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CHARACTERIZATION OF ENVIRONMENTS FOR ERGOT DISEASE DEVELOPMENT IN PEARL MILLET[1]

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ABSTRACT

Ergot disease, caused by *Claviceps fusiformis* Loveless, is important in some pearl millet (*Pennisetum glaucum* (L.) R. Br.) growing areas in certain years. Disease development is related to relative humidity ($\geq$ 80%), frequent rain showers, and cloudy days during the preanthesis stage but quantitative information is scarce. In this study, an attempt has been made to use agroclimatic data to characterize pearl millet growing environments for ergot development.

The information on ergot development, based on artificial inoculation, obtained from a multilocational ergot nursery has been superimposed on the pearl millet distribution map of India to show areas with high, medium, and low probabilities of disease occurrence.

A pearl millet growth simulation model was used to identify the susceptible growth stage (e.g., preanthesis) for pathogen infection. We have chosen the following criteria thought to be conducive for ergot development: daily rainfall

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($\geq$ 5 mm), relative humidity ($\geq$ 90% in morning, $\geq$ 70% in afternoon), and sunshine hours ($\leq$ 1 h) for the 4-day preanthesis stage. The percentage of years with at least one day, when one or more of the above criteria were met, ranged from 36 to 70% at Patancheru (high ergot incidence), and from 0 to 33% at Hisar (low ergot incidence). Limitations on the actual disease data for natural infection obtained from these locations are recognized.

More in-depth studies to quantify the relationship between the weather factors and ergot development would be of great value. Such information could be used more effectively in crop simulation models to screen environments for disease development, and to suggest alternate agronomic management practices (e.g., sowing dates, maturity duration of cultivars, etc.) for economic control of ergot in pearl millet.

INTRODUCTION

Pearl millet (Pennisetum glaucum (L.) R. Br.) is a staple food crop of arid and semi-arid India, grown on about 12 million ha, with a total production of nearly 7.5 million t (De and Gautam, 1987). The crop is almost entirely grown under rainfed conditions (i.e., during the monsoon) using low managerial inputs. Pearl millet suffers from a number of diseases caused by fungi, bacteria, viruses, and nematodes. These factors (biotic and agronomic), either individually or in combination, cause significant yield loss. Experimental evidence shows that, given adequate attention, yield levels in a given environment can be substantially increased (De and Gautam, 1987).

Ergot disease, caused by *Claviceps fusiformis* Loveless, is important in some pearl millet growing areas, in certain years, causing substantial yield loss. In addition to reducing grain yield, the disease causes health problems to human beings, livestock, and poultry by contamination of grain with toxic, alkaloid-containing sclerotia of the pathogen.

The primary disease cycle begins with sclerotia left in the field during harvest or mixed with seed at the time of threshing and sowing in the next season. Following rain showers, these sclerotia germinate and release numerous ascospores, which are carried by air currents to stigmas of flowering pearl millet panicles where they germinate and cause infection (Thakur and King, 1988). Pearl millet flowers are susceptible to infection only after stigma emergence and before pollination. The sequence of flowering events in pearl millet is shown in Figure 1. Under favorable weather conditions (relative humidity 80% or more, and temperatures of 20-30 ^{o}C), honeydew symptoms appear 4-6 days and sclerotia 15-20 days after inoculation (Ramaswamy, 1968; Dwarakanath Reddy et al., 1969; Thakur and King, 1988). Pollination has been shown to reduce ergot infection (Thakur and Williams, 1980). Ergot can become severe when pollination is inhibited by "pollen wash" caused by heavy rains during anthesis (Thakur and King, 1988).

