leq$ 8 hrs). This results in very high PE intensities (on an hourly basis). Often such high PE intensities cannot be met by crops even on relatively moist soils and temporary wilting results.

Hargreaves (1975)[1/] suggested that the climatic moisture availability index (MAI), a ratio between rainfall and potential evapotranspiration could give a more useful indication for climatic water sufficiency. An analysis of the MAI status for the period July to November is given in Table 10.

Table 10

Values of MAI at given probability levels during the monsoon crop growing period at Hyderabad

Crop duration and stages*		Period	Probability			
Medium	Long		75%	50%	25%	
Initial	Initial	Jul 2 - 15	0.40	0.76	1.30	0.95
Vegetative		Jul 16 - 29	0.71	1.21	1.91	1.42
	Vegetative	Jul 30 - Aug 12	0.50	0.89	1.43	1.06
Reproductive		Aug 13 - 26	0.37	0.81	1.54	1.11
Maturity**		Aug 27 - Sep 9	0.48	0.99	1.76	1.28
	Reproductive	Sep 10 - 23	0.62	1.20	2.06	1.51
		Sep 24 - Oct 7	0.11	0.50	1.44	1.09
	Maturity	Oct 8 - 21	0.02	0.16	0.74	0.65
		Oct 22 - Nov 4	≠ 0	0.06	0.48	0.50

* Assuming a medium duration crop of 100-110 days and a long duration crop of 130-150 days.

** Maturity refers to the physiological maturity. Harvest maturity is exhibited 2-4 weeks later by most crops.

The data generated for the MAI during the monsoon crop season at Hyderabad (Table 10) show that from Aug 13 to Sep 9, the climatic water availability will be deficient to moderately deficient in 25% of the years. Since this period coincides with the reproductive phase of the medium duration crops, this may result in lowering of yields of crops sensitive to environmental water stress at ontogenetic phases of growth.

1/ Hargreaves suggested the following classification for climatic water availability:

MAI	= 0.00 - 0.33	deficient
"	= 0.34 - 0.67	moderately deficient
"	= 0.68 - 1.00	somewhat deficient
"	= 1.01 - 1.33	adequate
"	= 1.34	Excessive

The second phase of decreased MAI values is observed after September 24. These coincide with the recession of the monsoons over the Hyderabad area and is a desirable characteristic during the maturation periods of crops. The crops which are still actively growing are not likely to suffer from moisture deficiency because the potential evapotranspiration (Table 4) decreases to ≈ 4 mm/day in the last week of September and subsequently. The diurnal variations in temperatures also increase in October and November compared to the initial months of the monsoon crop season (Table 1). All these factors favour the availability of stored soil moisture for crop use. Therefore, in soils with medium to high water storage capacity, the long duration crops are not likely to be exposed to moisture stress. In the case of soils with low moisture storage capacity, however, the long duration crops will suffer from drought and enforced maturity.

Thus far, consideration has been given to the moisture availability from the soil environment and to growing period variations. For crop planning, an assessment of the moisture requirements of crops is also necessary.

(f) Moisture Requirements of Crops: A knowledge of the crop and plant water requirements is necessary for water resource planning and utilisation. The rates of evapotranspiration of crops relative to potential evapotranspiration have been intensively studied over the past two decades. An objective review on the subject has been presented in Appendix IV.[1/]

1/For details see:

a) ASCE Technical Committee on Irrigation Water Requirements of the Irrigation and Drainage Division, "Consumptive use of Water and Irrigation Water Requirements", American Society of Civil Engineers, 1973, 215 p.

b) Crop Water Requirements: Irrigation & Drainage Paper 24. FAO (Rome 1975), 179 p.

Briefly, it may be stated that the crop water requirements differ with the species and within a crop, on the phenology of its cultivars. Forages and range crops require an actual evapotranspiration (Eo) to potential evapotranspiration (PE) ratio of 1.0 - 1.2 for maximum production throughout the growing season. For field crops, however, Eo/PE requirements depend upon the stage of growth; the range is between 0.2 and 0.8 or more. Some examplified stepped functions of water requirements of a range of crops of various durations are shown in Figure 12 (Appendix IV).

Hargreaves (1975) investigated the moisture adequacy-yield relationship for a wide range of crops and reported that the ratio of the observed yield to the maximum yield (under prevailing fertility and cultural conditions) Y, can be expressed by the equation: $Y = 0.8X + 1.3X^2 - 1.1X^3$, where X = the ratio of actual moisture available during the crop season divided by the amount for which yield is maximum. Good data coverage was available for the range of X = 0.35 to X = 1.00. Hargreaves concluded that in absence of other limiting factors, the yield of field crops is primarily dependent upon the sufficiency of available water over the growing season.

Grain yields of sorghum and wheat trials at Biloela (Central Queensland) in relation to crop water stress were analysed by Nix and Fitzpatrick (1969). They observed that in both the crops final yields were strongly correlated with the water availability at flowering and anthesis.

In the case of sorghum, the following interesting relationships between EA/PE ratios and yields were reported.

Growth Stage	EA/PE range[1/]	Sorghum[2/] Varieties A	B
		r =	
Vegetative (4-6 wk)	0.5 - 1.0	.04 NS	.17 NS
Pre-heading (2 wk)	0.4 - 1.0	.47 NS	.33 NS
Heading & Early grain filling (2 wk)	0.4 - 1.0	.61*	.68**
Later Grain Filling (2 wk)	0.4 - 1.0	.01 NS	.28 NS

1/ EA = estimated crop available water; PE = potential evapotranspiration.

2/ Varieties A = Wheatland, B = Kalo.

NS = Non-significant at P = 0.05;
* Significant at P = 0.05;
**Significant at P = 0.01.

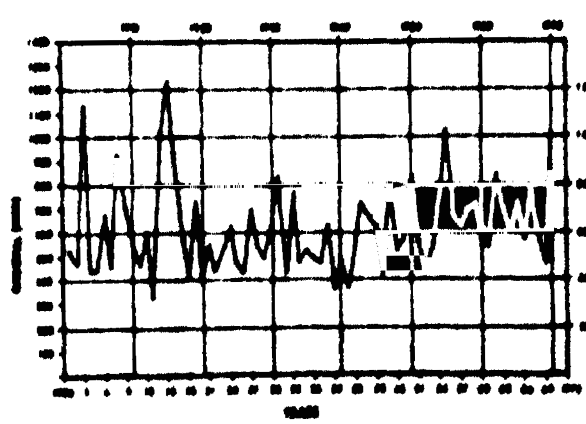
These two examples suggest that the water environment of the crop ecosystem is a major determinant of yield. However, the final yield depends to a large degree upon the adequacy of crop available water at some critical growth stages. Water stress can to some extent be borne by the crop at non-critical stages. Nevertheless a 'conditioning effect' of water deficits on yields of several crops at a stage prior to the ontogenetic phase has been reported by several workers.[1/]

1/ Stewart, J.I., Misra, R.D., Puritt, W.O., and Hagan, R.M. Irrigating Corn and Grain Sorghum with Limited Water. Paper presented at ASAE Annual Meeting, Stillwater, Oklahoma,1974, 32p.

g) Proposal for a Technique of Systems Analysis to identify suitable crops, cropping patterns and planting dates.

In the preceding section, it has been shown that the water required to maintain optimum rates of crop growth varies with different phenological stages. Consequently, at each of the growth stages, there is an optimum demand of water, which, if not adequately met, affects the crop yields to a degree which again depends upon the growth stage. In a major part of the semi-arid tropical areas, rainfall is the only source of water available for crop sustenance.

Unfortunately these regions are characterised by a highly erratic and variable rainfall and also by relatively high potential evapotranspiration during most of the crop growing season. An analysis of the Hyderabad rainfall, presented in Table 2, shows a coefficient of variation of 26% for annual precipitation. The CV ranges between 45 and 57% for the monsoon months and exceeds 100% for the pre and post-monsoon months. The trend of the seasonal rainfall (June to early October) for the period 1901-70 for Hyderabad is shown in the Figure below:



It has been reported by Griffiths (1972) from a study of climates of Africa that the potential evapotranspiration demand for a specific location does not vary much from year to year (CV < 5%). This has the implication that a more or less fixed climatic and crop moisture demand is faced by an erratic supply of water. The identification of the safe crop growing periods, from the point of view of water availability, and the development of cropping pattern strategies to optimise the use of the scarce and undependable rainfall source therefore assume great importance under such conditions.

To meet the research requirements for the identification of a range of suitable varieties and cropping systems, two types of possibilities exist: (a) evaluation of a wide range of crops and their varieties in relation to changing rainfall environments through field experiments over a sufficiently long period of time, or (b) conduct of an analytic study of the historical weather data (of the immediate past and for a sufficient number of years) in terms of the characterisation of the crop-water environment. There are convincing reasons to select the latter alternative.

Such an analysis would primarily evaluate the variations in the total crop growing period and the proabbilities of adequate water availability at different crop growing stages (see preceding sections). Such location specific information derived on the basis of rainfall variability, soils, and climatic water demand by water budgeting techniques would also provide data on periods of water surpluses and deficits as well as soil moisture variations. Since the crop water demand is rather fixed at different phenological stages of its growing cycle, a comparison of these with the availability of moisture could provide answers regarding the suitability of crops and their cultivars in a particular location. A primary advantage of such an analytic technique is not only that it allows a critical evaluation of the present cropping patterns and projections for new introductions, but also that it would substantially reduce the time and effort required for the selection of suitable varieties and cropping patterns through a process of elimination. Since the approach has the advantage of studying the system variabilities on a long term base, it would aid in evolving plans for experiments on crop-environment interaction and in arriving at decisions on suitable cropping patterns. It also would allow for quantification of the soil, rainfall, and climatic complex characterising a location and therefore facilitate a process of identification of isoclimes and their zonation in the SAT areas on the basis of crop suitability considerations. The methodology could be of advantage in efforts to transfer farm technology from one area to another.

The estimates of the crop water availability distribution during the growing season and an illustration of the potential use of the systems analytic methodology for determining desirable varietal characteristics as well as suitable cropping patterns for the Hyderabad region are discussed in the following section.

(h) Estimates of crop moisture availability and crop planning for the Hyderabad region.

The water balance model used in this study (Appendix III) was based on a climatic approach for estimating the amounts and variation in crop moisture availability. The model consists of a simple book-keeping procedure in which all precipitation occurring (when the soil moisture content is below the water storage capacity), is treated as a moisture increment. Moisture is lost from the soil as evapotranspiration. Precipitation occurring when the soil storage is filled to capacity, has been treated as surplus and is lost through percolation and runoff. Week-to-week changes in the available soil moisture were calculated through computer processing. From this, the amount of crop available water (EA) was computed.1/ The ratios of EA/PE2/ for all the 52 weeks of the year were calculated from the rainfall data for Hyderabad from 1901 through 1970, individually for each year for three soil types of varying root-profile water-holding capacities.3/ The use of "standard" available water holding capacities permits the use of one of the data sets for a particular crop in a given soil type (see for details: Appendix III).

