AGROCLIMATOLOGY
FARMING SYSTEMS RESEARCH PROGRAM
FIVE-YEAR REPORT 1978-83

ICRISAT
International Crops Research Institute
for the Semi-Arid Tropics

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NOTE TO THE READER

This is an informal report of work for 1978-83. This report is designed to stimulate thinking and comments from professional colleagues and is not to be considered as a formal publication bearing the endorsement of the Institute.

This is one of seven subprogram reports from the Farming Systems Research Programme. The seven subprogram reports include the following:

- Agroclimatology
- Soil Physics and Conservation
- Soil Fertility & Chemistry
- Farm Power & Equipment
- Land & Water Management
- Cropping Systems
- On-Farm Research

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I. SUMMARY

The agroclimatology subprogram of the Farming Systems Research Program is concerned with all the meteorological elements affecting crop production. In the dry tropics variation in the timing and amount of precipitation are the key factors influencing agricultural production possibilities. The agricultural value of rainfall varies with the factors that influence evapotranspiration. In determining the agricultural potentialities of any semi-arid area, a quantification of the rainfall, soil, and evapotranspiration is of importance. Appropriate quantification of the growing season and its characteristics could be of great help in crop planning. The objectives of agroclimatology research are:

- To understand rainfall variability for quantifying associated risks in crop production.
- To characterize crop response to prevailing moisture environment; to assist in crop planning for increased and stabilized agricultural production.
- To develop a climate-driven production model to predict crop performance at different locations.
- To develop agronomically relevant classification of the climate to facilitate the transfer of technology.

SOME IMPORTANT CONTRIBUTIONS

a. Revised maps of SAT: We revised the SAT maps of India, northeast Brazil, and Africa, using an enlarged data base. This revision places 88% of the geographical area of India in the tropics. The dry semi-arid tropics cover about 57% of India. The revised SAT map of northeast Brazil is based on data from 180 locations, while the revised map of Africa uses data from 300 locations in West Africa and 180 locations in the rest of Africa. A revised map of the semi-arid tropical world has been prepared.

b. Rainfall characteristics of Niger: There is a characteristic decrease in the amount of rain and the duration of the rainy season with increasing latitude in Niger. Only in the Gaya and Dosso regions are the average 4-week rainfalls above 100 mm where the length of the growing season is 4 or 5 months. Probability analyses of rainfall for 77 locations have been conducted. These would provide a basis for evaluating agronomic feasibility of alternative systems of cropping. A complete report of this study is available (ICRISAT, Information Bulletin No. 5, 1979).

c. Rainfall probabilities: We have computed rainfall probabilities for 77 locations in India (ICRISAT Research Bulletin No.1, Revised 1982), 77 locations in Niger and 80 locations in Mali (under publication 1983) based on weekly data. These data have been used to pinpoint the likely periods of moisture adequacy or drought during periods associated with different stages of phenological development of crop. Our efforts in this direction will continue. Rainfall climatology bulletins of Botswana, Malawi, and Thailand are under preparation.

We have noted that mean monthly rainfall data do not yield information on the dependability of precipitation to meet potential demand. The dependable precipitation amounts are much lower, and so one must consider dependable precipitation rather than mean rainfall. One application of such analysis is to delineate the probability of success of different types of crops.

d. Dry seeding of rainy season crops in the SAT: The methodology for identification of areas of dependable rainfall has been standardised. The areas of deep Vertisols in India where farming systems technology developed at ICRISAT would probably be successful are delineated. Dry seeding is an important component of the improved technology for deep Vertisols. Based on rainfall probability analysis of more than 90 stations in India, the areas offering possibilities of dry seeding on Vertisols are mapped. Our studies show for example the technology for dry seeding of crops generated at ICRISAT Center could be applied with a fair degree of success to Akola, Jabalpur, Indore, and Udaipur, whereas at Sholapur, Dharwar, Bijapur, and Ahmedabad the likely success of dry seeding is low due to the high risk associated with it.

e. Constant probability analysis for monthly rainfall: In most cases one of the first things that one wants to know for a location is its agricultural potentialities for dryland agriculture. Hargreaves method (MAI) could be adopted as an index for measuring water deficiencies and excess. MAI can provide an approximation of water availability.

Such an analysis could clearly demonstrate the agricultural potentials of the area, the length of the core growing season and climatic moisture balance for the rainy months. For example, in Mali the length of the growing season would be approximately 120 days, at Bamako, while only a 60-day crop could be grown successfully at Douentza. The Gao area is not suitable for crop land agriculture as there the rainy season is too short.

A handbook of the Rainfall Climatology of West Africa covering 4.2 million sq. km has been prepared (ICRISAT Information Bulletin No.6, 1980).

f. Field work-day probability: A methodology for the estimation of field work days has been developed. The results of this work show that at Hyderabad for a 90 to 100-day sorghum crop, the possibility of getting into the field for harvest is about 77% in the Alfisols and only 29% in the Vertisols. In the deep Vertisol areas, harvesting a medium-duration sorghum could be problem. The analysis shows that either we should develop mold resistant short duration sorghum or select 120-130 day sorghum cultivars which could escape rains at the seed setting stage of growth. This work is now being extended to evaluate the possibilities of investments in tillage equipment for several areas of the SAT in a World Bank study.

g. Stochastic modeling using the water balance approach: By estimating the amounts of available water in the root zone in relation to potential evapotranspiration demand at weekly intervals, the probabilities of water availability at pre-determined levels can be evaluated for a particular soil type. Our studies for Hyderabad regions have shown that a long-duration crop in a soil with 50 mm available water-storage capacity will be exposed to soil-moisture inadequacy at several growth stages, but if the soil-moisture storage capacity were 150 or 300 mm, the risks of water deficiency are much less. Thus one might select for shallow soils a drought-hardy crop (e.g. millet, sorghum or castor bean), whereas in deeper or heavier soils a crop with medium sensitivity to drought (such as maize, pigeonpea) would be suitable. We are utilizing this methodology for providing first approximation information on the suitability of different cropping systems for diverse agroclimates.

h. Crop-weather modeling: Studies on crop-weather modeling were initiated in 1978 with the adaptation of the SORGF model from Texas. A multilocation project on sorghum modeling was also initiated. As the experience with this model increased, several subroutines were revised. These revisions, labelled as SORGF-1 and SORGF-2, improved the coefficient of determination (R2) significantly from 0.27 (SORGF) to 0.74 for SORGF-2. The sorghum model can be used with modifications to produce a growth model for pearl millet.

i. Training/Workshops: The subprogram has organized the following training activities/workshops and meetings.

1978: International Workshop on Agroclimatological Research Needs of the SAT.

1979: Collaborators' Meeting on Sorghum Modeling.

1980: Consultants' Meeting on Climatic Classification.

1981: Collaborators' Meeting on Sorghum Modeling.

1982: WMO/ICRISAT Symposium on Agrometeorology of Sorghum and Millet.

Interagency Training Course on Agrometeorology in Cooperation with WMO/FAO/& INTSORMIL.

1984: ICAR/ICRISAT Training Meeting on Agroclimatology.

II. CONCEPTUAL FRAMEWORK OF THE AGROCLIMATOLOGY SUBPROGRAM

Definition and Scope

Agroclimatology aims to characterise and quantify the weather elements in relation to agricultural production leading to a better understanding of the climatic environment of crops grown in the SAT. Because the applicability of crop production technologies varies with agroclimate of a region, our research efforts focus on the development of principles, concepts, and methodologies that are transferable and have broad application. Information on the SAT world's weather and climate in a form suitable for assessing the natural and global food production systems and human environmental conditions is of considerable importance for planning and decision making at national and international levels.

A conceptual framework of research in agroclimatology is shown in Figure 1.1.

Areas of Research

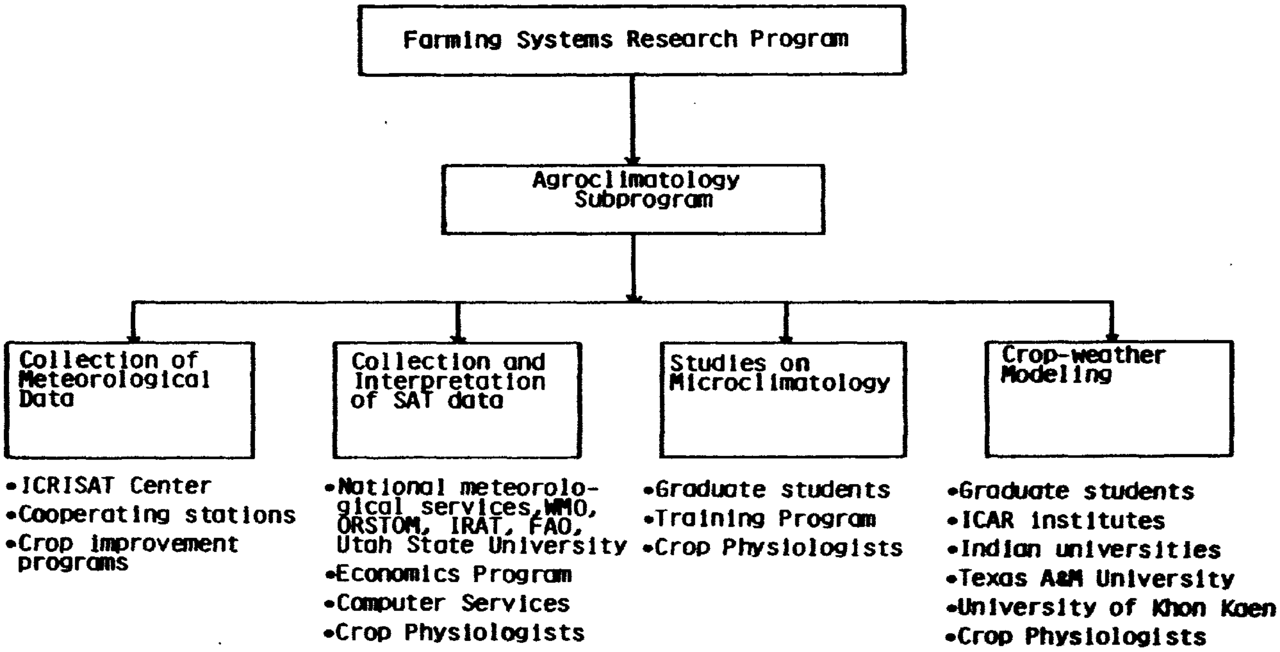
The four main areas of research through which the above objectives are to be fulfilled are:

Areas of research		Year started	Area's share in sub-program's resources (%)
I	Collection of meteorological data	1973	10
II	Collection and interpretation of SAT data	1975	40
III	Studies on microclimatology	1977	30
IV	Studies on crop phenology and crop-weather modeling	1978	20

Area I: Collection of Agrometeorological Data from SAT Locations

Of the different environmental factors that effect plant growth and yield formation, meteorological factors are very important. Such data are needed for the assessment of macro-climate and micro-climate of a region. Records of daily weather observations are essential in studying interactions of weather with yield-limiting factors and serve as inputs for building up suitable crop-yield weather models. The spatial variability of different meteorological elements differs widely in different climatic zones. In the semi-arid tropics, wide variability of rainfall over relatively small areas is commonly observed. Therefore in order to spatially integrate the rainfall it is essential to have several rainfall-recording stations over the research areas. The goal is to achieve acceptable levels of predictability for reducing (and quantifying) the element of risk in crop production.