Agroclimatic analysis and crop modeling can help determine operations aimed at increasing and stabilizing agricultural production. Crop simulation models are used at ICRISAT Center to

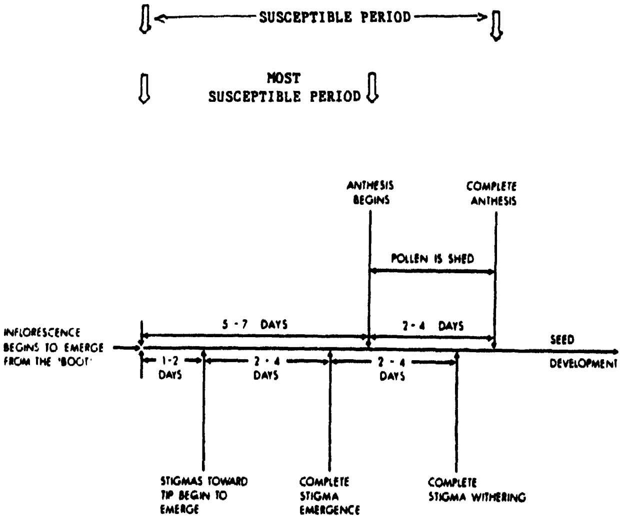


Figure 1. The sequence of flowering events in pearl millet and stages of ergot susceptibility (adapted from Thakur and King, 1988).

PEARL MILLET ERGOT SEVERITY ASSESSMENT KEY

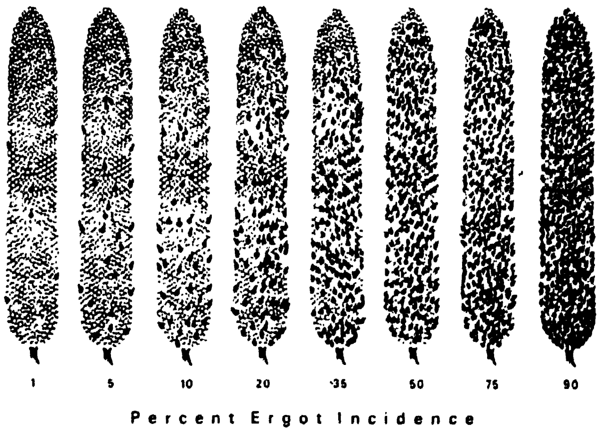


Figure 2. Pearl millet ergot severity assessment key (adapted from Thakur and Williams, 1980).

estimate probabilities of crop production potential and to evaluate risks of different agronomic practices (e.g., sowing dates, plant densities, irrigation dates and amounts) to alleviate crop yields. Lack of quantified information on the effect of environmental factors on biotic stress, and its impact on crop growth and yield, is a major limiting factor for successful applications of simulation models in estimating yields in farmers' fields.

The objective of this study is to characterize pearl millet growing environments for ergot development, and to use a crop model to identify the susceptible growth stage (e.g., preanthesis) for pathogen infection.

APPROACHES

Two approaches were followed: (i) superimposition of the information on ergot occurrence on the pearl millet distribution map of India to identify areas with high, medium, and low probabilities of ergot occurrence, and (ii) climatic analysis and crop simulation modeling technique to identify the susceptible growth stage (e.g., preanthesis) for pathogen infection.

Superimposing Ergot Severity Information on Pearl Millet Map: The ergot disease severity data for eight locations were obtained from ICRISAT reports on multilocational testing through the International Pearl Millet Ergot Nursery. In the multilocation study, 40 plants (1 panicle/plant) were inoculated at each location and the percent florets affected in each plant were scored using an ergot severity key (Fig. 2) (Thakur and Williams,

Table 1. Some agroclimatic features for eight selected locations in India where ergot disease development study was conducted. Rainfall and number of rainy days are total, while temperature and relative humidity are average daily values during June to October. Ergot severity data of a pearl millet cultivar (BJ 104) under artificial inoculation, collected over a number of years at these locations, are given.