It has been shown earlier that in most crop plants the ratio of actual evapotranspiration to potential evapotranspiration (EO/PE) varies between 0.3 and 0.8. The seedling stage is characterised by required EO/PE ratios in the range of 0.2 to 0.4; the vegetative growth phase by ratios of 0.4 to 0.6 and the flowering and the reproductive stages by ratios of 0.6 to 0.8 or above. The demand for water by crops considerably lowers at seed-set and maturity stages until at harvest the crop water requirements

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1/ After Denmead and Shaw (1962). For details see: Relationships between soil moisture, actual and potential evapotranspiration. Baier, W. Internal Report, Agrometeorology Section, Canada Dept. of Agriculture, pp.52.

2/ EA/PE signifies the amount of crop available water in a given environment. Weekly PE (Potential evapotranspiration) values given in Table 4 were used here.

3/ Refer to p. 4, for a description of soils.

are practically nil. With these reasons in mind, a relatively low threshold value of EA/PE being at least 0.25 has been selected to indicate water sufficiency for crop survival and any value of EA/PE exceeding the threshold has been assumed to indicate water availability for growth purposes. A higher value of EA/PE $\geq$ 0.75 has been selected to indicate a state of water adequacy in amounts sufficient to meet the requirements of dryland crops at critical growth stages. It must, however, be pointed out that these upper and lower limits of EA/PE are tentative and need further requirement. These limits should be adapted depending on the drought sensitivity of crops.

A probability analysis of the weekly values of EA/PE $\geq$ 0.25 and of EA/PE $\geq$ 0.75 for the monsoon crop period commencing with week 27 (July 2) for three soil types is shown in Figure 8. It is based on seventy years of data for which a water balance study has been carried out.

The basic requirement of improved cropping systems for semi-arid tropical agriculture is to increase and stabilize the production through optimal use of land and water resources. A crop cultivar expected to yield a high and stable production will, given a large number of other requirements, be the one which essentially fits in with a given soil-climate water availability situation.1/ The aim in matching water requirements of crops

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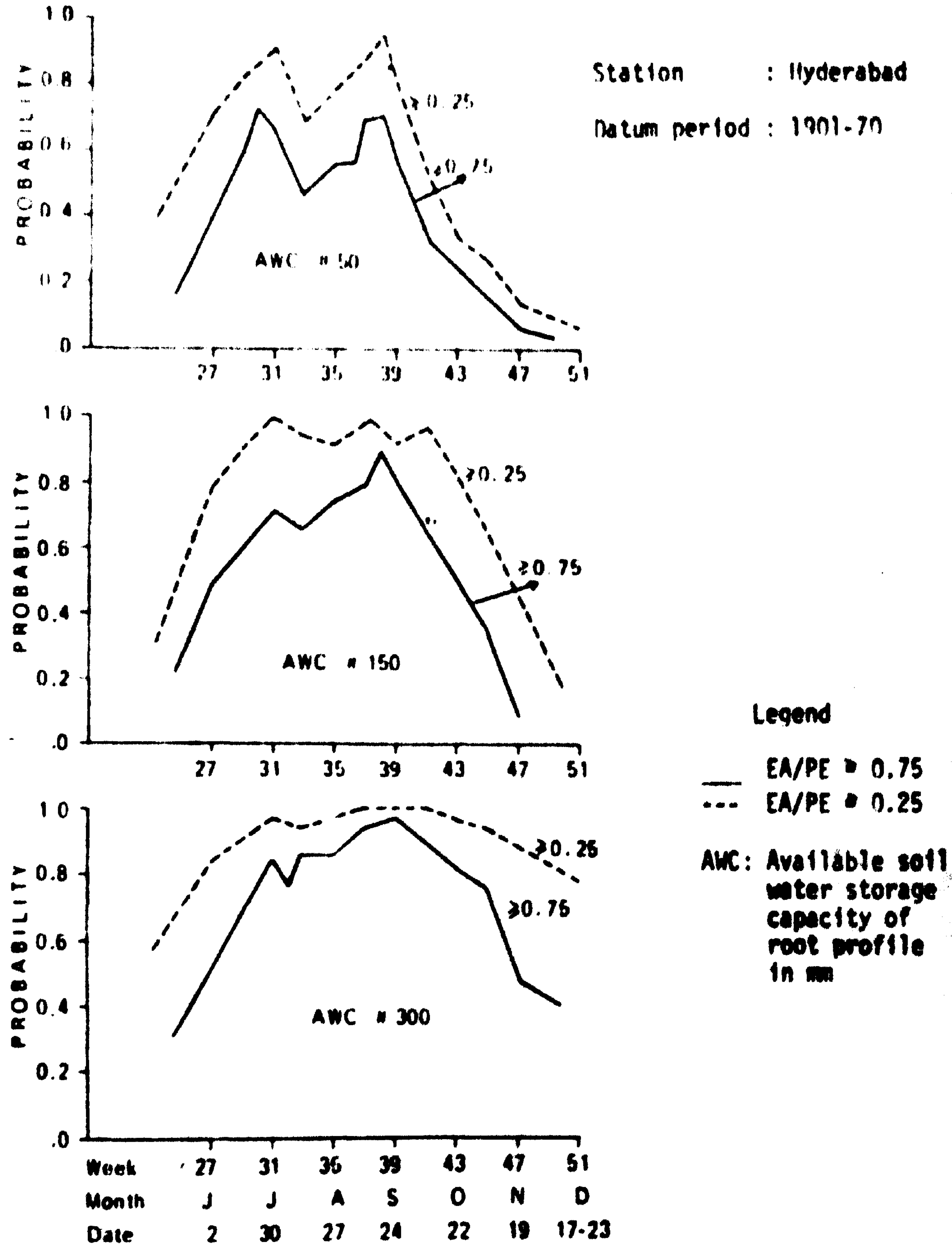
1/ According to recent literautre on crop yield and water relationships reviewed by Mather, J.R. in his book: Climatology: Fundamentals and Applications; "some investigators have argued that no real genetic differences in drought resistance exist among wheat varieties but rather that different varieties reach the "critical" developmental period at different times"...."Two given varieties may actually have the same moisture demands, so that neither is more drought resistant than the other, but yield in one that flowers at a time of less moisture stress will be greater".

Figure 2

PROBABILITY OF OCCURRENCE OF TWO LEVELS OF EA/PE RATIOS DURING THE KHARIF CROP SEASON IN THREE SOIL TYPES



to the probabilities of water availability, should therefore be to achieve a balance, in which the most critical crop stage coincides with the highest chances of occurrence of moisture adequacy. The crop water demand curve should essentially pass between the relevant set of moisture availability distribution curves. The use of this type of analysis in terms of the selection of crops or genotypes is illustrated in the next few paragraphs.

The Hyderabad region grows sorghum on a large scale. The crop occupies 38% of the total cropped area and 65% of the total cereal area in the District.1/ The available varieties and hybrids of this crop range in maturity period from about 100 to 150 days or more; the potentially highest yielders require from 90 to 115 days. The question before an agronomist is: which variety or hybrid should be selected for a particular soil situation such that sustained high yields can be expected; the question before a breeder is to develop a HYV which best suits the soil climatic environment. Some answere to these questions can be derived through analysing the situation by fitting a 90-110 day crop of sorghum (say CSH1) or a 130-150 day maturity sorghum (e.g. locals) in the three idealised soil environment situations presented in Figure 8.

The sowing rains are received in week 26, the last week of June (Table 7) when monsoon season crops are planted.(delay of sowing with a crop like sorghum increases shootfly risk). A 130-150 day sorghum will commence flowering around week 36 (last week of September) and reach physiological

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1/ Season and Crop Report of Andhra Pradesh 1972-73. Published by the Bureau of Economics & Statistics, Government of Andhra Pradesh, Hyderabad,pp.190.

maturity at about week 42. It will be caught in a water-deficit situation at the ontogenetic phase in most years in the low water storage soils (Figure 9). In medium and high water storage capacity soils, the crop will normally be relatively well supplied with available water to meet its requirement in most years. This contention is substantiated by the data shown in table 11. The probabilities of obtaining

Table 11

Conditional Probabilities of Moisture Availability for Specified Crop Phenological Stages of Different Crops in Three Soil Types1/

Growth Stage		EO/PE ratio required	Prob.of obtaining reqd.AE/PE in Soil Type		
			Shallow Red	Deep [illegible]/ Med.Black	Deep Black
			(a) 130-150 day duration crop2/		
Seedling	(4 wk)	0.30	0.412	0.661	0.702
Vegetative	(6 wk)	0.60	0.377	0.738	0.730
Veg/Rep.3/		0.80	0.350	0.702	0.754
Reproductive	(6 wk)	0.80	0.173	0.686	0.797
Maturity	(4 wk)	0.60	0.056	0.483	0.672
			(b) 90-100 day duration crop		
Seedling	(2 wk)	0.30	0.588	0.768	0.789
Vegetative	(4 wk)	0.60	0.492	0.750	0.725
Veg/Rep.3/		0.80	0.431	0.674	0.659
Reproductive	(4 wk)	0.80	0.418	0.719	0.772
Maturity	(4 wk)	0.60	0.407	0.864	0.877
			(c) 65-70 day duration crop		
Seedling	2 wk	0.30	0.588	0.768	0.789
Vegetative	2 wk	0.60	0.750	0.865	0.881
Reproductive	4 wk	0.80	0.467	0.772	0.789
Maturity	2 wk	0.60	0.725	0.725	0.985