Figure 1.1. Conceptual Framework of Agroclimatology Subprogram



Objectives

- To establish and operate agroclimatological observatories at the ICRISAT Center and cooperating research centers.
- To investigate the relationships between meteorological observations recorded throughout the SAT.
- To develop agronomically meaningful resource data from primary meteorological observations (rainfall, temperature, solar radiation, evaporation) for use by researchers in the SAT.

Area II: Collection and Interpretation of Agroclimatological Data

The program is inter-disciplinary as well as inter-institutional because it involves collaboration with national (soil survey and meteorological) and international (IRAT, ORSTOM, Utah State University, FAO and WMO) research organisations. The collection and classification of information on soil, water, and climatic resources provides a data base for generalizing results of site-specific studies for wider application. Two major kinds of research involved are: (i) collection, compilation, and documentation of data in usable form. In this, ICRISAT is striving to complement rather than duplicate the work of other agencies; and (ii) development of interpretative classification systems for the basic resource data.

Work is in progress to develop an agronomically relevant basis for interpreting climatic data. Data are being organized to characterize the rainfall and crop-moisture environments for semi-arid locations with the final aim to develop a climate-driven model for crop production. It will be used to delineate agroclimatic regions within which the interaction of the climate, soil, and crop would be expected to produce similar crop-production responses under similar management conditions. The identification of such iso-agroclimes will provide a rational basis for generlized results from site-specific experiments and a rational basis for selecting locations for conducting such experiments.

Objectives

- To develop at ICRISAT data banks for soil and climatic resources of the semi-arid tropics.
- To develop agronomically meaningful units for classification from the primary resource data and to demonstrate the validity of such classifications for controlled generalization of results from site-specific performance.
- To develop a better appreciation in our colleagues of the validity and utility of a more quantitative analytical use of basic

resource data in agricultural research and planning.

Area III: Studies on Microclimatology

Increasing our understanding of the microclimatological process would provide a basis for predicting plant response in crops of economic importance. Such research would enable us to relate processes, such as photosynthesis and transpiration, to other climatic factors of the field environment. Such a research would then involve a collaborative approach between agroclimatology, plant physiology, and soil physics.

Objectives

- o Prediction and control of the physical environment for better agricultural production.
- o The response of the crops to the physical environment.
- o Appraisal of an appropriate environment for a crop and modification of the given environment towards optimisation.

Basic to the prediction of physical micro-climatic environment is the energy balance equation relating the different energy terms.

Studies on the response of the biosystem to the physical environment include the plant response to available water in the soil, because the results reported in recent years show that plant growth is controlled directly by water deficits in plants and only indirectly by soil-water deficits and atmospheric stresses. Such studies involve measurements of growth and dry matter accumulation; stomatal and osmotic regulations controlling the plant-water status; leaf and canopy characteristics. Studies on stomatal physiology, leaf-water potential, diurnal and seasonal variations in the stomatal conductance and leaf-water potential would help relate plant-stress parameters to growth and dry matter accumulation, so that the plant response to available water in the soil can be quantified. Studies of diurnal variations in the crop-canopy temperatures and influencing factors can aid towards reduction of evapotranspiration resulting in improved water use efficiency. Characterization of the effects of changes in the canopy micro-climate would enable us to simulate the incidence and/or outbreak of such diseases and pests.

Area IV: Studies on Phenology and Crop-Weather Modeling

Modeling is useful in defining problems, constructing hypotheses of proof or disproof, promoting integration of research projects, and making better use of the combined results. The increasing cost of applied research is one of the main reasons for the current trend towards simulation modeling to test the interaction of weather and cultural practices. The simulation approach also offers one of the important means of guiding research for improving the efficiency of crop-production systems. The main purpose here is to marshall the reduction of a large amount of research data into a "useable, integrated form, meaningful beyond the restrictions of individual analytic disciplines."

Modeling offers us an unique opportunity to generalize many sites and years and test a variety of treatments. Priorities must be identified. It is also imperative that modeling approacher serve only as an aid in the decision-making matrix, rather than as an end in themselves. The approach is interdisciplinary, involving several research groups at ICRISAT Center and other institutions.

Objectives

- To integrate information on different aspects of growth and development of ICRISAT mandate crops using systems approach.
- To develop quantitative understanding through modeling on responses of these crops to the environment leading to yield simulations.
- To identify areas where further knowledge is required and to generate such knowledge.
- To develop and use process based simulation models for answering "what if" questions required for the transfer of technologies.

III FIVE-YEAR REPORT OF RESEARCH

Within the four areas of research we developed four projects to work during the period from 1979 to 1983. The objectives, achievements and training provided within the scope of each project are discussed below:

Project I: Collection and interpretation of climatic data

Objectives and Scope

1. Recording and analysis of meteorological observations at ICRISAT Center and at the cooperating centers.
2. Analysis and interpretation of climatic data to classify climatologically homogenous zones of the semi-arid tropics.
3. To develop a quantitative understanding of the climate of distinct regions, required for developing sound farming systems and crop improvement research and to establish guiding parameters for region specific agricultural development.

Achievements

1. In addition to other routine meteorological observations at the ICRISAT observatory, soil temperature at five depths, dry and wet bulb temperatures at different heights, global solar radiation and

net radiation on an hourly basis are also recorded. Long term daily rainfall data have been acquired for 15 locations in India, 300 locations in West Africa, 50 locations in Thailand, and 80 locations in Botswana and 100 locations in Malawi (Table 2.1). Weekly rainfall data for 85 locations in India and monthly rainfall data for 700 locations in Brazil are also available. Available data were computerized, scrutinized and stored on tapes of the ICRISAT computer system. Long term monthly temperature data for several locations in Mali and Upper Volta was also obtained and computerized.

2. Using the data collected from 1976 to 1982 on the spatial variability of rainfall at ICRISAT Center, the optimum network of rain gauges over the research center has been determined. The probabilities of selected deviations of rainfall with distance from the meteorological observatory have been determined (Table 2.2).

3. Methods for estimation of potential evapotranspiration (PE) over West Africa, Thailand and Brazil were developed and computed PE values were published.

4. A handbook on the monthly rainfall, potential evapotranspiration, and dependable precipitation for 300 locations in West Africa was published.

5. Several methods for classification of semi-arid tropics (SAT) were evaluated and modified Troll's map showing SAT regions were prepared for India, West Africa and Thailand.

6. A principal component analysis program was adopted to the ICRISAT computer system and analysis of climatic data for India (150 locations)and West Africa (300 locations) was carried out.

Project II: The quantification of moisture environment for crop growth

Objectives and scope

1. To develop an understanding of rainfall variability across diverse locations for quantifying associated risks in crop production.

2. To evaluate computer simulation techniques to quantify moisture environment from rainfall, evapotranspiration and soil factors for prediction of optimal cropping systems in the semi-arid tropical areas.

3. To prepare computer programs to quantify the moisture environment in seeding zone of the soil for evaluating risk associated with the dry seeding technology.

4. To quantify the intra- and inter-seasonal droughts for evaluating the role of on-farm water storage systems in stabilizing crop production.

Table 2.1. Climatological data bank at ICRISAT Research Center.

Country	Rainfall		Temperature	
	No. of locations	Data format	No.of locations	Data format
India	85	Weekly	----	----
	15	Daily	----	----
Niger	82	Daily	----	----
Mali	81	Daily	32	Monthly
Upper Volta	115	Daily	10	Monthly
Senegal	126	Daily	----	----
Chad	56	Daily	----	----
Malawi	100	Daily	----	----
Botswana	53	Daily	----	----
Thailand	50	Daily	----	----
Brazil	700	Monthly	----	----

Table 2.2. Probability (%) of deviation of rainfall recorded by raingauges situated at varying distances from the mean rainfall recorded at the meteorological observatory at the ICRISAT Research Center (data base 1976-1982).

Distance from Met observatory (meters)	Deviation of rainfall within				
	5%	10%	15%	20%	25%
0-500	55	78	87	92	94
500-1000	46	64	74	81	86
1000-1500	38	55	65	74	80
1500-2000	31	44	55	64	69
2000-2500	30	41	50	57	63
2500-3000	28	40	51	57	65
>3000	26	34	44	51	57

Achievements

1. A simulation study on the quantification of moisture environment for crop growth was carried out at ICRISAT to test the methodology for prediction of optimal cropping systems.

2. Rainfall probability analysis for 77 locations in semi-arid India (8-30 N) has been computed. Use of the probabilities to examine the location specificity of moisture environment was demonstrated, using the data for Hyderabad and Sholapur.

3. Rainfall climatology analysis for 75 locations in Niger was completed. Use of the analysis for crop planning was demonstrated.

4. Rainfall probability analysis for 53 locations in Botswana was completed. Water balance analysis for 8 locations in Botswana was carried out to show the prospects for cropping in these areas.

5. A study on the climatology of 81 locations in Mali was completed. The analysis showed the most fruitful areas for regional crop planning in Mali. A bulletin describing this analysis has been completed.

6. With the National Meteorological Services of the Government of Upper Volta, a cooperative project on the preparation of a detailed bulletin on the 'climatology of Upper Volta' was initiated. Long term rainfall data for 115 stations in Upper Volta were analysed and maps were prepared showing the relative potential for cropping in different regions.

7. We assisted the National Meteorological Services of the Government of Malawi in the computerisation and analysis of long term rainfall data for over 100 stations.

8. In cooperation with the sorghum pathologists, we have analysed the International Grain Mold Nursery data and formulated a climatological model for the prediction of grain mold (Table 2.3). Using this model we were able to estimate from long term climatological data the probabilities of incidence of grain mold with varying intensities for Hyderabad (Table 2.4).

9. We have analysed long term rainfall data for several locations in Karnataka, Maharashtra, and Madhya Pradesh to assist in the transfer of ICRISAT deep Vertisol Technology.

10. A simple method for estimation of soil water balance was developed and computerized. Several other soil water balance models (Keig and McAlpine, 1974, Baier and Robertson 1966, Ritchie 1976) were computerised and at a pre-planning meeting of the 'ICRISAT-WMO Symposium/Planning Meeting on the Agrometeorology of Sorghum and Millet' these models were evaluated using input data from India and several countries in Africa. In order to effectively simulate the soil water in various soil layers with changing rooting depths of crops a layered soil water balance routine was incorporated into the model of Ritchie (1976) and was evaluated for the [illegible]rtisols [illegible]nd Alfisols at ICRISAT Center. An [illegible] of the

Table 2.3. Selected climatological model for the prediction of grain mold for hybrid CSH-1 (data base: International Grain Mold Nursery data 1978-1981).

Explanatory variables	Coefficient	Standard error of coefficient
1. Days to flowering	-0.07913	0.03227
2. Rainfall (mm) during the first 10 days after flowering (RFI)	0.03314	0.03348
3. Rainfall (mm) from 10-20 days after flowering (RFII)	-0.03538	0.03709
4. Rainfall (mm) from 20-30 days after flowering (RFIII)	-0.02571	0.04873
5. Rainfall (mm) from 30-40 days after flowering (RFIV)	0.00860	0.01310
6. (RFI) (Rainy days I)	-0.00579	0.00750
7. (RFII) (Rainy days II)	0.00778	0.00999
8. (RFIII) (Rainy days III)	0.00297	0.01393
9. (RFIV) (Rainy days IV)	-0.00233	0.00196

$R^2 = 0.85$

Table 2.4. Probabilities of incidence of grain mold for hybrid CSH-2 predicted from the climatological data for Hyderabad (data base 1901-1970).

Predicted mold score	Number of years	Probability of incidence (%)
0-1	5	7
1-2	3	4
2-3	7	10
3-4	12	17
4-5	13	61

improvement brought about in the prediction of soil water is shown in Figure 2.1 for a nonirrigated sorghum crop on a deep Vertisol at ICRISAT Center.

Training Provided

Trainees from India, Mexico, Brazil, Thailand, Mali, Malawi, and Upper Volta spent 1-6 months at ICRISAT learning various methodologies for analysis of climatic data.

A week-long preplanning meeting was held at ICRISAT Center preceding the 'ICRISAT/WMO Symposium/Planning Meeting on the Agrometeorology of Sorghum and Millet' which was attended by participants from Kenya, Malawi, Botswana, Upper Volta, Niger, Mali, Zambia, Brazil, Mexico, Sri Lanka, Thailand, and India. The participants evaluated using data from their countries the operational models and methodologies developed and available at ICRISAT Center for climatic analysis and evaluation of crop potential.

Project III: Microclimatological and crop phenological investigations in the crop canopies

Objective and scope

1. To evaluate the degree of difference in the efficiency of conversion of Photosynthetic Photon Flux Density (PPFD) into dry matter in different crop canopies.

2. To evaluate the plant and environmental factors which might determine the differences in the water use efficiency of crops under different cultural practices.

3. To measure the changes in the components of energy balance, i.e., net radiation, soil heat flux and sensible heat flux over different crop canopies for estimating actual evapotranspiration.

4. To observe the phenological changes in crops under different cultural practices.

5. To study the quantitative changes in stomatal conductance, leaf-water potential and leaf temperature of crops with changes in the soil and atmospheric continuum.

Achievements

a. Light use efficiency of crop canopies

1. Data collected over 32 months on daily solar radiation (RS) and photosynthetically active radiation (PAR) at ICRISAT Center were used to evaluate the relationship between RS and PAR. Daily total measurements over 900 days gave a near constant PAR/RS ratio of 0.48 ± 0.05; and the monthly values gave a ratio of 0.47 ± 0.02. This study confirms that a PAR/RS ratio of 0.5 given for high and

mid-latitude conditions can be used for low latitudes also with an acceptable range of error.

2. Measurements of profiles of PPFD and leaf area index in sorghum, pigeonpea, maize and maize/pigeonpea were used to develop predictive equations for estimation of intercepted radiation using the Bouguer-Lambert law. As shown in Fig. 2.2 for maize and sorghum, the equations were useful to predict intercepted PPFD by the canopy.

3. Using data collected on solar radiation and dry matter production by sorghum in the rainy and postrainy seasons over a five year period from 1977 to 1981, comparisons were drawn between potential productivity and actual productivity of sorghum in three growth phases i.e., GS1, GS2, and GS3 in the rainy and postrainy seasons (Table 2.5). Actual productivity of sorghum in the rainy season was 20% of the net potential productivity while it was only 11% in the postrainy season. The largest difference in actual productivity between the two seasons occurred in the GS2 and GS3 phases.

4. Using the relationship between cumulative intercepted PPFD (MJ/msq) and dry matter (g/msq), efficiency of conversion of intercepted radiation into dry matter was computed for sorghum, millet, maize, pigeonpea and maize/pigeonpea under different cultural practices (Table 2.6). Maize/pigeonpea was the most efficient canopy in the production of dry matter per unit intercepted PPFD followed by millet, maize, sorghum and pigeonpea. Sorghum grown during the rainy season showed a higher efficiency than the postrainy season crop.

5. Using the available data on light interception measurements (n = 30) for sorghum, a simple model for prediction of dry matter production was evaluated and incorporated in the dynamic grain sorghum simulation model (SORGF). A similar approach is under evaluation for predicting dry matter production by millet.

b. Evaluation of plant and environmental factors in crop water use efficiency

1. For the postrainy season sorghum, strategies designed to maximize soil water availability and utilisation (particularly during grain filling) are more important than those promoting better light interception. For example, application of 11 cm of water enabled a postrainy sorghum crop on the Vertisols to produce 0.93 g/msq of dry matter with an extraction rate of 321 mm of water while the nonirrigated crop used 213 mm of water to produce 0.51 g/msq of dry matter. For a postrainy season continuously irrigated sorghum grown on the Alfisols, a water use efficiency of 20 kg/ha/mm was associated with a light use efficiency of 0.60 g/einstein of PPFD while a sorghum crop under terminal stress had a water use efficiency of 11.8 kg/ha/mm and a light use efficiency of 0.28 g/einstein during a 20 day stress period.

2. The relative contributions of soil evaporation and transpiration from the crop have a significant effect on the canopy evapotranspiration and water use efficiency. Early canopy growth

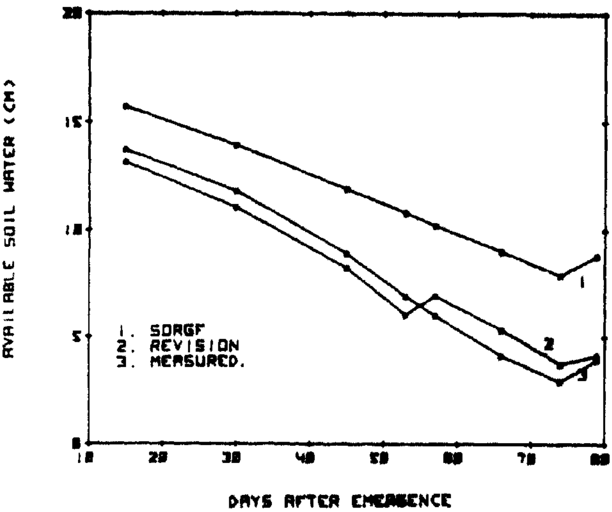


Fig. 2.1. Seasonal changes in the available soil water for nonirrigated sorghum in a deep vertisol.

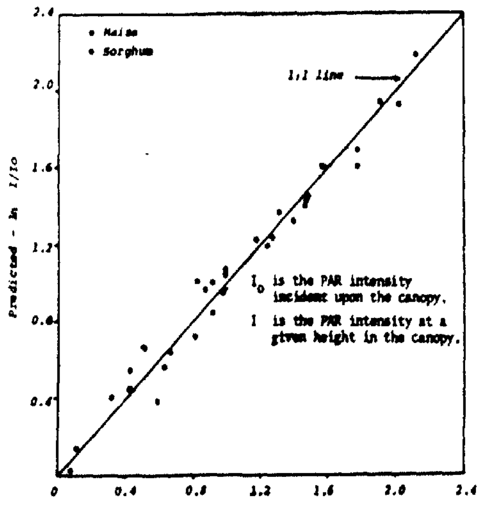


Figure 2.2. Relationship between measured Y and predicted Y for maize and sorghum.

Table 2.5. Net potential and actual productivity (g/m²) of sorghum in three growth phases during the rainy and postrainy seasons at ICRISAT Center (Data averaged over 1977 to 1981).

Parameter	Growth phases GS1	GS2	GS3	Total
Rainy season:				
Total solar radiation (ly)	8754	12769	13254	34777
CV (%)	18	12	8	7
Net potential productivity (g/m^2)	1375	2005	2081	5461
CV (%)	18	12	8	7
Actual productivity (g/m^2)	39	582	473	1094
CV (%)	57	31	44	17
Productivity (% of net potential productivity)	2.8	29.0	22.7	20.0
Postrainy season:				
Total solar radiation (ly)	10328	17460	16790	44578
CV (%)	17	8	7	6
Net potential productivity (g/m^2)	1621	2741	2636	6998
CV (%)	16	8	7	6
Actual productivity (g/m^2)	41	436	294	771
CV (%)	76	28	49	30
Productivity (% of net potential productivity)	2.5	15.9	11.2	11.0

Table 2.6. Conversion efficiency of photosynthetically active radiation (PAR) for different crop canopies.

Crop	PAR conversion efficiency (gm of dry matter/MJ of PAR)
Maize/pigeonpea	4.28
Millet	3.60
Maize	3.13
Sorghum	3.00
Pigeonpea	1.06

and development of maximum leaf area index increase the canopy demand for water through increased transpiration. For a postrainy season groundnut crop, stress imposed from emergence to appearance of first pegs could reduce the canopy transpiration through reduction in leaf area index but did not reduce the water use efficiency. However when stress was imposed after full leaf area development, the transpirational demand was very high; the moisture supply was inadequate and the water use efficiency was low (Table 2.7).