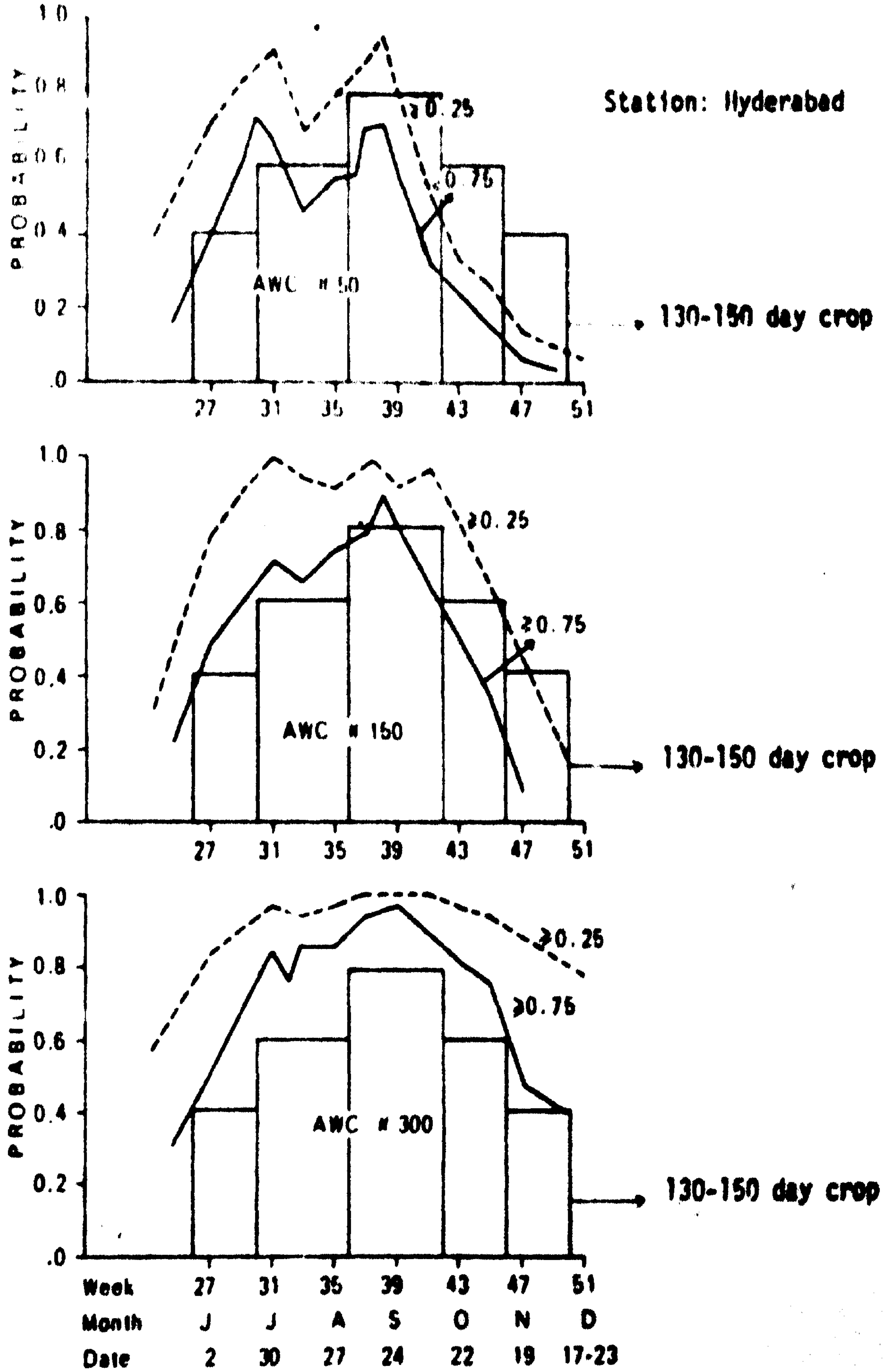
1/ Based on water balance study for Hyderabad (1901-70 data) Appendix III.

2/ Approximate duration of growth. It is assumed that the crop has been seeded in week 26 (last week of June).

3/ In crops in which vegetative growth and flowering occur simultaneously - e.g. castor, groundnut.

Figure 9

FITTING OF A LONG DURATION (130-150 DAY) CROP IN THREE SOILS OF THE HYDERABAD REGION IN RELATION TO THE PROBABILITIES OF CROP WATER AVAILABILITY



favorable moisture conditions are upwards of 70% in most cases, certainly during critical periods. These estimates would seem to suggest that both in the deep red and in the medium or deep black soils, a 130-150 day crop of sorghum and also a 90-110 day crop will be a success. However, if one considers the precipitation probabilities at the physiological and harvest maturity periods (Table 12), then it becomes clear that the relatively shorter duration sorghum (maturing around week 38) will be caught in heavy rainfall in 5 to 6 years out of 10. The longer duration varieties will get into the reproductive phase around wk 42 and the probability of heavy rainfall is only 3 or fewer years out of ten. A reference to Figure 7 shows that in medium and deep soils the profile has adequate available moisture, and since the temperatures around the middle of October (Table 1) show a lowering trend, the crop will normally be adequately supported by the profile moisture.

Table 12
Amount of rainfall expected at maturity periods of monsoon season crops at Hyderabad1/

Period		Expected amount of rainfall at a given probability					
Weeks	Date	80%	70%	60%	50%	40%	30%
					(mm)		
35-36	Aug 27 - Sep 9	17.1	26.1	36.2	47.8	61.7	79.4
37-38	Sep 10 - Sep 23	23.2	33.7	45.1	57.9	73.0	91.8
39-40	Sep 24 - Oct 7	29.1	40.9	53.3	67.2	83.3	103.2
41-42	Oct 8 - Oct 21	4.0	9.2	16.9	27.9	43.3	65.6
43-44	Oct 22 - Nov 4	0.4	1.6	4.3	9.1	17.4	31.3
45-46	Nov 5 - Nov 18	0	0.3	1.2	3.5	8.4	18.4
47-48	Nov 19 - Dec 2	0	0	0.4	1.1	3.0	7.1

1/ Based on 1901-70 data. The expected amounts are derived from Gamma distribution.

The damage to the maturing seeds of the sorghum crop caused by disease infestation due to rainfall, can be to a great extent avoided by harvesting the crop during dry spells even if the rainy season is extended.

The relative probabilities of at least 3 consecutive field work days[1] in the two major soil types of the region is for crops of three assumed durations, shown in Table 13.

Table 13

Percent probability of at least 3 consecutive Field Work days at Hyderabad (based on 1901-70 rainfall data)

Period	Soil type: Black	Soil type: Red
	SHORT DURATION (65-70 DAY) CROP	
(A) Aug 27 - Sep 9	9	50
(B) Sep 10 - Sep 23	4	50
	MEDIUM DURATION (90-100)DAY CROP	
(A) Sep 10 - Sep 23	4	50
Sep 24 - Oct 7	23	64
(B) Oct 8 - Oct 21	29	77
	LONG DURATION (130-150 DAY) CROP	
(A) Oct 22 - Nov 4	59	79
Nov 5 - Nov 18	73	93
(B) Nov 19 - Dec 2	83	93

** (A) Physiological maturity; (B) Harvest maturity.

The data in Table 13 show that a sorghum crop of about 100 days duration (harvest maturity in the second week of October) can be successfully harvested in about 80% of the years in the red soil situations but the probability of satisfactorily harvesting the crop in a black soil is relatively low (29%). Sorghum variety CSH5 which is of slightly longer duration than 100 days, when planted in the first week of July, offers the best possibility. However, in the case of black soils, a longer duration variety of sorghum of approximating 130-150 days duration would be more suitable if single cropping or intercropping is the objective. Unfortunately, no high yielding variety is available currently with such a duration.

1 Field work day: For a field work day to occur it is assumed that the soil moisture in the surface 15 cm must be reduced to 22% in a black soil and to 12% in a red soil.

Another alternative under these conditions would be the generation of mould resistant short duration varieties; in case of non-ratooning genotypes this would increase the potentials for double cropping, particularly on the deep black soils[1].

The fitting of long, medium and short duration crops and some suggestions for scheduling crops well after the on-set of the monsoon rains are, for selected cases, shown in Figures 9 to 11.

The long duration crops (Figure 10), will be exposed to moisture stress at critical periods, in the shallow red soils at various growth stages, thus suggesting that an indeterminate crop would be most suitable. Examples of such crops are castor, groundnut, forages and grasses. A short duration crop like pearl millet could also be grown and efforts be made to plant it as early as possible in the season (Fig. 10). This would ensure better yields[2]. If such a possibility is not met in any given year, it is suggested that the August sown crop would perform better than a crop planted late at the commencement of the season because of the higher probability of good conditions at harvest time. Pearl millet, however, should be planted as an intercrop with a long duration base crop in these shallow soils, if early sowing is feasible.

[1] However, if no intercrop were grown in such a sorghum, the yield potentials would have to be extremely high to attain a rainfall use efficiency approximating that which could potentially be reached by a double cropping system on such soils.

[2] The AICRPDA has already shown that planting of pearl millet in the last week of June resulted in higher yields compared to planting in the first or second week of July.

In the case of medium water holding (AWC#150) soil situation, the fit of different crops shown in figures 9-11, reveals that a long duration crop has a relatively high probability of being exposed to water stress at the reproductive phase of growth. The probability of meeting the required EO/PE is 0.655 (Table 11). Under such circumstances, a long duration indeterminate crop like castor or intermediate[1/] crops like pigeonpea would suit best. The probabilities of moisture adequacy for medium and short duration crops at various stages of growth (table 11) are around 70% or higher. These crops could be successfully grown as intercrops. Setaria, maize, sorghum and groundnut would be expected to yield well under the deep red and medium black soil conditions. Groundnut, in black soils, could be planted only under conditions where the surface soil has a coarse texture (generally < 5% clay). The pearl millet crop suits the moisture environment perfectly well although difficulties in the harvesting of the crop and protecting the seed from deterioration at ripening would arise due to the higher rainfall probabilities during its maturity period and limited field work day probabilities (Tables 12 and 13).

The deep black soils offer an excellent crop water availability environment at all stages of growth for short, medium and long duration crops (table 11). The potential for sequential and relay cropping is great, because these soils after August have sufficient available moisture in the soil to last for several weeks after the recession of the monsoon rains (Figure 7). The only constraint in these soils consists of difficult working conditions

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1/Intermediate crops are those in which the vegetative growth and flowering occur simultaneously.

Figure 10

FITTING OF SHORT (65-70 DAY) AND MEDIUM (90-100 DAY) DURATION CROPS IN THE THREE SOILS FOR PLANTING AT THE COMMENCEMENT OF KHARIF SEASON