3. In an investigation on the combined effects of soil moisture stress in the root zone and atmospheric evaporative demand on the growth and yield of chickpea, we found that lower air temperatures and low atmospheric demand during the period from flowering to maturity of chickpea favoured early planted chickpea. Under late planting, high air temperatures and increased vapor pressure deficit led to poor pod setting and reduced yields. Hence the efficiency of applied water was low (Table 2.8).

4. Vapor pressure deficit is an important environmental factor modulating the influence of soil moisture stress on the transpiration rate of groundnut. With a water application rate of 670 mm, transpiration was not reduced even up to a saturation deficit of 10 mb. However under reduced supplemental water application (increasing soil moisture stress) transpiration rates decreased even at a low saturation deficit of 5 mb.

5. It was shown that under adequate soil water availability in irrigated sorghum, stomata continue to respond to irradiance. In nonirrigated sorghum, stomatal conductance was greatly reduced and no longer responded to increasing irradiance.

6. Increased availability of soil water at the time of early vegetative growth and flowering of millet was found to increase the water use efficiency when compared to the water availability at the time of grain filling.

Table 2.7. Effect of stage of growth at which water stress is imposed on the leaf growth and water use efficiency of groundnut.

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

Table 2.8. Water use efficiency of two chickpea cultivars at various sowing dates and irrigation levels.

Date of sowing	Water use efficiency (kg/ha/mm of water applied)					
	Annigeri			L-550		
	Io	I1	I2	Io	I1	I2
20 Oct	15.7	9.3	9.0	9.6	6.6	8.3
04 Nov	10.7	8.1	9.7	7.7	7.1	8.6
19 Nov	8.2	6.8	9.5	5.2	6.4	6.8
04 Dec	9.7	6.4	7.2	6.7	4.9	4.6
Mean	11.1	7.6	8.8	7.3	6.2	7.1

Io: No irrigation
I1: Two irrigatins 30 and 70 DAS
I2: Four irrigations 30,50,70 and 90 DAS.

c. Energy balance studies:

1. Diurnal variations in the net radiation and solar radiation were monitored over irrigated and nonirrigated sorghum, chickpea and groundnut crops during the postrainy seasons of 1977 to 1982. The difference in the net radiation between the irrigated and nonirrigated treatments could account for the difference in the transpiration rates. For example, integrated over the day,the difference in net radiation between irrigated and nonirrigated sorghum was 31 ly/day, sufficient to account for more than 0.5 mm of higher transpiration rate in the irrigated sorghum as compared to that of the rainfed crop.

2. Using the detailed measurements of net and solar radiation and linear regression techniques, equations were developed to estimate net radiation from solar radiation over sorghum, chickpea and groundnut (Table 2.9).

3. Albedo, an important input in simulation models, was measured at 15-minute intervals on a diurnal basis throughout the growing season over bare soil and sorghum, millet and groundnut under different moisture regimes. Bare soil albedo was initially low when the soils were wet (Table 2.10) and increased steadily with increasing soil dryness. Albedo of three sorghum cultivars grown on an Alfisol varied from 0.26 to 0.19 from 44 DAE to 79 DAE. Irrigated sorghum showed lower albedo when compared to nonirrigated sorghum. Albedo of three millet cultivars varied from 0.16 to 0.21.

d. Plant-water relations

1. Experiments conducted with sorghum, millet and groundnut using the line-source sprinkler irrigation technique during the postrainy and summer seasons during 1978 to 1982 demonstrated clearly the effectivity of this powerful technique in studying the plant water relations under varying profile moisture regimes and growth stages.

2. Measurements of stomatal conductance, leaf-water potential, leaf temperature and transpiration made over the period 1977-82 with sorghum, millet, chickpea, and groundnut under different moisture regimes provided conclusively that plant water deficits can be usefully quantified by means of these measurements.

3. The pressure chamber technique was successfully adopted for the measurement of leaf-water potential of chickpea and was used to monitor the canopy water status with changes in available soil water.

4. Diurnal changes in the canopy temperature of groundnut grown under differential water regimes using a line source sprinkler irrigation during the postrainy season were shown to follow closely the changes in available soil water.

5. Canopy-air temperature differential of chickpea measured mid-afternoon every day throughout the growing season showed a close correlation with the canopy water use, proving that these

Table 2.9. Intercept (a), slope (b) and standard error for regression of net radiation over sorghum, chickpea and groundnut on solar radiation.

Crop	Treatment	a	b	S.E.* of b	r^2
Sorghum	Non Irrigated	-0.037	0.636	0.009	0.95
Sorghum	Irrigated	-0.030	0.661	0.013	0.94
Chickpea	Non-Irrigated	-0.037	0.642	0.012	0.95
Chickpea	Irrigated	-0.024	0.641	0.011	0.96
Groundnut	Narrow rows (30 cm)	-0.027	0.531	0.016	0.86
Groundnut	Wide rows (90 cm)	-0.017	0.507	0.014	0.88

*S.E. = Standard error

Table 2.10. Albedo of bare Vertisols and Alfisols in a drying cycle at ICRISAT Center, India.

Days after wetting	Vertisols	Alfisols
2	0.13	0.19
4	0.15	0.19
6	0.20	0.24
8	0.22	0.29
10	0.22	0.29

measurements could be used to quantify the moisture stress effects on chickpea. The 'Stress Degree Days' (SDD) computed from the cumulative canopy-air temperature differentials of chickpea measured over a three year period (1979-82) showed a close correlation with measured yields (Fig. 2.3).

6. Measurements of leaf transpiration under field conditions proved useful to monitor and differentiate the stress induced adaptation ability between different genotypes of sorghum.

Training Provided

Two research scholars have completed their Ph.D. dissertation work relating to the following aspects:

(1) Canopy architecture-light interception; water use and dry matter production relationships in pearl millet.

(2) Response of groundnut to moisture stress in rainy and postrainy seasons.

Four in-service trainees have undergone training in soil-plant-water relations and instrumentation.

We assisted in a new post-graduate course on plant-water relations at AP Agricultural University, Rajendranagar.

Project IV: Studies on crop-weather modeling

Objectives

1. To use crop weather model as a framework upon which to interact with other ICRISAT programs and disciplines to bring together information on different aspects of crop growth giving a unified picture and stimulating collaboration and team work.

2. To develop a quantitative understanding of crop response to the environment leading to yield prediction.

3. To identify areas where quantitative knowledge is lacking and is needed to plan alternative strategies for cropping, land use and water management to increase and stabilize crop production in semi-arid tropical areas (where location specificity is strongly exhibited).

4. As a means to answering the classical "what if" questions or more appropriately to optimise resources whether they be physical, h[illegible] or econ[illegible]ic.

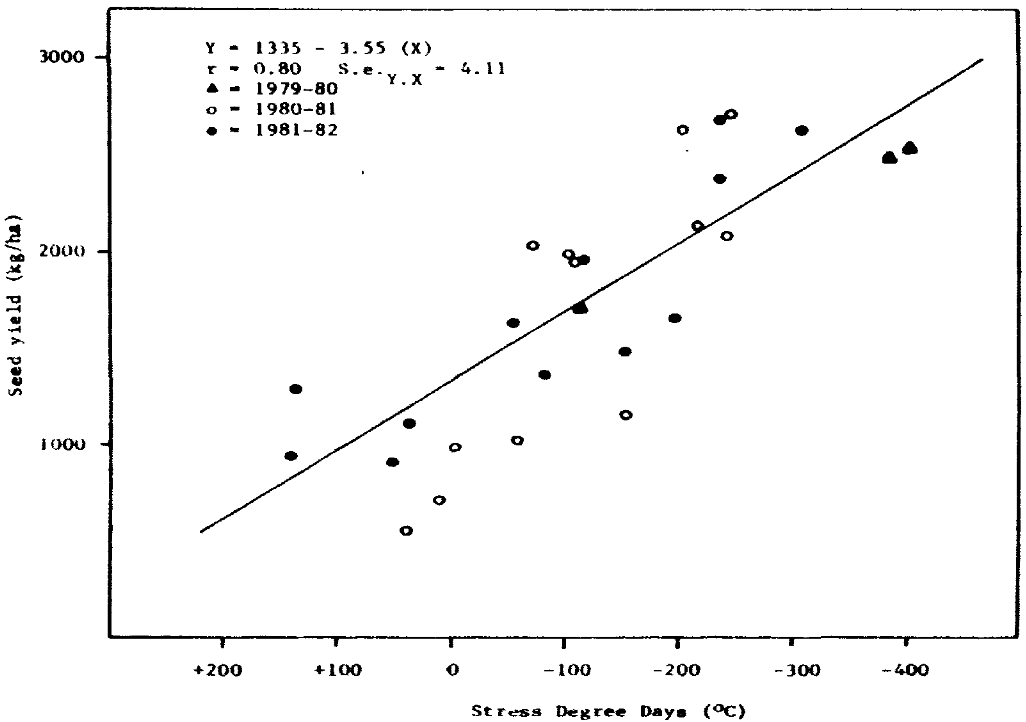


Figure 2.3. Relationship between seed yield and stress degree days (CSDD) of chickpea var. Annigeri grown at ICRISAT Center during three seasons.

Achievements

a. Sorghum Modeling

1. Dynamic simulation was identified as the approach to be adopted for crop-weather modeling research at ICRISAT. SORGF--a dynamic growth simulation model developed at Texas A & M University was adopted to the computer system at ICRISAT.

2. SORGF model was tested with preliminary data available. The need to collect uniform data sets over several locations to test and validate the model was felt. A collaborative multilocation project (India, USA, Thailand) on sorghum modeling was started. A manual for collection of meteorological, crop and soil data for crop-weather modeling research was prepared and circulated to all cooperators.

3. Some subroutines in SORGF viz., phenology,leaf growth, soil water and light interception were identified for detailed examination and for suitable modifications. To simulate sorghum responses to water stress, field experiments on moisture stress affects in sorghum were initiated.

4. Using all the available data on sorghum, existing subroutines on light interception and dry matter production were evaluated and modified to improve the predictability.

5. A layered soil water balance model was incorporated in the sorghum model to improve model simulation of field water stress. Subroutines on phenology, partitioning of dry matter, and leaf development were suitabley modified. The revisions made in SORGF improved the predictability of the model.

6. Experiments on the sorghum response to moisture stress were continued. Since the model validation over the past years mainly considered three genotypes i.e. CSH-6, CSH-8 and M-35-1, additional genotypes not included earlier in the modeling experiments were included to test the model versatility.

7. Further improvements in subroutines like phenology, dry matter partitioning, soil water, etc., are made using other data sets available.

8. The revised algorithms for calculating phenology were tested against 10 independent field data sets. The root mean square error (RMSE) for SORGF and the revised model are given in table 2.11. The RMSE for all the three stages were considerably reduced using the revised algorithms compared to the original SORGF model and thus simulating the phenological events close to the actual values.

9. Regression coefficients relating the product of leaf length and maximum width to leaf area of sorghum for four genotypes grown at ICRISAT Center are given in Table 2.12. This information is very useful where facilities for measuring leaf area directly are not available.

Table 2.11. Root mean square error (days) for different growth stages for 10 independent field study data sets.

Stages	SORGF	Revision
GS1	7	4
GS1+GS2	7	6
GS1+GS2+GS3	18	3

2.12. Regression coefficients relating the product of leaf length and maximum width to leaf area of sorghum.

Season	Genotype	No. of Observations	Regression coefficient (b)	R^2
1979 rainy	CSH-1	512	.6973	.99
	CSH-6	447	.7111	.98
1979 postrainy	CSH-8	3135	.6829	.98
	M-35-1	3589	.6654	.92
1980 rainy	CSH-1	1728	.7017	.98
	CSH-6	2117	.7129	.98
1980 postrainy	CSH-8	2479	.6911	.97
	M-35-1	2101	.7101	.98

Y=b.L.W. where Y, L, and W are leaf area, leaf length and maximum width respectively.

10. The revised SORGF model was used to obtain first approximation answers to questions on screening environments for sorghum production, selecting appropriate date of sowing, and to determine when and how much irrigation water to be applied to achieve optimum grain yield. Simulation results, were compared with the observed data (Fig. 2.4) obtained from the date of planting experiments conducted by the plant breeders on sorghum during the 1979-80 postrainy season at Patancheru to find optimum date of sowing. Lower grain yield was obtained with the delay in planting, suggesting early planting is the best under the particular agroclimatic environment; similar conclusion can also be drawn from the simulation results. The highest yield (4,527 kg/ha) was obtained with 12 September planting. The reduction in yield was 85% with 29 November planting.

11. The revised model was used by Huda et al. (1984) to construct cumulative probability distribution of sorghum grain yields for two locations (Bamako and Tombouctou) in Mali. Historical weather data (rainfall and temperature) for 49 and 43 years for Bamako and Tombouctou were used respectively. Analysis showed that under adequate management conditions, sorghum can be grown rainfed in Bamako but in Tombouctou without irrigation sorghum cultivation could involve a high element of risk.

12. The mean annual rainfall for Bijapur, Karnataka is 646 mm. Sorghum grain yield response to simulated drought stress levels at different growth stages showed that the model is sensitive to stress levels with varying intensities and durations. The results showed that if drought stress could be released at establishment of the crops as well as at anthesis, it is possible to achieve average grain yield of 3200 kg/ha under adequate management.(Table 2.13).

13. Data obtained from collaborative multilocation sorghum modeling experiments were analysed to develop simple models for predicting sorghum grain yield. Models that included one or more of the independent variables namely soil water at planting, rainfall, mean temperature, solar radiation, evapotranspiration for the whole crop growing season and for three growth stages were developed from 48 data sets. The three growth stages included; emergence to panicle initiation (GS1), panicle initiation to anthesis (GS2), and anthesis to physiological maturity (GS3). Stepwise regression techniques and Cp criterion were used to select models. No single environmental factor sufficiently explained variability in sorghum yield. The following model which had R^2 of 0.73 was selected based on high R^2 and low Cp criterion. This model when tested with 11 independent data sets could explain 59% yield variation.

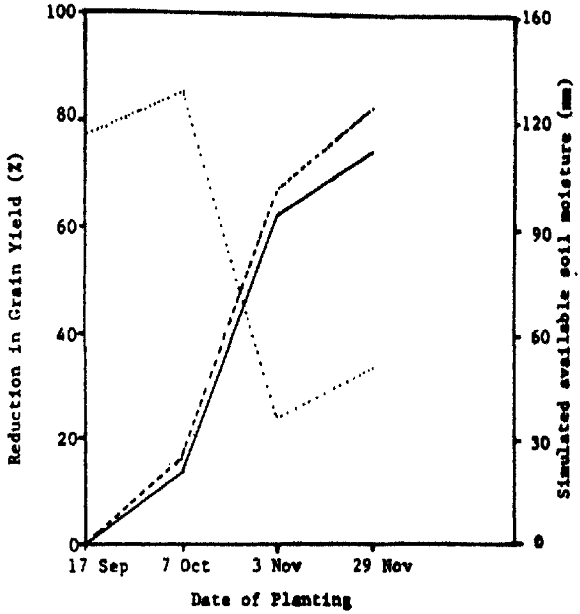


Figure 2.4. Comparison between simulated (---) and observed (——) reduction in grain yield of sorghum (Cv. CSH-1) due to delay in planting under residual moisture during the postrainy season of 1979-80 at Patancheru. Data on simulated available soil moisture (...) are also shown.

Table 2.13. Sorghum grain yield response to simulated stress levels at different growth stages during the postrainy season at Bijapur, Karnataka (simulation base: 16 years).

Stress levels at			Grain yield (kg/ha)		
Sowing	Panicle initiation	Anthesis	Mean	Maximum	Minimum
X	X	X	2128	4263	1488
+	X	X	2181	4263	1488
+	+	X	2409	4264	1668
+	X	+	3211	4263	2346
+	+	+	3433	4264	2580

No water application;

\+ Stress released by applying 50 mm of water.
Sowing date was assumed to be 15 September.

$$Y = 782.11 + \underset{(1.9345)}{7.8741}\,SW - \underset{(0.132)}{0.2403}\,R2T2 - \underset{(0.0354)}{0.1232}\,R2ET2 + \underset{(0.009)}{0.0539}\,R3ET3 + \underset{(0.1322)}{0.719}\,R2SR2$$

Where Y = Observed grain yield (kg/ha)
SW = Available soil water (mm) at planting
R2T2 = Product of total rainfall (mm) and mean temperature (C) in GS2
R2ET2 = Product of total rainfall (mm) and evapotranspiration (mm) in GS2
R3ET3 = Product of total rainfall (mm) and evapotranspiration (mm) in GS3
R2SR2 = Product of total rainfall (mm) and solar radiation (ly/day) in GS2

b. Pearl Millet Modeling

1. Pearl millt was the next choice for extending our modeling efforts. To develop a model for simulating pearl millet growth and development, we started experiments involving several genotypes and treatments (moisture, methods of planting, row spacing) inthe 1981 rainy season.

2. A framework for a pearl millet simulation model was developed (Fig. 2.5) and a preliminary model was assembled. Minimum data set required for this model was identified and these data are being collected from experiments.

3. Variations in the duration of different phenological stages of pearl millet genotypes (BJ-104, ICH-412 and Ex-Bornu) were studied (Table 2.14). The maximum and minimum number, mean number of days, and the coefficient of variation for three growth stages for one genotype (BJ-104) pooled from different experiments conducted in different seasons at ICRISAT Center are given in table 2.15. Greater variability in GS1 suggests that variation in temperature and daylength should be examined to explain the variability in GS1. The relationship between growing degree days (GDD) and the daylength showed that with the increased daylength, the duration of GS1 also increased (Fig.2.6). When daylength correction was introduced, variability in GS1 was reduced to 10%.

4. The relationship between intercepted PAR and dry matter during the growing season was studied for three pearl millet genotypes (BJ-104, WC-C75 and ICMS-7703). 3.96 g of dry matter was produced for WC-C75 per MJ of radiation intercepted up to anthesis (GS2); after anthesis, dry matter production dropped to 1.6 g per MJ of radiation intercepted (Fig. 2.7).

5. Total dry matter and its partitioning to leaf, culm, head, and grain were periodically estimated throughout the growing season. Combined total dry matter of main culm and tillers and its partitioning to different plant parts in genotype BJ-104 were given in Figure 2.8. The prediction of total dry matter partitioned to various plant parts in genotype BJ-104 grown in different seasons varied with growth stags (Table 2.16).

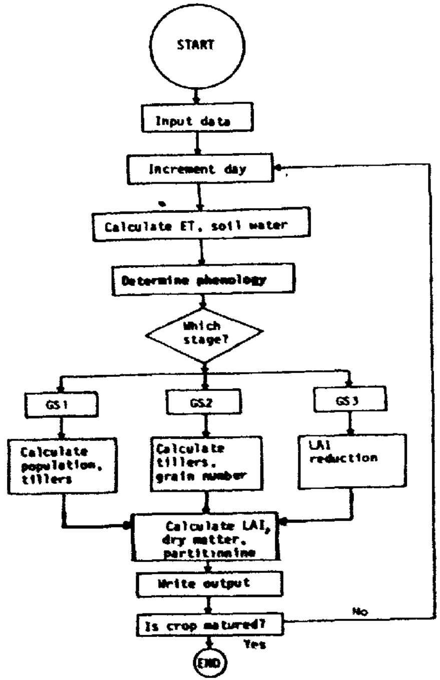


Fig2.5. A suggested flowchart for pearl millet simulation model

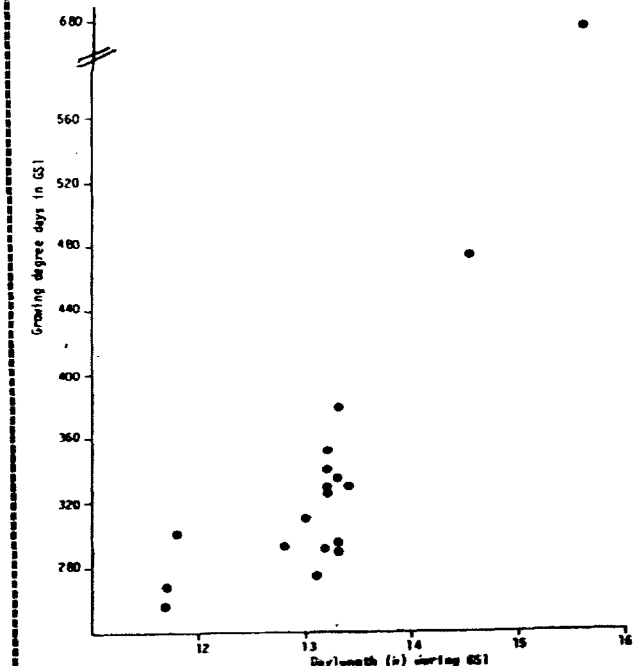


Fig2.6. Relationship between growing degree days for GS1 and daylength during GS1 for pearl millet genotype BJ-104 at Patancheru.