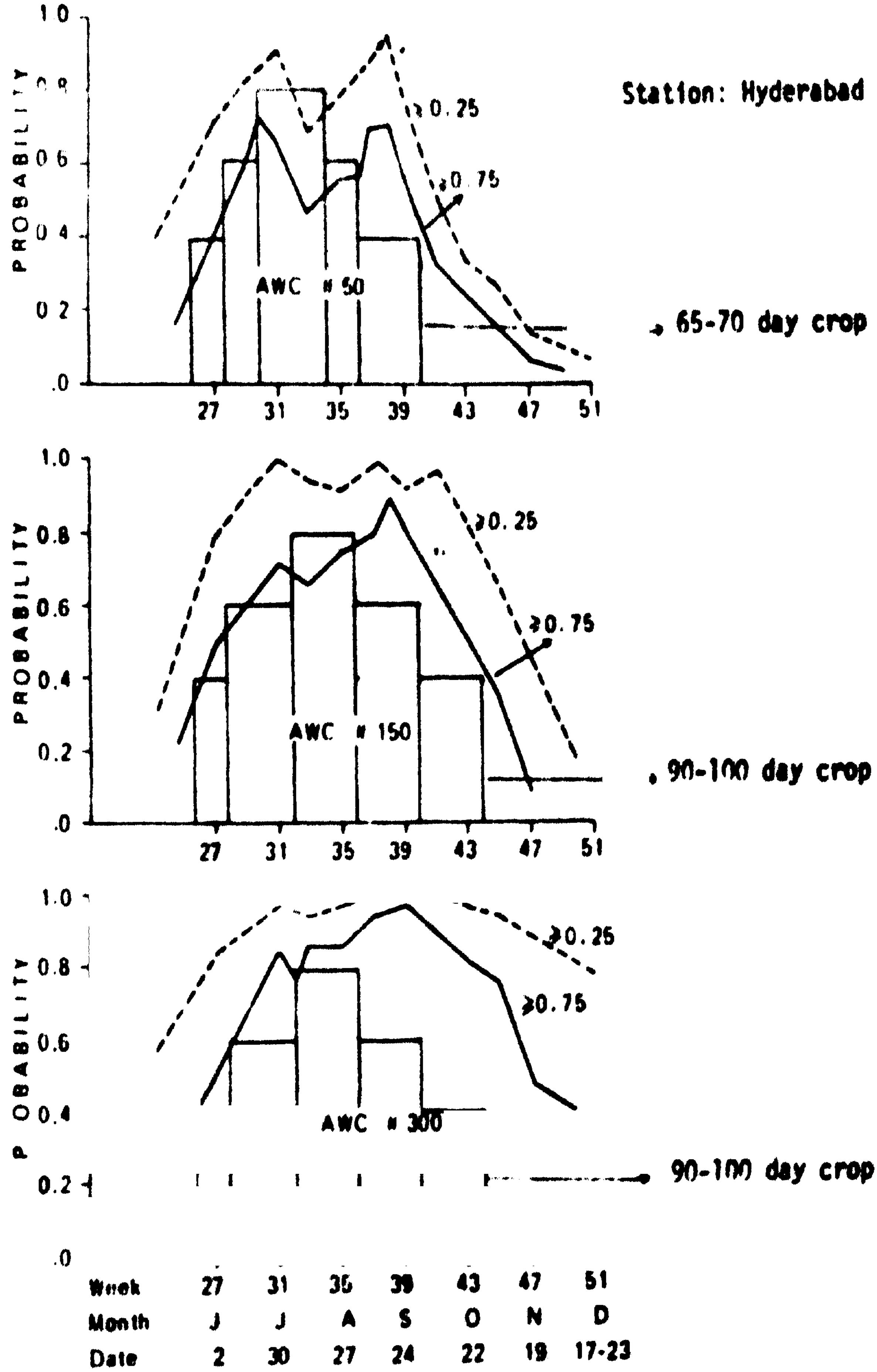
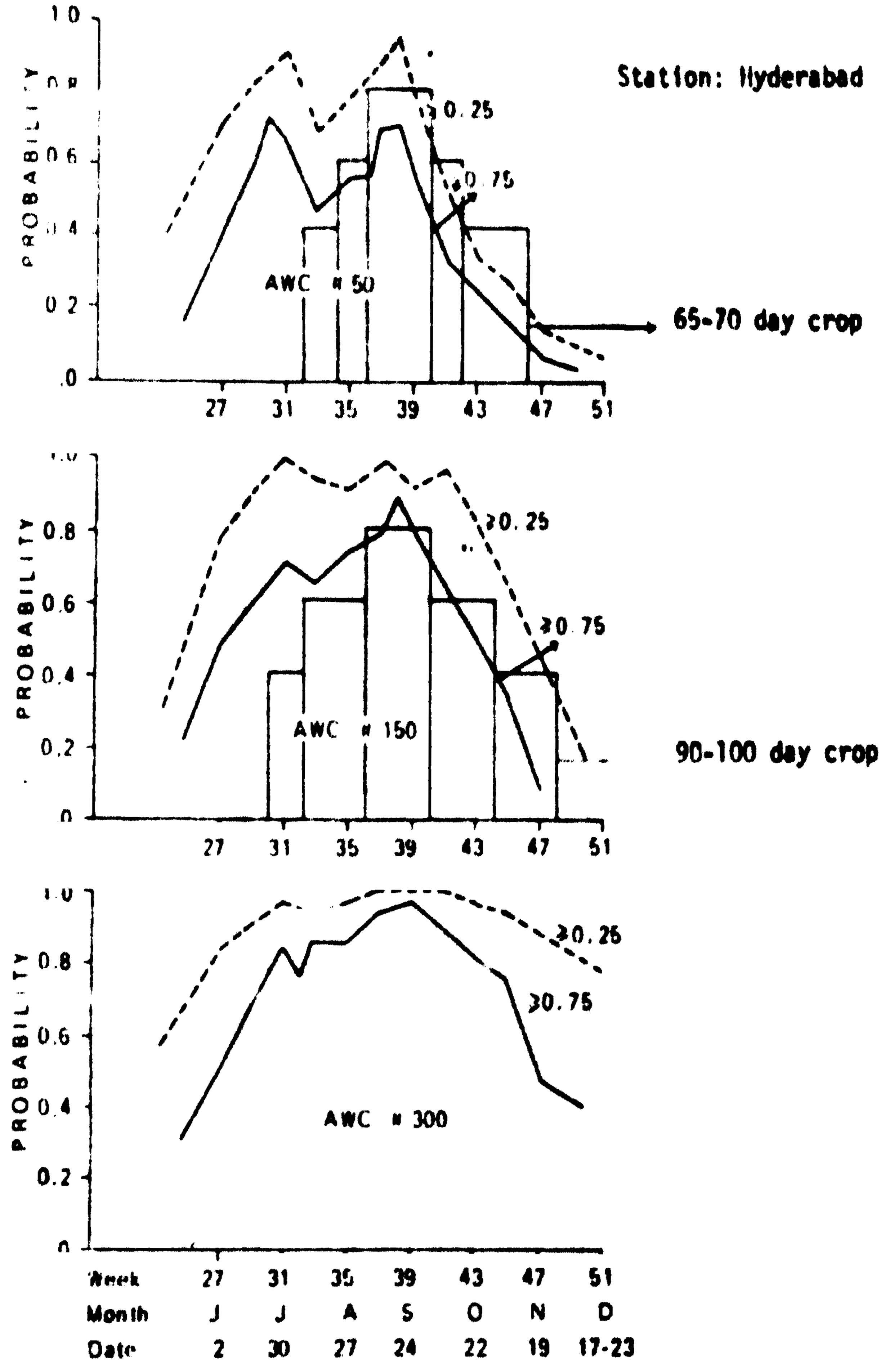


Figure 11

FITTING OF SHORT (65-70 DAY) AND MEDIUM DURATION CROPS IN THE THREE SOILS FOR RELAY/SEQUENTIAL PLANTING OR INTERCROPPING



Dry seeding, as shown earlier, is a must and crops which do not deteriorate at maturity due to exposure to rains and which can stand delays in harvest at maturity would be preferred. A determinate crop of sorghum with 130-150 day duration would be the best cereal crop.[1/] In legumes, pigeonpea is likely to be the best crop, if adequate drainage[2/] requirements are met. Maize as an intercrop also seems to have good potential.

In summary, the following crops can be suggested for the three soil situations.

Soil Type	Suggested crop/forage
1. Shallow red	Grasses and Forages Castor Pearl millet
2. Deep red	Pigeonpea Setaria Castor Sorghum (Medium duration) Groundnut
3. Medium black	As in the case of deep red soils. If the clay content in the surface soil is more than 5% groundnut should be deleted.
4. Deep black	Pigeonpea Sorghum (preferably > 120 day duration) Maize

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1/ According to Krantz & Kampen (1976) some valuable agronomic characteristics of sorghum would be the following:

(1) Mould resistant, short season varieties which can be successfully ratooned for grain after a first grain harvest.

(2) Mould resistant, short season varieties which do not ratoon and can be used in relay and sequential cropping systems.

(3) Longer duration varieties (150 days) which would permit intercropping in the monsoon season.

(4) Medium duration determinate varieties (130-150 days) which could be grown in a single crop system (a double cropping practice would be lost in this case)

2/ Planning on ridges and furrows, which are linked to adequate drains would offer a suitable soil, water and air environment.

2. Plant growth and water balance in the post-monsoon season (rabi):

The post-monsoon season crops are planted towards the first fortnight of October, generally following the recession of the monsoon rains. The planting couldbe early (last week of September) in years with an early recession of rains or delayed (upto the middle or the end of November) in case of late recession of the monsoons over the Hyderabad areas.

This cropping season is characterised by the absence of rains; it is relatively cool with relatively lower PE values (Table 4); day lengths are shorter and higher diurnal temperature variations occur than in the monsoon season. The post-monsoon crops are harvested around the end of February. The major crops of the region are sorghum, safflower and some area is under chickpea. These are well suited for utilising the conserved profile moisture.

A generalised phenology of the post-monsoon crops and their use at different stages in relation to PE is shown in table 14.

Table 14 - Water use by post-monsoon crops under conserved moisture conditions at Hyderabad

Months	Period	Crop Stage	EO/PE ratio	ET(mm)
Oct	2 wks	Seedling	0.2	11
	2 wks	Early growth	0.3	16
Nov	2 wks	Early grand growth	0.4	21
Nov	2 wks)	Grand growth	0;6	56
Dec	2 wks)			
Dec	2 wks	Flowering & antogenetic	0.8	76
Jan	2 wks	Seed set	0.4	20
Feb	2 wks	Maturity	0.2	
		Total estimated water use		211

The data (table 14) show that for optimum growth of post-monsoon crops under Hyderabad conditions, about 210 mm of plant available water is required in the root zone of the crop, thus only deep black soils can be cropped without supplemental water[1/] (figure 7). The results of the water balance studies show that in about 80% of the years there would be adequate water in the soil profile to support post-monsoon crops.

A multiple correlation analysis of the amount of available water stored in the soil profile with the total amount of monsoon rainfall and precipitation for the individual months from June through October for 70 year data for Hyderabad showed that:

$$Y = -9.65 + .147\ (RMTL) + .172\ (RSEP) + .333\ (ROCT)$$

where Y = Total available moisture in (mm) in a deep black soil profile in Oct.

RMTL = Total amount of rainfall received during the period June - Oct.

RSEP = Rainfall in September

ROCT = Rainfall in October

The analysis of the growing season showed an average length of 15 weeks, with a range from 11 to 17 weeks. Generally, in years when the September and October rainfall is highly sub-normal or total monsoon precipitation is less than 580 mm (which account for approximately 20% of the years), post-monsoon cropping may not be possible due to inadequacy of profile moisture, if the soil has been cropped during the monsoon season.

1/ Although the amount of stored moisture in deep black soils would be sufficient to meet the total requirements of water except at critical growth, the rate of availability may be limited due to potential evapotranspiration requirements. Supplemental water availability could help in increasing crop yields particularly in the case of crops sensitive to moisture stress at ontogenetic stage (e.g. sorghum, maize).

V. THE ROLE OF CLIMATOLOGY IN THE AGRICULTURAL DECISION PROCESS

The studies reported in the foregoing pages, evaluating the effect of climate on crops, are ultimately directed towards the key problem in agriculture: how can available knowledge be put to profitable use to aid the farmer in making economically wise decisions? The simple knowledge of the relation between the crop moisture environment to yield may not serve the purpose, unless one utilizes it in some decision making process that will aid in the development of a more rational farm program. Improved agricultural farm technology in recent years has shown the potential for increased crop yields, it,however, has also increased the fixed cost inputs and profit margins. Agricultural inputs like fertilizers and irrigation equipment are expensive items and decisions on the extent of the use of these production factors need sound justification. Studies on the use of climatic analysis in relation to economic aspects of weather variability, of weather control, and on the use of such data in the whole field of economics and risk in farming and agriculture-based industry have increased. However, weather and climatic data are seldom given in a form directly usable in economic decision making and few farmers know what questions to ask of the applied climatologist, in order to be able to obtain fundamental information on the effect of alternate courses of action. In fact, only a beginning has been made to explore the relationships of weather and farm management decisions.