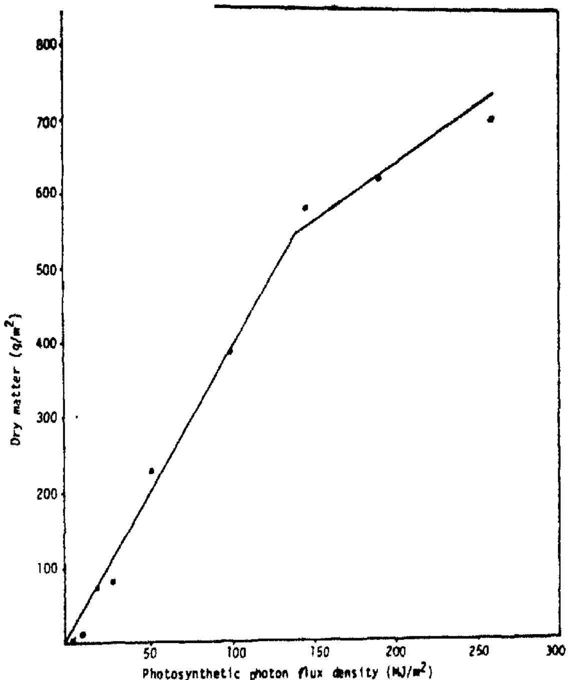


Figure 2.7. Relationship between dry matter and intercepted photosynthetic photon flux density (PPFD) for pearl millet genotype WC-C75 grown during the 1981 rainy season at Patancheru.

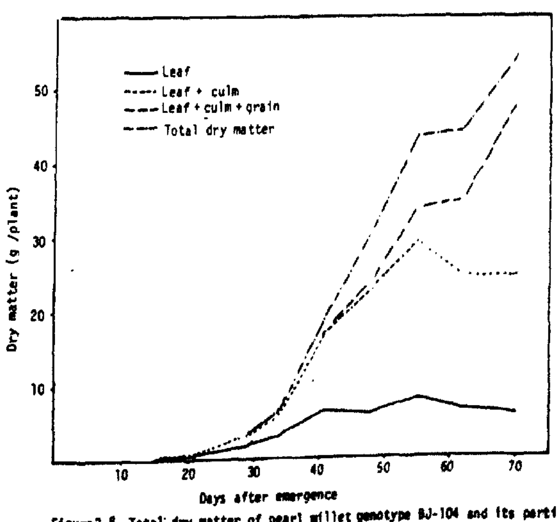


Figure 2.8. Total dry matter of pearl millet genotype BJ-104 and its partitioning to different plant parts during the 1981 rainy season at Patancheru.

Table 2.14. Duration (days) of growth stages of three genotypes of pearl millet grown in the 1982 rainy season at Patancheru.

Growth stage	Genotype		
	BJ-104	ICH-412	Ex-Bornu
GS1	15	18	18
GS2	25	36	34
GS3	27	28	27
GS1+GS2	40	54	52
GS1+GS2+GS3	67	82	79

Table 2.15. Variation in phenology of pearl millet genotype BJ-104 grown over different seasons at Patancheru.

Growth stage	Maximum	Minimum	Mean	SD	CV (%)
		--days--			
GS1	34	13	18	5	28
GS2	36	21	25	3	13
GS3	35	25	30	3	10

Table 2.16. Partitioning of total dry matter (%) at three growth stages of pearl millet genotype BJ-104 grown over different seasons at Patancheru.

Plant part	Panicle initiation	Anthesis	Maturity
Leaf	66	30	10
Culm	34	54	30
Head		16	16
Grain			44

Training

Three in-service trainees from Thailand, Niger and Malawi worked with this project in 1980, 1981 and 1983 respectively.

Cooperating scientists and technicians from eight locations in India and one location in Thailand were trained about methods of data collection, the use of instrumentations and the use of simulation models.

IV. SOME IMPORTANT CONTRIBUTIONS

1. Revised SAT Maps of India, NE Brazil and Africa

The classification of climate provides a useful index of the ecological conditions, agricultural potentialities, and general environment of a location. Based on Troll's classification (World Maps of Climatology, 1965, Springer-Verlag, Berlin), the semi-arid areas are defined as those with two to seven humid months (months in which mean rainfall exceeds potential evapotranspiration) in the warm season. However Troll's World Maps of Climatology did not show the number of locations on which his global survey was based. These maps place the desert regions of northwest India and the northern parts of West Africa in the semi-arid zone. Therefore, we revised the SAT maps of India, northeast Brazil, and Africa, using an enlarged data base.

This revision, based on data from about 300 locations, places 88% of the geographical area of India in the tropics (Fig. 3.1). The dry semi-arid tropics cover about 57% of India. The revised SAT map of northeast Brazil is based on data from 180 locations, while the revised map of Africa used data of 300 locations in West Africa and 180 locations in the rest of Africa.

2. Rainfall Characteristics of Niger

Daily rainfall data for 78 locations supplied by the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) Paris, show a characteristic decrease in the amount of rain and the duration of the rainy season with increasing latitude (Fig. 3.2). Only in the Gaya and Dosso regions are the average 4-week rainfalls above 100 mm for a 4- or 5-month cropping season.

From a proabibility analysis of the 38 stations having rainfall records of 15 years or more, maps showing the spatial and temporal distribution of the probabilities of receiving 5, 10, and 20 mm of rain in each week were prepared.

From another analysis, maps were prepared that show the amounts of rain that would be received at 25 and 50% probabilitiy levels for each 4-week period. These maps also show the characteristic decrease in rain from south to north and its seasonality, indicated by the annual rainfall isohyets.

When used with data on the water storage characteristics of the soil and the rooting behavior and developmental phenology of the crop, the probability analyses provide a basis for evaluating

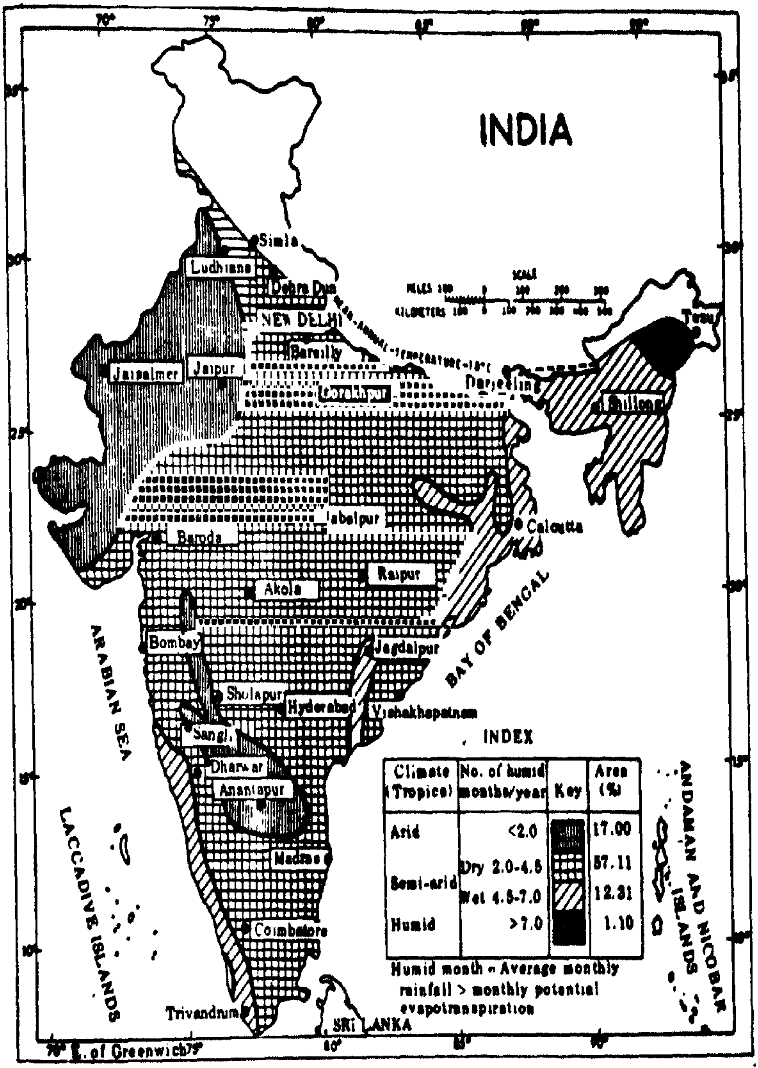


Fig3.1. Semi-arid tropics of India (revised using Troll's approach).

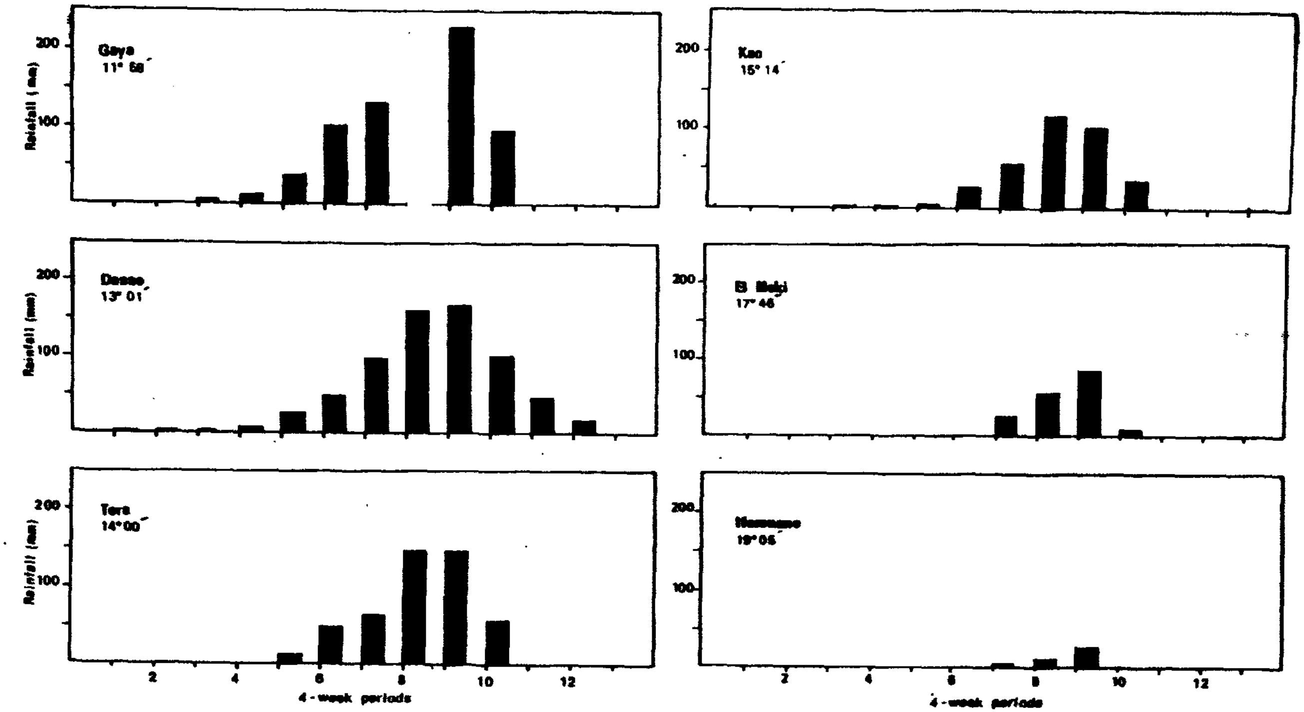


Fig 3.2. Latitudinal distribution of 4-week period rainfall (mm).

in stochastic terms the agronomic feasibility of alternative systems of cropping. A complete report of this study is available (ICRISAT Information Bulletin No. 5).

3. Rainfall probabilities

We have computed rainfall probabilities for 75 locations in India, 77 locations in Niger and 53 locations in Botswana based on weekly data. These data have been used to pinpoint the likely periods of sufficient moisture input or drought during periods associated with critical stages of crop development.

Many agricultural decisions/operations revolve around the probabilities of receiving a given amount of rainfall. Such decisions influence the pattern and quantum of investments in modern inputs. Large-scale operational planning often requires interacting decisions with respect to resources, manpower needs, available work days, etc. A comprehensive idea regarding the probabilities of rainfall is essential in view of the economic implications of weather-sensitive operations. Computations of rainfall probability are not a one-time exercise. Each year adds to the data base and to the soundness of probability figures. Our efforts in this direction will continue.

The mean monthly rainfall data do not yield information on the dependability of precipitation to meet potential demand. Hargreaves (1975) has defined dependable precipitation (PD) as the amount of rainfall which could be received at 75% probability. It is evident that the dependable precipitation amounts are much lower than the mean rainfall received, and so one must consider dependable precipitation rather than mean rainfall. The moisture availability index--defined as the ratio of dependable precipation to mean rainfall--shows that adequate moisture is available for the rainy months of July, August, and September at Hyderabad. These analyses, however, do not give information on the continuity or breaks in rainfall and its adequacy to meet environmental demand on a short-term basis.

One application of such analysis is to delineate the probability of success of different types of crops. Our studies on the relationship between dependable rainfall and suitability of crops for selected locations in India (Fig. 3.3) show that in areas with a high dependability of rainfall (e.g. Varanasi) the growing season is about 14 weeks at the 70% probability level. Dryland determinate crops could be successfully grown at this location. At Bangalore, on the other hand, even if one chooses a lower probability level of 60%, only indeterminate crops could be grown.

4. Dry seeding of rainy season crops in the SAT

The areas of dependable rainfall can be identified using the methodology of rainfall possibility. An example is given in Figure 3.4. The areas of deep Vertisols in India where farming systems technology developed at ICRISAT would probably be successful are delineated. This methodology of rainfall probabilities could also be used to demarcate the risk associated

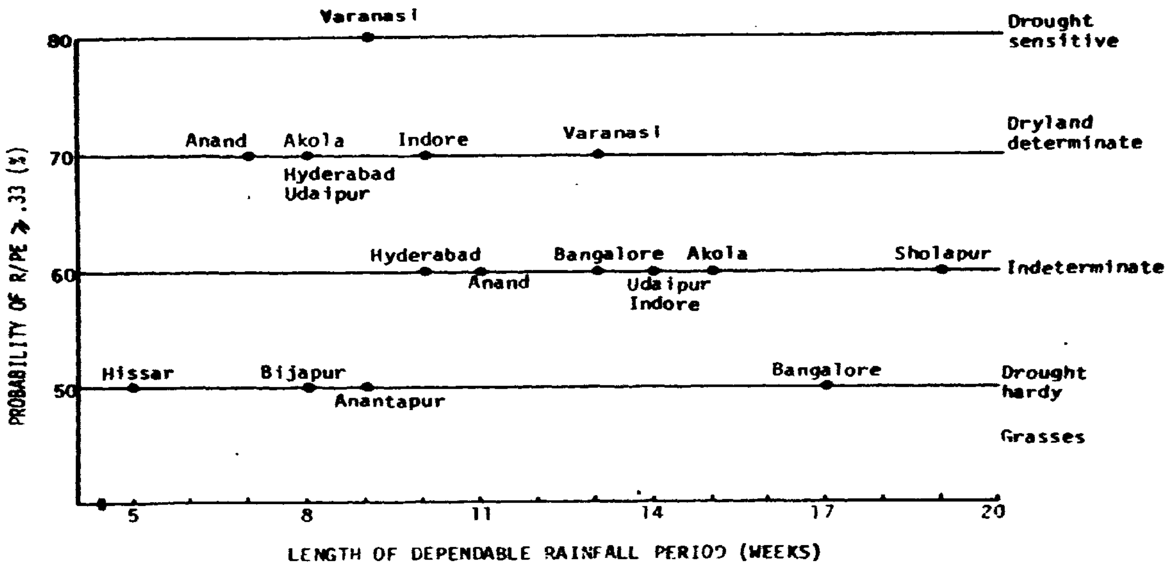


Fig 3.3. Relationship between dependable rainfall and suitable crops at selected locations in Indian SAT.

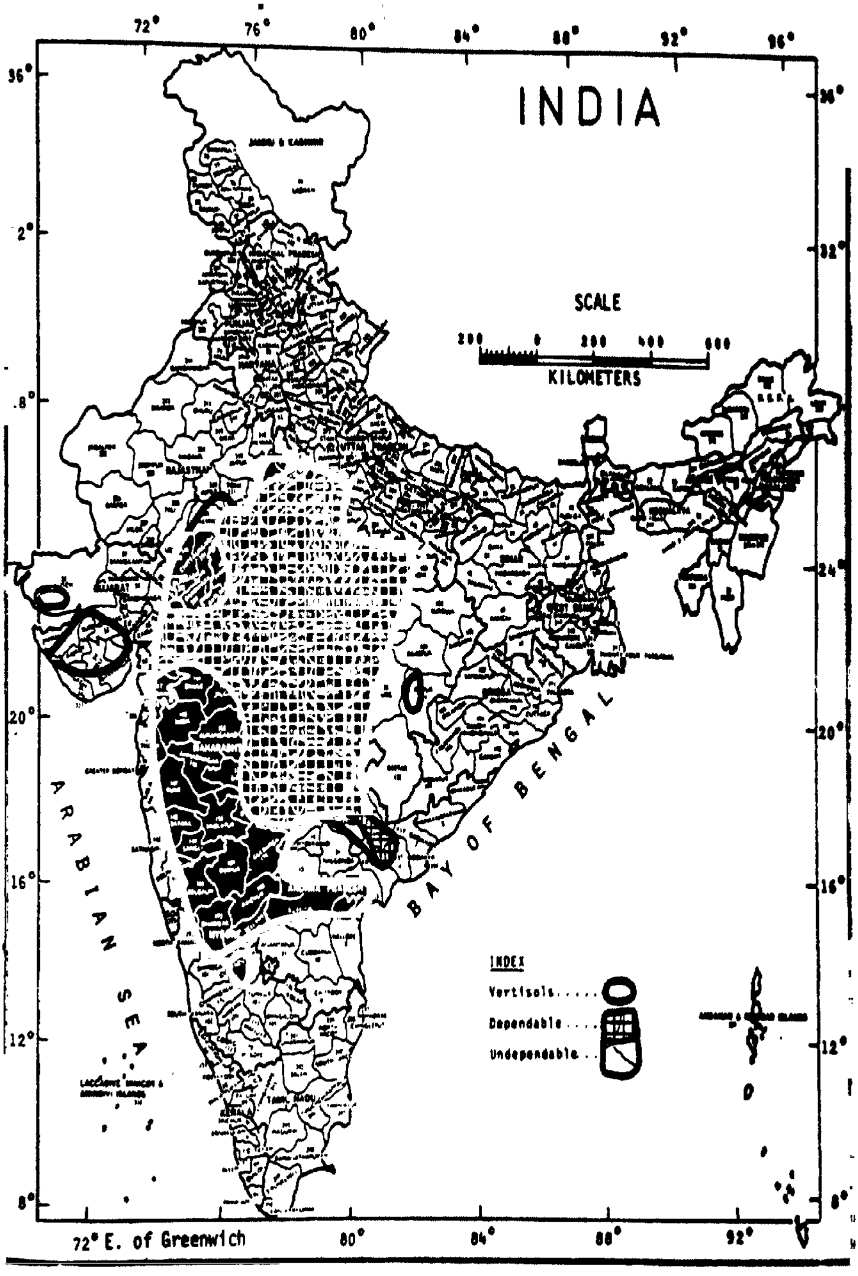


Fig 3.4. The Vertisol areas of India where rainfall is dependable and undependable.

with dry seeding of rainy season crops in the SAT. Dry seeding is an important component of the improved technology for deep Vertisols. The dry seeding period for rainy season crops will be a couple of weeks ahead of the onset of seasonal rainfall which is abrupt at Hyderabad and the probabilities of continuance of rain are high. Therefore this location offers excellent scope for dry seeding. At locations such as Sholapur, the onset of rains at the commencement of the season is not marked and the chances of the continuity of rains after onset are not as high. Such locations therefore pose a risk to dry seeding. Based on rainfall probability analysis of more than 90 stations in India, the areas offering possibilities of dry seeding on Vertisols are mapped. Again the methodology is to use the dependability of precipitation and soil moisture storage. It appears that one could distinguish very easily the risk associated with dry seeding possibilities at different locations in the deep Vertisols spread over large areas in India. For example, the technology for dry seeding of crops generated at ICRISAT Center could be translated with a fair degree of success to Akola, Jabalpur, Indore, and Udaipur, whereas at Sholapur, Dharwar, Jalgaon, and Ahmedabad the likely success of dry seeding is low due to the high risk associated with it.