Duckham (1967)[1/] presented the hypothesis of resource allocation in accordance with the risk of satisfactory completion of different weather dependent operational programs. The whole focus of the use of Duckham's

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1/ For further details see Taylor, "Weather and Agriculture" (1967) Perganon Press Limited.

methodology, can be illustrated by means of a partly hypothetical example of dairy farming on pastures in Southeastern England.

At the commencement of the pasture growing season, the farmer is confronted with the question of stocking dates, fertiliser purchase and the use of limited irrigation resources. Duckham set up the following three possible operational programs:

(1) Very high stocking rates and N application with irrigation;

(2) High stocking rates & N application without irrigation, and;

(3) Medium stocking rates, low nitrogen, without irrigation.

The frequency of different types of rainfall years was found to be: 3 wet, 4 normal and 3 dry in a 10 year period. Duckham further found that operational program (1) gave maximum returns in a wet year; program (2) in a normal year and program (3) in a dry year. For long term profit stability, Duckham argues that the resource allocation under such a situation should be made in the ratio of 3:4:3 for the three operational programs enumerated above in any given year.

Following the logic of risk distribution discussed above, the amount of land area to be allocated to different crops can be suggested. Appendix V (Tables 2.1 - 2.3) shows the ratio of estimated crop available water to potential evapotranspiration demand on a weekly basis at various probability levels. In shallow red soils, averaging an available moisture storage capacity of 50 mm in the root profile, the data in Table 2.1 show that severe moisture deficit is likely to prevail at different times in the monsoon crop growing season in 25% of the years. To maintain stability, the cropped area in such soils should be around 75% while 25% of the area should be put under forages and grasses. A long duration indeterminate crop coupled with a short duration crop will be successful in most of the years. If the long duration crop has a slow vegetative growing habit (e.g. castor), it could be intercropped with a short duration crop like pearl millet both under optimum plant populations.

The results in Tables 2.2 and 2.3 (Appendix V) show that in the deep red and medium black or deep black soils with profile moisture storage capacities exceeding 150 mm in terms of available water, medium and long duration crops are likely to give optimum yields in 90% of the years. The area allocation to different crops will depend upon their relative productivity. Sequential, relay and intercropping systems will all prove useful in these soils under Hyderabad conditions.

The data on the probabilities of adequacy of available moisture at different growth stages of crops of various durations for the three soil conditions are shown in Table 11. In the case of shallow red soils, the long and medium duration crops are likely to be exposed to moisture deficit at almost all the growth stages in most of the years. Even in short duration crops (65-70 days), the chances of meeting adequate moisture demand at the reproductive stage of the crop are only 47%. Fortunately, these soils are characterised by a very high amount of runoff and this water, if properly stored, could be applied at times when the crop is under moisture stress (Appendix 7). The feasibility of such an alternative needs to be also explored in deep red or medium black soils.

IN CONCLUSION

The semi-arid tropical regions depend primarily on agriculture; the present low income levels are caused by low and unstable agricultural production. The distinctive characteristics of the tropical environment have a major influence on the distribution of natural endowments: soils, rainfall and climate. These areas are well supplied with radiant energy, however, due to the sunlight regime, temperatures and orographic influences, a variety of rainfall patterns are produced. As a result of higher temperatures, the rate of evaporation is intense, so that the moisture content of the air tends to be high, particularly during the wet season. Higher temperatures, of course, also mean that the water holding capacity of the air is greater. Because of the marked uniformly high temperatures during most of the growing season, variations in the timing and amount of precipitation are generally the key factors influencing agricultural production possibilities.

Moreover, the effect of differences in rainfall on the availability of moisture in tropical agriculture is especially great because of the rapid evaporation and transpiration by plants. The agricultural value of rainfall varies with the climatic factors that influence the return of moisture to the air by evapotranspiration. Since plants meet almost all of the water requirements from the root rhizosphere, the importance of water retention and release characteristics of the soils is evident. Therefore, in determining the agricultural potentialities of any semi-arid area, a quantification of the rainfall (timing, amount and durations), soil (intake, storage and release) and evapotranspiration characteristics is of fundamental importance. Given the variability of the semi-arid tropical environment, such a quantification also contributes substantially in delineating the potentially most rewarding areas for agricultural research.

This paper entitled "The Agricultural Climate of the Hyderabad Region: a Sample Analysis", is a study of the edaphological, rainfall and weather characteristics of the Hyderabad area. he probability analysis of rainfall with respect to its occurrence and continuity during the monsoon and post-monsoon periods has been carried out. Expected amounts of rainfall have been calculated at selected probability levels. Climatic water balance studies, using weekly rainfall as inputs to the soil moisture storage and estimated evapotranspiration as withdrawals, were carried out to evaluate the soil moisture regime and the amounts of crop available water week-by-week. Based on this analysis, the lengths of the crop growing periods in the monsoon and the post-monsoon cropping seasons were calculated for some of the dominant soil groups. Based on historical daily rainfall records for the period 1901-70, fluctuations in the total length of the crop growing periods were assumed. From the water balance studies, the data on the amounts of climatologically excess water, which is lost as surface runoff and as deep drainage has been calculated.

A systems analytic technique has been developed by which the probabilities of crop available water over the growing season are estimated. These estimates, when compared with the water demand of crops or their varieties at different phenological stages, yield a fair first approximation, regarding their suitability and potential success in a given soil-climate environment. Some examples of the fitting of crops of various durations and characteristics have been shown. Some tentative projections on crop scheduling have been made. The probabilities of rainfall and field work days at sowing, growth and maturation stages of crops have been given for the Hyderabad region and certain implications with regard to varieties and crops were derived.

This type of analysis gives an integrated index of the precipitation, soil and evapotranspiration. Since it quantifies the crop growing period and its characteristics in terms of water stress and sufficiency periods, the selection of crops with the required phenological characteristics is facilitated with substantial refinement, the methodology could be applied to many regions. It is envisaged that such a technique will substantially reduce the time and effort required to arrive at a suitable cropping system for a location. It also allows for the identification of ecological iso-climes with a similar moisture environment, thus making the transfer of appropriate farming systems technology easier.

Because of great diversity in agricultural systems imposed by the physical environment in the semi-arid tropics, the plant breeding efforts for producing suitable and high yielding crop varieties will have to be integrated with farming systems research. The technique of quantitatively determining the crop growing environment at specified bench mark locations, across the semi-arid regions, will assist plant breeders in identification of zones for which suitable crop varieties need to be bred and in determining the required characteristics.

The study presented herein made a few assumptions with regard to the water balance and estimated evapotranspiration in relation to climatic water demand. Few standard research references are found in the literature for quantifying, for semi-arid tropical environments, the relationships between the total available water in the root profile of crops to the water use under different potential evapotranspiration (PE) regimes. It is not uncommon to encounter PE rates exceeding 10 mm/day during the growing season of the crops during breaks in rainfall. Most available literature relates to PE rates around 4-6 mm/day in temperate regions. Thus, there is an urgent need to evaluate the water release, crop water use and photosynthetic activity relationships for crops in semi-arid climates. Assumptions with regard to water use by crops have been made on the basis of studies reported from irrigated agriculture. Lysimetric work on water use by crops in relation to water content of the soil, needs to be intensified. Also, research on yield as influenced by varying moisture regimes need to be initiated across diverse agroclimatic regions. The data, when available, will greatly assist in projecting crops or their genotypes which will fit the simulated water environment estimates for any location.

Finally, the results of the present analysis clearly show that in the majority of the soils of the studied region, the probabilities of water stress to crops at different growth stages are quite high. Fortunately, the funoff probabilities are also high in these soils. In the analysis presented, all the rainfall received was added to the available soil moisture storage, until it was filled to a defined capacity. A general characteristic of the tropical rainfall is its intensity. This means that the probabilities of runoff are high and that the agricultural value of rainfall is reduced accordingly. A better appreciation of rainfall in relation to physical conditions of soils and hydrological considerations is necessary.

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APPENDIX I

Rainfall in the Indian sub-continent:

Rainfall in India is determined by regional as well as local phenomena. The most important are: a) the movement of the equatorial low pressure belt following the solar path; b) the occurrence of monsoons, created by the heating and cooling of large masses; c) orographic lifting; d) diurnal heating of land areas; and e) cyclone formation.

From May to September a broad south-westerly stream of air, the south-west monsoon, flows over South-East Asia including India from the South Indian ocean. The arrival of the south-west monsoon marks the beginning of the rainy season. A continuous inflow from the south-east trade winds of the southern hemisphere compensates for the outflow of the air from the Indian ocean. When equatorial low pressure belt reaches its most northerly point, the combination of both systems results in a peak rainfall generally occurring around September.

During the northern winter, low temperatures over Siberia cause successive anti-cyclones to form. The outflow from these is a broad semi-permanent stream over Eastern Asia and Indonesia. The onset of the north-east monsoon initiates the rainy season in all places exposed to the north between China and Java.

Generally, it can therefore be said that the area north of the equator has a rainy season between May and October with peaks around September. While the onset of the rainy season is gradual, the retreat of the equatorial low pressure belt and the cooling of land masses at the same time cause a very abrupt end of the rainy season, followed by a marked dry season.

APPNEDIX II

Table 1.1

PROBABILITY OF WEEKLY RAINFALL

Station: Hyderabad

Datum Period: 1901-70 Cumulative weekly rainfall ≥ 1 mm

Week	Date	Probability					
		Initial		Conditional			
		Wet (W)	Dry (D)				
				Pre-monsoon			
18	Apr 30 - 6	.463	.536	.468	.531	.675	.324
19	May 7 - 13	.434	.565	.433	.566	.512	.487
20	May 14 - 20	.478	.521	.484	.515	.611	.388
21	May 21 - 27	.565	.434	.564	.435	.633	.366
22	May 28 - 3	.623	.376	.697	.302	.653	.346
23	Jun 4 - 10	.681	.318	.680	.319	.500	.500
24	Jun 11 - 17	.797	.202	.709	.290	.428	.571
				Monsoon			
25	Jun 18 - 24	.927	.072	.812	.187	.400	.600
26	Jun 25 - 1	.971	.028	.940	.059	.500	.500
27	Jul 2 - 8	.927	.072	.968	.031	0	1.0
28	Jul 9 - 15	.913	.086	.920	.079	0	1.0
29	Jul 16 - 22	.956	.043	.924	.075	.333	.666
30	Jul 23 - 29	.985	.014	.955	.044	0	1.0
31	Jul 30 - 5	.956	.043	.984	.015	0	1.0
32	Aug 6 - 12	.913	.086	.952	.047	0	1.0
33	Aug 13 - 19	.898	.101	.919	.080	.142	.857
34	Aug 20 - 26	855	.144	.898	.101	.100	.900
35	Aug 27 - 2		.101	.854	.145	.142	.857
36	Sep 3 - 9	.927	.072	.906	.093	.200	.800
37	Sep 10 - 16	.869	.130	.916	.083	0	1.0
38	Sep 17 - 23	.898	.101	.854	.145	0	1.0
39	Sep 24 - 30	.869	.130	.900	.100	.111	.888
40	Oct 1 - 7	.623	.376	.906	.093	.192	.807
41	Oct 8 - 14	.565	.434	.717	.282	.500	.500

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				Post-monsoon			
42	Oct 15 - 21	[illegible]	[illegible]	.575	.424	.444	.555
43	22 - 28	.362	.637	.680	.320	.636	.363
44	29 - 4	.318	.681	.363	.636	.638	.361
45	Nov 5 - 11	.376	.623	.538	.461	.813	.186
46	12 - 18	.246	.753	.647	.352	.711	.288
47	19 - 25	.231	.768	.375	.625	.792	.207
48	26 - 2	.159	.840	.363	.636	.793	.206
49	Dec 3 - 9	.072	.927	.600	.400	.875	.125
50	10 - 16	.159	.840	.090	.909	.931	.068
51	17 - 23	.101	.898	.571	.428	.887	.112
52	24 - 31	.043	.956	.666	.333	.924	.075
1	Jan 1 - 7	.072	.927	0	1.0	1.0	0
2	8 - 14	.072	.927	.200	.800	.937	.062
3	15 - 21	.057	.942	.250	.750	.938	.061
4	22 - 28	.043	.956	.333	.666	.954	.045
5	29 - 4	.115	.884	.125	.875	.967	.032
6	Feb 5 - 11	.086	.913	.333	.666	.904	.095
7	12 - 18	.130	.869	.333	.666	.950	.050
8	19 - 25	.144	.855	.300	.700	.898	.101
9	26 - 4	.130	.869	.555	.444	.916	.083
10	Mar 5 - 11	.086	.913	0	1.0	.857	.142
				Summer			
11	Mar 12 - 18	.173	.826	.166	.833	.929	.070
12	19 - 25	.202	.797	.428	.571	.890	.109
13	26 - 1	.246	.753	.411	.588	.865	.134
14	Apr 2 - 8	.434	.565	.366	.633	.846	.153
15	9 - 15	.434	.565	.466	.533	.589	.410
16	16 - 22	.420	.579	.482	.517	.600	.400
17	23 - 29	.391	.608	.370	.629	.547	.452

APPENDIX II

Table 1.2

PROBABILITY OF WEEKLY RAINFALL

Station: Hyderabad

Datum Period: 1901-1970 · Cumulative weekly rainfall > 5 mm

Week	Date	Probability					
		Initial		Conditional			
		Wet (W)	Dry (D)	W/W	W/D	D/D	D/W
				Pre-monsoon			
18	Apr 30 - 6	.246	.753	.294	.705	.788	.211
19	May 7 - 13	.202	.797	.357	.642	.781	.218
20	May 14 - 20	.275	.724	.315	.684	.840	.160
21	May 21 - 27	.420	.579	.310	.689	.750	.250
22	May 28 - 3	.463	.536	.562	.437	.702	.297
23	Jun 4 - 10	.565	.434	.564	.435	.666	.333
24	Jun 11 - 17	.666	.333	.630	.369	.565	.434
				Monsoon			
25	Jun 18 - 24	.811	.188	.696	.303	.461	.538
26	Jun 25 - 1	.869	.130	.816	.183	.222	.777
27	Jul 2 - 8	.826	.173	.842	.157	0	1.0
28	Jul 9 - 15	.826	.173	.877	.122	.416	.583
29	Jul 16 - 22	.826	.173	.824	.175	.166	.833
30	Jul 23 - 29	.913	.086	.841	.158	.333	.666
31	Jul 30 - 5	.913	.086	.920	.079	.166	.833
32	Aug 6 - 12	.753	.246	.884	.115	0	1.0
33	Aug 13 - 19	.782	.217	.777	.222	.333	.666
34	Aug 20 - 26	.710	.289	.836	.163	.350	.650
35	Aug 27 - 2	.840	.159	.689	.310	.181	.818
36	Sep 3 - 9	.768	.231	.886	.113	.312	.687
37	Sep 10 - 16	.797	.202	.800	.200	.357	.642
38	Sep 17 - 23	.782	.217	.759	.240	.066	.933
39	Sep 24 - 30	.695	.304	.791	.208	.238	.761
40	Oct 1 - 7	.492	.507	.794	.205	.400	.600
41	Oct 8 - 14	.478	.521	.606	.393	.611	.388

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Hyderabad

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					Post-monsoon			
42	Oct	15 - 21	.289	.710	.100	.900	.734	.265
43		22 - 28	.231	.768	.500	.500	.773	.226
44		29 - 4	.217	.782	.333	.666	.796	.203
45	Nov	5 - 11	.159	.840	.363	.636	.810	.189
46		12 - 18	.086	.913	.500	.500	.873	.126
47		19 - 25	.072	.927	.400	.600	.937	.062
48		26 - 2	.043	.956	.333	.666	.939	.060
49	Dec	3 - 9	.028	.971	.500	.500	.970	.029
50		10 - 16	.014	.985	0	1.0	.970	.029
51		17 - 23	.028	.971	0	1.0	.985	.014
52		24 - 31	.028	.971	.500	.500	.985	.014
1	Jan	1 - 7	.014	.985	0	1.0	1.0	0
2		8 - 14	0	1.0	0	0	.985	.014
3		15 - 21	.028	.971	0	1.0	1.0	0
4		22 - 28	.014	.985	0	1.0	.970	.029
5		29 - 4	.057	.942	0	1.0	.984	.015
6	Feb	5 - 11	.014	.985	0	1.0	.941	.058
7		12 - 18	.043	.956	0	1.0	.984	.015
8		19 - 25	.072	.927	0	1.0	.953	.046
9		26 - 4	.043	.956	.666	.333	.954	.045
10	Mar	5 - 11	0	1.0	0	0	.956	.043
					Summer			
11	Mar	12 - 18	.043	.956	0	1.0	1.0	0
12		19 - 25	.072	.927	.200	.800	.968	.031
13		26 - 1	.028	.971	.500	.500	.940	.059
14	Apr	2 - 8	.057	.942	0	1.0	.969	.030
15		9 - 15	.101	.898	.142	.857	.951	.048
16		16 - 22	.115	.884	.250	.750	.918	.081
17		23 - 29	.057	.942	.250	.750	.892	.107

APPENDIX II

Table 1.3

PROBABILITY OF WEEKLY RAINFALL

Station: Hyderabad

Datum Period: 1901-70 Cumulative weekly rainfall > 20 MM

Week	Date	Probability					
		Initial		Conditional			
		Wet (W)	Dry (D)	W/W	W/D	D/D	D/W
				Pre-monsoon			
18	Apr 30 - 6	.086	.913	.166	.833	.952	.047
19	May 7 - 13	.086	.913	0	1.0	.904	.095
20	May 14 - 20	.101	.898	.142	.857	.919	.080
21	May 21 - 27	.217	.782	.066	.933	.888	.111
22	May 28 - 3	.115	.884	.250	.750	.786	.213
23	Jun 4 - 10	.275	.724	.105	.894	.880	.120
24	Jun 11 - 17	.391	.608	.259	.740	.714	.285
				Monsoon			
25	Jun 18 - 24	.492	.507	.441	.558	.657	.342
26	Jun 25 - 1	.623	.376	.488	.511	.500	.500
27	Jul 2 - 8	.594	.405	.585	.414	.321	.678
28	Jul 9 - 15	.550	.449	.657	.342	.483	.516
29	Jul 16 - 22	.666	.333	.565	.434	.478	.521
30	Jul 23 - 29	.739	.260	.627	.372	.222	.777
31	Jul 30 - 5	.608	.391	.785	.214	.333	.666
32	Aug 6 - 12	.463	.536	.656	.343	.432	.567
33	Aug 13 - 19	.478	.521	.545	.454	.611	.388
34	Aug 20 - 26	.463	.536	.437	.562	.486	.513
35	Aug 27 - 2	.521	.478	.388	.611	.454	.545
36	Sep 3 - 9	.521	.478	.611	.388	.575	.424
37	Sep 10 - 16	.550	.449	.631	.368	.612	.387
38	Sep 17 - 23	.594	.405	.536	.463	.428	.571
39	Sep 24 - 30	.492	.507	.676	.323	.485	.514
40	Oct 1 - 7	.275	.724	.631	.368	.560	.440
41	Oct 8 - 14	.217	.782	.266	.733	.722	.277

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				Post-monsoon			
42	Oct 15 - 21	.391	.608	.407	.592	.476	.523
43	22 - 28	.347	.652	.666	.333	.755	.244
44	29 - 4	.304	.695	.380	.619	.666	.333
45	Nov 5 - 11	.304	.695	.571	.428	.812	.187
46	12 - 18	.159	.840	.727	.272	.775	.224
47	19 - 25	.217	.782	.333	.666	.888	.111
48	26 - 2	.115	.884	.375	.625	.803	.196
49	Dec 3 - 9	.072	.927	.400	.600	.906	.093
50	10 - 16	.072	.927	0	1.0	.921	.078
51	17 - 23	.072	.927	.200	.800	.937	.062
52	24 - 31	.028	.971	.500	.500	.940	.059
1	Jan 1 - 7	.072	.927	0	1.0	1.0	0
2	8 - 14	.057	.942	.250	.750	.938	.061
3	15 - 21	.057	.942	.250	.750	.953	.046
4	22 - 28	.028	.971	.500	.500	.955	.044
5	29 - 4	.086	.913	.166	.833	.984	.015
6	Feb 5 - 11	.086	.913	.166	.833	.920	.079
7	12 - 18	.115	.884	.375	.625	.950	.049
8	19 - 25	.101	.898	.285	.714	.903	.096
9	26 - 4	.086	.913	.333	.666	.920	.079
10	Mar 5 - 11	.028	.971	0	1.0	.910	.089
				Summer			
11	Mar 12 - 18	.144	.855	.100	.900	.983	.016
12	19 - 25	.115	.884	.250	.750	.868	.131
13	26 - 1	.144	.855	.300	.700	.915	.084
14	Apr 2 - 8	.231	.768	.187	.812	.867	.132
15	9 - 15	.275	.724	.315	.684	.800	.200
16	16 - 22	.304	.695	.380	.619	.770	.229
17	23 - 29	.231	.768	.250	.750	.679	.320

APPENDIX II

Table 1.4

PROBABILITY OF WEEKLY RAINFALL

Station: Hyderabad

Datum Period: 1901-70 Cumulative weekly rainfall> 40 mm

Week	Date	Probability					
		Initial		Conditional			
		Wet (W)	Dry (D)	W/W	W/D	D/D	D/W
				Post-monsoon			
18	Apr 30 - 6	.014	.985	0	1.0	.970	.029
19	May 7 - 13	.014	.985	0	1.0	.985	.014
20	May 14 - 20	.043	.956	0	1.0	.984	.015
21	May 21 - 27	.057	.942	0	1.0	.953	.046
22	May 28 - 3	.043	.956	0	1.0	.939	.060
23	Jun 4 - 10	.173	.826	.083	.916	.964	.035
24	Jun 11 - 17	.115	.884	.250	.750	.836	.163
				Monsoon			
25	Jun 18 - 24	.362	.637	.200	.800	.931	.068
26	Jun 25 - 1	.391	.608	.333	.666	.619	.380
27	Jul 2 - 8	.231	.768	.500	.500	.641	.358
28	Jul 9 - 15	.333	.666	.304	.695	.804	.195
29	Jul 16 - 22	.420	.579	.379	.620	.700	.300
30	Jul 23 - 29	.492	.507	.441	.558	.600	.400
31	Jul 30 - 5	.362	.637	.640	.360	.590	.409
32	Aug 6 - 12	.188	.811	.230	.769	.607	.392
33	Aug 13 - 19	.289	.710	.200	.800	.816	.183
34	Aug 20 - 26	.362	.637	.320	.680	.727	.272
35	Aug 27 - 2	.405	.594	.321	.678	.609	.390
36	Sep 3 - 9	.289	.710	.650	.350	.693	.306
37	Sep 10 - 16	.362	.637	.320	.680	.727	.272
38	Sep 17 - 23	.391	.608	.444	.555	.690	.309
39	Sep 24 - 30	.362	.637	.440	.560	.636	.363
40	Oct 1 - 7	.131	.869	.777	.222	.700	.300
41	Oct 8 - 14	.173	.826	.166	.833	.877	.122