5. Constant Probability Analysis for Monthly Rainfall

In most cases one of the first things that one wants to know for a location is its agricultural potentialities for dryland agriculture. Hargreaves method could be adopted as an index for measuring water deficiencies and excess. Hargreaves suggested the following classification for dryland agriculture:

MAI = 0.00 to 0.33 moisture very deficient
= 0.34 to 0.67 moisture moderately deficient
= 0.68 to 1.00 moisture somewhat deficient
= 1.01 to 1.33 moisture adequate
= >1.34 excessive

MAI can provide an approximation of water availability.

The constant probability analysis can be carried out by using Incomplete Gamma distribution functions. A computer program to carryout such analysis is available at the ICRISAT computing unit.

A handbook on the Rainfall Climatology of West Africa covering 4.2 million sq. km has been prepared. It gives information on rainfall, PE and dependable precipitation for over 280 locations located between 7 and 15 north latitude and 17 west and 24 east latitude. An examplified data set for a few locations in Mali is shown in Table 3.1. The data show that at Bamako the MAI exceeds 0.33 for 4 months from June to September; the moisture availability is excessive in the months of July, August, September. On the other hand the data for Douentza and Gao reveal that MAI exceeds 0.33 value only for two months of July and August and at Gao only in the month of August.

Table 3.1. Mean monthly rainfall (P), dependable precipitation (PD), and potential evapotranspiration (PE) at three locations in West Africa.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Bamako	P	0	0	4	17	64	142	241	325	213	63	9	0	107
	DP	0	0	1	5	33	106	195	256	157	27	0	0	
	PE	143	160	204	198	185	152	125	113	119	135	128	134	179
	MAI				0.02	0.18	0.70	1.56	2.26	1.32	0.20			
Douentza	P	0	0	2	4	17	67	132	167	87	19	0	0	49
	DP	0	0	0	1	4	39	97	126	50	4	0	0	
	PE	145	164	210	223	214	198	160	143	146	154	140	130	202
	MAI					0.02	0.20	0.61	0.88	0.34	0.03			
Gao	P	0	0	0	1	6	25	72	111	36	5	0	0	258
	DP	0	0	0	0	1	10	46	76	17	2	0	0	
	PE	141	165	213	221	246	227	200	171	182	181	147	141	2235
	MAI						0.04	0.23	0.44	0.09	0.01			

Such an analysis could clearly demonstrate the agricultural potentials of the area, the length of the core growing season and climatic moisture balance for the rainy months. For example a 120-day crop could be easily grown at Bamako, a 60-day crop at Douentza; the Gao area is not suitable for crop land agriculture as there the rainy season is too short.

6. Field work-day probability

Field work-day probabilities at harvest time can be estimated from rainfall probabilities. These probabilities have been computed for millet (Pennisetum americanum) and sorghum (Sorghum bicolor) crops at different durations (Table 3.2). The importance of such field work-day probabilities in relation to harvest of sorghum in two soil types is shown in this table. Farmers in this area grow a long-duration sorghum crop of 130 to 150 days duration. There is a high degree of probability for having at least 3 consecutive work-days in either the Alfisols or the Vertisols at harvest time of a long-duration sorghum. Hence there would be no difficulty in harvesting the crop. On the other hand, if one is growing a 90- to 100-day sorghum crop, the possibility of getting into the field for harvest is about 77% in the Alfisols and 29% in the Vertisols.

It is fairly common to have intense rain storms (of at least 60 to 70 mm) in this area in the month of August and September. In the deep Vertisol areas, harvesting a medium-duration sorghum could be a problem. Since the sorghum crop is affected with grain mold and also grain rot during wet weather, 90- to 100-day cultivars of sorghum are not likely to be successful in the Hyderabad Vertisol region unless the crop is grain mold/rot resistant. The analysis of field work-day probabilities shows that it is not only important to grow a good crop but it is also important to harvest the crop at the opportune time.

Table 3.2 Field-work day probabilities at harvest of sorghum and millet crops at Hyderabad

Crop	Duration	3 Consecutive work day probability	
		Alfisols (%)	Vertisols (%)
Millet	65 - 70	50	4
Sorghum	90 - 100	77	29
Sorghum	130 - 150	93	83

7. Stochastic Modeling Using the Water Balance Approach

From water-balance analysis carried out as per CSIRO systems, it is apparent that in shallow Alfisols there is very little soil moisture storage for crop use over extended drought periods. In deep Alfisols and medium Vertisols, there is a fair degree of storage for a fairly longer time during the growing season. Thus, under identical rainfall conditions, the effects of short-term intra-seasonal droughts on crop-moisture status will differ in the three soil types. The amount of water lost as runoff would also differ, and the potential benefits derived from supplemental applications of water would vary with the soil type.

By estimating the amounts of available water in the root zone of crops in relation to potential evapotranspiration demand at weekly intervals, the probabilities of water availability at pre-determined levels can be determined for a particular soil type. A comparison of these with soil moisture availability estimates should give a better appreciation of the 'likely' fitting of crops in a given soil-rainfall-evaporation complex. Figures 3.5a and b depict such an exercise for Hyderabad conditions in typical soils and for short-, medium-, and long-duration crops. It is apparent that a long-duration crop in a soil with 50 mm available water-storage capacity will be exposed to soil-moisture inadequacy at several growth stages, but if the soil-moisture storage capacity were 150 or 300 mm, the risks of

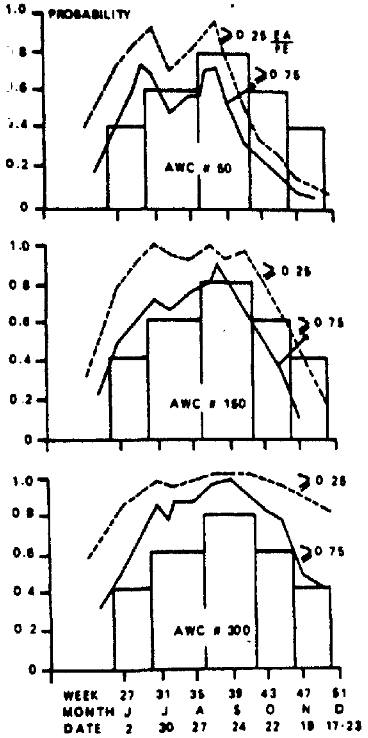


Fig 3.5a. Fitting of a long-duration crop in three soils.

(BARS = CROP WATER REQUIREMENT AND CURVES = WATER AVAILABILITY AT TWO PROBABILITY LEVELS)

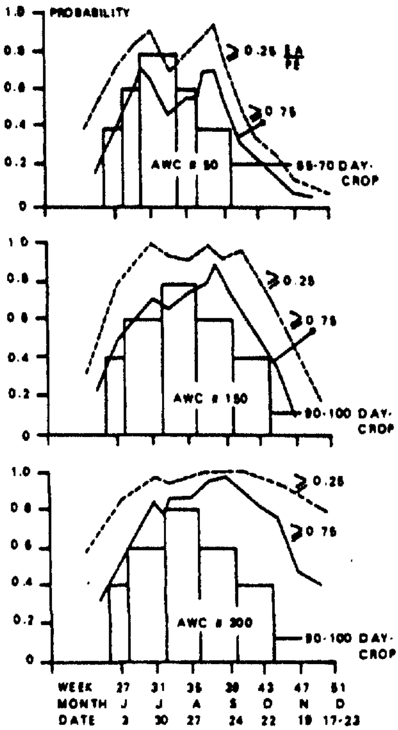


Fig3.5b. Fitting of short – (65 to 70 days) and medium – (90 to 100 days) duration crops in three soils.

(BARS = CROP WATER REQUIREMENT AND CURVES = WATER AVAILABILITY AT TWO PROBABILITY LEVELS) water deficiency are much less. thus one might select for shallow soils a drought-hardy crop (e.g. castor bean, *Ricinus communis*), whereas in deeper or heavier soils a crop with medium sensitivity to drought (such as pigeonpea), would be suitable. Similarly one could fit in short- and medium-duration crops. Effects of changes in seeding dates and the influence of different phenological characteristics on crop performance could also be assessed as first approximation in such analyses.

8. Crop-weather modeling

Studies on crop-weather modeling were initiated in 1978 with the adaptation of the SORGF model from Texas A & M University. A multilocation project on sorghum modeling was also initiated. As the experience with the model increased and the data set became enlarged, several subroutines were revised. These revisions, improved the coefficient of determination (R2) significantly. When pooled data over different seasons and genotypes from ICRISAT Center and other cooperating centers was used to simulate grain yields, R2 improved from 0.27 (SORGF) to 0.74 for revised SORGF. The closeness between the observed and the simulated parameters of sorghum growth is illustrated in Table 3.3. Phenology, light interception, dry matter accumulation, dry matter partitioning, soil water availability were more accurately predicted. Results were shown in the previous section.

Table 3.3. Performance of the revised SORGF model

Parameter of Sorghum (mean of 27)	Observed	Simulated
Grain yield (kg/ha)	3954	3680
Drymatter (kg/ha)	9444	8645
Physiological maturity (DAE)	97	98
Maximum LA1	2.39	3.2
Final LA1	1.24	1.12

The framework of sorghum model is used with modifications to produce a growth model for pearl millet. Modifications include changing the individual leaf concept to leaf area index and developing a tillering subroutine.

V. LOOKING AHEAD

As referred by the Technical Advisory Committee (TAC) while reviewing the Farming Systems Research (FSR) at International Centers (TAC 1978), base data analysis is inimical to the success of any program using the FSR approach. Climate evaluation which includes presentation of general climatic characteristics of different regions and assessment of crop potential is an important first step in planning for the resource-based technologies for improved crop production in the SAT. Our work in this area would place emphasis on the following aspects:

- o Providing meaningful climate classification using different methodologies for outlining crop potentials for different regions and to assist in transfer of technology,
- o Continuing the studies on rainfall climatology to provide first approximation answers to water availability and the associated spatial and temporal variability, and
- o Computing the water balance of different SAT areas so as to evaluate the traditional systems of cropping using the simulated water balance components and to seek alternative technologies for improved crop water use efficiencies.
- o Further refinement in crop-weather modeling on sorghum, millet and groundnut with a view to understand the parameters controlling crop growth across different soil-climate complexes.

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