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Hyderabad
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Post-monsoon

42	Oct	15 - 21	.217	.782	0	1.0	.777	.222
43		22 - 28	.188	.811	.230	.769	.700	.214
44		29 - 4	.072	.927	.400	.600	.828	.171
45	Nov	5 - 11	.043	.956	0	1.0	.924	.075
46		12 - 18	.028	.971	1.0	0	.985	.014
47		19 - 25	.043	.956	.333	.666	.984	.015
48		26 - 2	.028	.971	.500	.500	.970	.029
49	Dec	3 - 9	.014	.985	0	1.0	.970	.029
50		10 - 16	0	1.0	0	0	.985	.014
51		17 - 23	0	1.0	0	0	1.0	0
52		24 - 31	.014	.985	0	1.0	1.0	0
1	Jan	1 - 7	.014	.985	0	1.0	1.0	0
2		8 - 14	0	1.0	0	0	.985	.014
3		15 - 21	.014	.985	0	1.0	1.0	0
4		22 - 28	0	1.0	0	0	.985	.014
5		29 - 4	0	1.0	0	0	1.0	0
6	Feb	5 - 11	0	1.0	0	0	1.0	0
7		12 - 18	.014	.985	0	1.0	1.0	0
8		19 - 25	.028	.971	0	1.0	.985	.014
9		26 - 4	.014	.985	0	1.0	.970	.029
10	Mar	5 - 11	0	1.0	0	0	.985	.014

Summer

11	Mar	12 - 18	.014	.985	0	1.0	1.0	0
12		19 - 25	.057	.942	0	1.0	.984	.015
13		26 - 1	0	1.0	0	0	.942	.057
14	Apr	2 - 8	.014	.985	0	1.0	1.0	0
15		9 - 15	.043	.956	0	1.0	.984	.015
16		16 - 22	.043	.956	.333	.666	.969	.030
17		23 - 29	.028	.971	.500	.500	.970	.029

APPENDIX III

WATER-BALANCE MODEL

Assumptions made in the development of a water balance model to calculate EA/PE[1] and Soil Moisture variations over the growing period:

(1) That the soil moisture reservoir is equal to the quantum of available moisture holding capacity of the soil in the rooting depth of the crop. Heavy soils (Clay # 25 or 30%) have been assumed to have a soil moisture storage capacity of 200 mm/meter; medium soils (clay # 15%) to have a storage capacity of around 125-150 mm/meter; and light sandy soils to have a storage capacity of 75-100 mm per meter.

Effective plant feeder root depths vary widely in different soils, and different species vary within a range. The following were adopted as generalised figures:

Rooting Depth	Crop	Depth in meters
Shallow	Groundnut, forages	0.5
Intermediate	Grain crops	1.0
Deep	Castor, pigeonpea	1.5

The method used for calculating available water storage capacity of the soil is shown in the following example.

Example: Say a groundnut crop is grown in a light sandy soil having an available water storage capacity of 100 mm/m depth; the soil moisture reservoir available for crop utilization will be 100 x .5[2] = 50 mm. On the same principle if a deep rooting crop like castor or pigeonpea is grown, it will have 100 x 1.5[2] = 150 mm of soil moisture reservoir available for use. If these latter crops are grown in a heavy clay soil (e.g. deep black soil), the available soil moisture reservoir will be 200 x 1.5[2] = 300 mm for crop use.

1/ Ratio of estimated crop available water to potential evapotranspiration.

2/ Values refer to effective rooting depth.

On the basis of the above, three soil moisture storage values of 50, 150 and 300 mm were adopted for the present case.

(2) That in the soil water reservoir, the amount of available water in the root zone, is retained between field capacity and the permanent wilting percentage.

(3) That runoff or deep drainage occur only when soil water is charged to the extent defined in para (1) for a particular soil type. This assumption, while undoubtedly an oversimplification of the actual picture, provides reasonable agreement with runoff data available for cropped conditions under good agronomic situations. At ICRISAT, it has been noted that under black soil conditions, most runoff occurs when the soil water reservoir is fully charged. Basinski (1960) also observed that in the Yass valley of Australia, the runoff was recorded primarily in winter and spring when the soil reservoir was fully-charged; and that even heavy falls in the summer months, when the soil water reservoir was practically depleted, produced little runoff.

In case of soils with poor or unstable structure (e.g. red soils) the runoff may take place before the root profile is charged, if water does not get adequate opportunity time to infiltrate. This could occur at a time prior to the land preparation phase or when adequate crop canopy is absent.

Despite this evidence, the assumption must be regarded with caution, and in particular the possibility of local runoff resulting in water accumulation in depressed and down slope areas must be borne in mind when interpretations of runoff estimates are made.

(4) That evapotranspiration of the stored soil water takes place equivelent to the PE rate when the soil water reservoir is fully charged or rainfall exceeds PE. The moisture extraction curves reported by Denmead and Shaw (1962) for different soil types under relatively high potential evapotranspiration conditions were adopted in the present case.

(5) In the application of the model, rainfall data were grouped into weekly totals, utilising the standard week units given in Appendix VI. With this set of data a simple budget was made up with rainfall as replenishing input of soil moisture and evapotranspiration as a depleting factor. Rainfall in excess of the soil moisture reservoir capacity, was regarded as runoff (surface runoff and deep drainage)[1/]. Evapotranspiration was subtracted at a rate determined [as described above (4)] by the amount of soil water available. Subject to other limiting factors, growth was considered to start whenever the net ratio of EA/PE $\geq .3$ and to cease or to be detrimental to plant life when $< .3$. At critical stages of plant growth, EA/PE of $\geq .75$ was considered to signify an adequate rate of water availability to crops. The computer techniques followed for water budgeting were essentially those outlined in CSIRO, Australia, Technical Memorandum 74/4 (Keig and McAlpine, 1974).

1/ The model does not allow for simulation of the effects of high intensity rainfall, part of which may runoff even when soil profile is not filled to its maximum capacity; this may in certain cases result in an over estimate of the level of moisture availability.

APPENDIX IV

MOISTURE REQUIREMENTS OF CROPS

Crops require water to meet the biological metabolic needs and evapotranspiration requirements. The water requirements of crops differ in different species, varieties, environmental conditions and soils. In general, it is difficult to obtain crop production data related to various levels of moisture adequacy. Procedures for determining the degree to which moisture is adequate or deficient have not been well standardised. In most of the reports (Hargreaves, 1975) only a portion of the full range of moisture adequacies is correlated with yields. Yield data are presented in a wide Variety of units.

Yield and water use data for sugarcane, alfalfa, corn, forage crops, potatoes, sugarbeets and peas from a a variety of sources were analysed by Hargreaves and Christiansen (1974). Available water was either calculated or estimated to include moisture stored in the soil at the beginning of the growing season plus rainfall received during the crop season and irrigation water applied. The results showed that all crops are not equally sensitive to moisture stress. The timing of moisture deficiencies and their extent at different crop phenological stages play an important role. In general, adequate moisture is of greater importance during flowering, grain formation and grain sizing stages than at other times during the growth cycle.

For corn [Steward et. al (1974); Krantz et. al. (1975)] and for grain sorghum [Stewart et.al. (1974); Nix and Fitzpatrick (1969)] it has been shown that the timing of water deficiency is of great importance. In corn the grain yield was observed to be an inverse function of ET deficits during the pollination period. For two varieties of sorghum, water stress over a two week period during the heading and grain filling stage was found to reduce yields to around 1000 kg/ha from over 35000 kg/ha yields obtained with adequate water availability

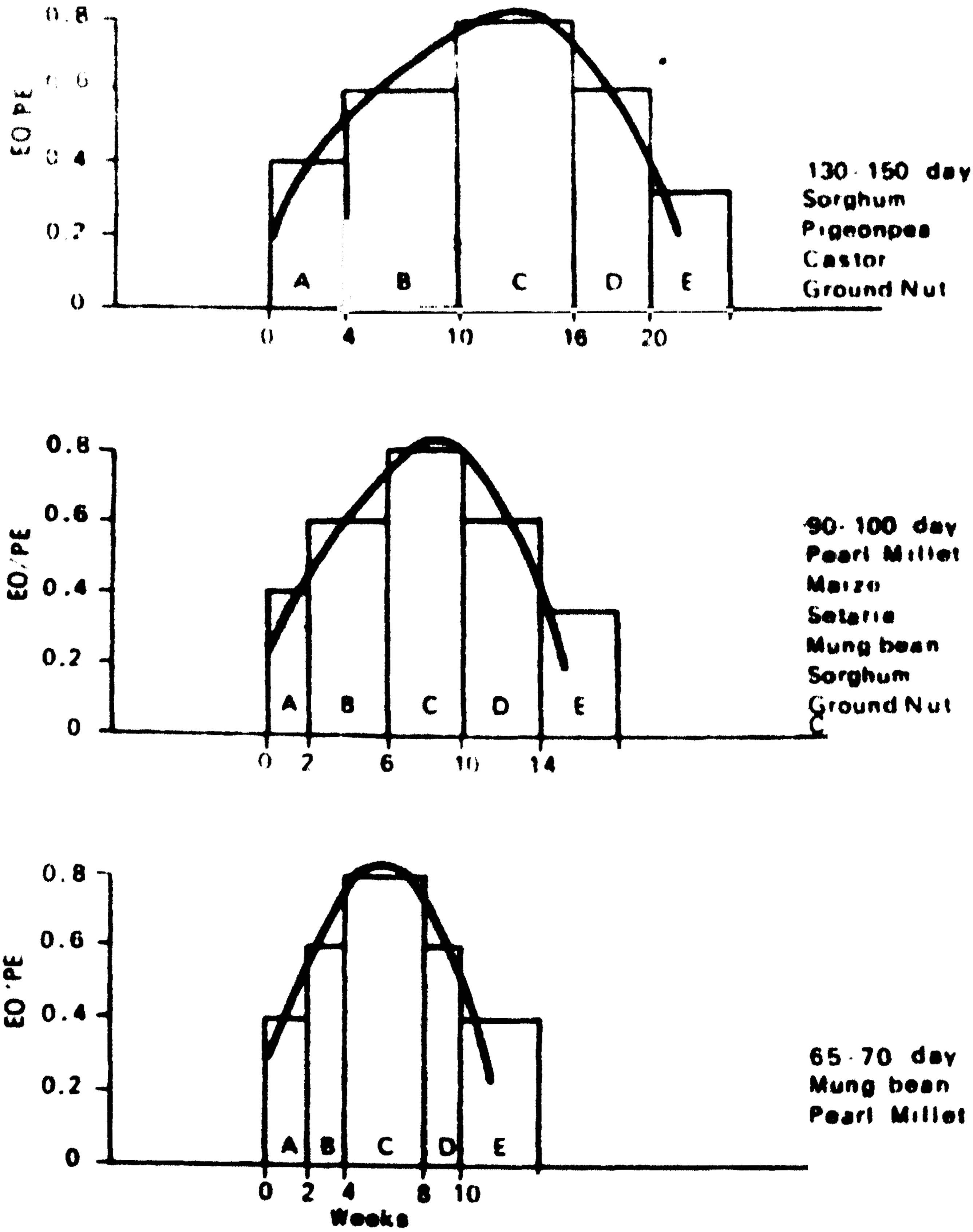
The production functions relating the relative yield reduction to the relative ET deficit at a critical stage (e.g. flowering and grain setting) are modified significantly by the conditioning effects of previous deficits. If cell division is not seriously retarded, cell enlargement can often catch up during a later period of moisture adequacy. Thus, moisture stress at the vegetative phase of crop growth can be made up at later stages if moisture sufficiency is restored. Also, for soils with good moisture storage capacities, there is a tendency towards a reduction in the adverse effects of poor distribution of rainfall.

Mean moisture stress in the root zone and yields of 14 forage crops gave a fairly linear relationship (Downey, 1972). A plot of the yield (% of maximum) as a function of ET, showed that much of the scatter is attributed to growth stages susceptible to water stress.

Hargreaves and Christiansen (1974) and Hargreaves (1975) have tried to standardise the diverse data and to compare results from different crops. It has been estimated that during initial seedling stage, the crop requirements are around EO/PE = 0.25. This value increases to about 0.8 at the preflowering stage. The nature of the curve is dependent upon the rate of growth. EO/PE rises to around unity during flowering and seed formation stage and drops to about 0.3 at harvest. Based on this information, some generalised curves of EA/PE requirements of crops at different phenological stages are shown in Figure 12.

Figure 12

RATE OF EVAPOTRANSPIRATION BY CROP RELATIVE TO POTENTIAL EVAPOTRANSPIRATION IN A SOIL WELL SUPPLIED WITH WATER



Crop Growth Stages:

A. Seedling Stage
B. Vegetative Phase
C. Reproductive Phase
D. Physiological Maturity
E. Harvest Maturity

Appendix V

TABLE 2.1

EA/PE RATIOS AT VARIOUS PROBABILITY LEVELS

STATION: Hyderabad
DATUM PERIOD: 1901-70

Average available moisture storage capacity of the soil: # 50 MM

Season	Week	Commencing	Prabiliity					
			90	75	50	25	10	Mean
Pre-monsoon	18	Apr 30	0	0	0.1	0.2	0.4	0.1
	20	May 14	0	0	0.1	0.2	0.4	0.1
	22	May 28	0	0	0.1	0.3	0.6	0.2
	24	Jun 11	0	0.1	0.2	0.5	1.0	0.4
Monsoon	26	Jun 25	0.1	0.3	0.6	1.0	1.6	0.7
	28	Jul 9	0.2	0.3	0.6	1.0	1.5	0.8
	30	Jul 23	0.3	0.5	0.8	1.2	1.5	0.9
	32	Aug 6	0.3	0.4	0.7	1.1	1.5	0.8
	34	Aug 20	0.2	0.3	0.6	1.0	1.5	0.8
	36	Sep 3	0.3	0.5	0.7	1.1	1.5	0.8
	38	Sep 17	0.4	0.6	0.8	1.1	1.4	0.9
	40	Oct 1	0.1	0.3	0.5	0.9	1.4	0.7
Post-monsoon	42	Oct 15	0.1	0.2	0.4	0.8	1.3	0.6
	44	Oct 29	0	0.1	0.3	0.6	1.1	0.4
	46	Nov 12	0	0	0.1	0.3	0.6	0.2
	50	Dec 10	0	0	0.1	0.1	0.2	0.1
	2	Jan 8	0	0	0	0.1	0.1	0.1
	6	Feb 5	0	0	0	0.1	0.1	0.1
	10	Mar 5	0	0	0	0.1	0.1	0.1
Summer	14	Apr 2	0	0	0	0.1	0.2	0.1
	16	Apr 16	0	0	0.1	0.2	0.3	0.1

Appendix V

TABLE 2.2

EA/PE RATIOS AT VARIOUS PROBABILITY LEVELS

STATION: Hyderabad
DATUM PERIOD: 1901-70

Average available moisture storage capacity of the soil # 150 mm

Season	Week	Commencing	Prabability 90	75	50	25	10	Mean
Pre-monsoon	18	Apr 30	0	0	0.1	0.2	0.3	0.1
	20	May 14	0	0	0.1	0.2	0.3	0.1
	22	May 28	0	0.1	0.1	0.2	0.4	0.2
	24	Jun 11	0.1	0.1	0.2	0.4	0.7	0.3
Monsoon	26	Jun 25	0.2	0.4	0.6	0.9	1.3	0.7
	28	Jul 9	0.3	0.4	0.7	1.0	1.3	0.8
	30	Jul 23	0.5	0.7	0.9	1.1	1.3	0.9
	32	Aug 6	0.4	0.6	0.8	1.1	1.4	0.9
	34	Aug 20	0.4	0.6	0.8	1.1	1.4	0.9
	36	Sep 3	0.6	0.7	0.9	1.1	1.3	0.9
	38	Sep 17	0.7	0.8	0.9	1.1	1.2	0.9
	40	Oct 1	0.6	0.7	0.9	1.1	1.3	0.9
Post-monsoon	42	Oct 15	0.4	0.5	0.8	1.1	1.4	0.8
	44	Oct 29	0.2	0.4	0.6	0.9	1.3	0.7
	46	Nov 12	0.1	0.2	0.4	0.7	1.0	0.5
	50	Dec 10	0	0.1	0.2	0.3	0.4	0.2
	2	Jan 8	0	0.1	0.1	0.1	0.2	0.1
	6	Feb 5	0	0	0.1	0.1	0.1	0.1
	10	Mar 5	0	0	0	0.1	0.1	0.1
Summer	14	Apr 2	0	0	0.1	0.1	0.2	0.1
	16	Apr 16	0	0	0.1	0.2	0.3	0.1

Appendix V

TABLE 2.3

EA/PE RATIOS AT VARIOUS PROBABILITY LEVELS

STATION: Hyderabad
DATUM PERIOD: 1901-70

Average available moisture storage capacity of the soil: # 300 mm

Season	Week	Commencing	Probability 90	75	50	25	10	Mean
Pre-monsoon	18	Apr 30	0	0	0.1	0.2	0.3	0.1
	20	May 14	0	0	0.1	0.2	0.3	0.1
	22	May 28	0	0.1	0.1	0.3	0.4	0.2
	24	Jun 11	0.1	0.1	0.2	0.4	0.7	0.3
Monsoon	26	Jun 25	0.2	0.4	0.6	0.9	1.3	0.7
	28	Jul 9	0.3	0.4	0.7	1.0	1.3	0.8
	30	Jul 23	0.5	0.7	0.9	1.1	1.3	0.9
	32	Aug 6	0.5	0.6	0.8	1.1	1.3	0.9
	34	Aug 20	0.5	0.6	0.8	1.1	1.3	0.9
	36	Sep 3	0.6	0.7	0.9	1.1	1.3	0.9
	38	Sep 17	0.7	0.8	0.9	1.1	1.3	1.0
	40	Oct 1	0.6	0.7	0.9	1.1	1.3	0.9
Post-monsoon	42	Oct 15	0.5	0.6	0.8	1.1	1.4	0.9
	44	Oct 29	0.3	0.5	0.7	1.1	1.4	0.8
	46	Nov 12	0.2	0.3	0.6	0.9	1.3	0.7
	50	Dec 10	0.1	0.2	0.4	0.7	1.0	0.5
	2	Jan 8	0	0.1	0.2	0.3	0.5	0.2
	6	Feb 5	0	0	0.1	0.1	0.2	0.1
	10	Mar 5	0	0	0	0.1	0.1	0.1
Summer	14	Apr 2	0	0	0.1	0.1	0.2	0.1
	16	Apr 16	0	0	0.1	0.2	0.3	0.1

APPENDIX VI

"THE STANDARD WEEKS"

Week No.		Dates	Week No.		Dates
1	January	1 - 7	27	July	2 - 8
2		8 - 14	28		9 - 15
3		15 - 21	29		16 - 22
4		22 - 28	30		23 - 29
5		29 - 4	31		30 - 5
6	February	5 - 11	32	August	6 - 12
7		12 - 18	33		13 - 19
8		19 - 25	34		20 - 26
9		26 - 4*	35		27 - 2
10	March	5 - 11	36	September	3 - 9
11		12 - 18	37		10 - 16
12		19 - 25	83		17 - 23
13		26 - 1	39		24 - 30
14	April	2 - 8	40	October	1 - 7
15		9 - 15	41		8 - 14
16		16 - 22	42		15 - 21
17		23 - 29	43		22 - 28
18		30 - 6	44		29 - 4
19	May	7 - 13	45	November	5 - 11
20		14 - 20	46		12 - 18
21		21 - 27	47		19 - 25
22		28 - 3	48		26 - 2
23	June	4 - 10	49	December	3 - 9
24		11 - 17	50		10 - 16
25		18 - 24	51		17 - 23
26		25 - 1	52		24 - 31**

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* In leap year the week No.9 will be 26 February to March 4, i.e. 8 days instead of 7.

** Last week will have 8 days, 24 to 31 December.

APPENDIX VII

Estimated runoff [1/] (mm) in two soils having variable soil moisture holding capacities (Hyderabad 1901-70)

	Runoff (mm) [2/] water holding capacity Low		Medium - high		Rainfall (mm)	
ANNUAL						
First Decile	24		.2		549	
First Quartile	59		5		648	
Median	134		39		772	
Third Quartile	257		154		911	
Monsoon period	Median	Mean	Median	Mean	Median	Mean
May 21 - 17 Jun	.1	1	0	0	42	57
Jun 18 - 15 Jul	1.1	15	0.1	4	122	132
Jul 16 - 12 Aug	6.8	45	1.5	26	141	154
Aug 13 - 9 Sep	6.9	44	3.2	33	125	141
Sep 10 - 7 Oct	9.9	63	6.0	54	123	145
Oct 8 - 4 Nov	.7	14	.3	7	27	64

1/ Climatologically excess water. Runoff means water lost by surface runoff and deep drainage. The model does not allow for simulation of the effects of high intensity rainfall, part of which may run off when the soil profile is not filled to its maximum capacity.

2/ Low water holding capacity has been assumed to be exemplified by soils having approximately 50 mm available water holding capacity in the root profile and medium to high water holding capacity by soils having at least 150 mm available moisture storage.