Location	Elev.	Rainfall	No. of rainy days	Air Temperature 0700 h	Air Temperature 1400 h	Relative humidity 0700 h	Relative humidity 1400 h	Ergot severity Min.	Ergot severity Mean	Ergot severity Max.
	m	mm		— °C —		— % —			— % —	
Mysore	767	509	35	19	28	83	68	51	60	79
Patancheru	541	748	45	22	31	85	56	83	91	98
Aurangabad	581	720	45	21	31	80	60	60	75	97
Jalna	-*	530	-	-	-	-	-	28	31	32
Jamnagar	23	476	20	25	33	78	64	28	41	47
New Delhi	216	630	30	25	35	64	49	24	53	66
Hisar	221	366	20	24	37	66	49	-	8	-
Ludhiana	247	569	25	24	36	68	50	52	63	82

Data base for Patancheru is 1974 to 1987; only rainfall for Jalna is available from 1975 to 1984; Data base for other locations is 1931 to 1960, as given by the Indian Meteorological Department (1967). A day which received at least 2.5 mm rain is termed as rainy day.

* - Data not available.

1980). The disease scores are based on data from several years from 1977. A high disease score was given when more than 66% pa florets were affected; medium score for 33 - 66%; and low score for < 33%.

Some agroclimatic features and the disease severity information for the eight locations studied are given in Table 1. The information on ergot development for a cultivar (BJ 104) has been superimposed on the pearl millet distribution map, to show areas with high, medium, and low probabilities of disease occurrence. Figure 3 shows that Patancheru and Aurangabad are locations of high disease severity, while less disease is expected in Jalna and Hisar. The other four locations (Ludhiana, New Delhi, Jamnagar, and Mysore) are intermediate in severity of ergot disease.

Climatic Analysis: Figure 4 shows the probability of receiving at least 20 mm rain in a week between June and October for three locations : Patancheru, Jamnagar, and Hisar. These three locations were chosen because they represent areas of high, medium, and low ergot infestation (Fig. 3). The criterion of 20 mm rain in a week was based on the assumption that this amount of rainfall in each week would provide a favorable environment for crop growth, and that such rainfall amount around anthesis could facilitate ergot occurrence. Assuming generally that sowing could be done in early July and anthesis occurs in about 50 days, the higher probability of rainfall around anthesis indicates higher likelihood of disease development. Figure 4 also shows that Patancheru has a higher probability of rainfall for a longer

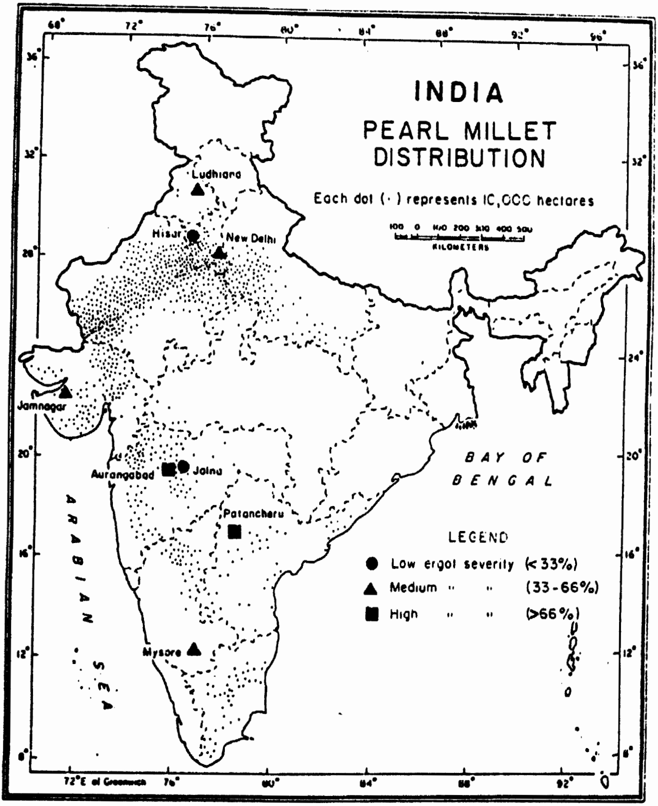


Figure 3. Information on ergot severity under artificial inoculation at eight locations in India, superimposed on the pearl millet distribution map.

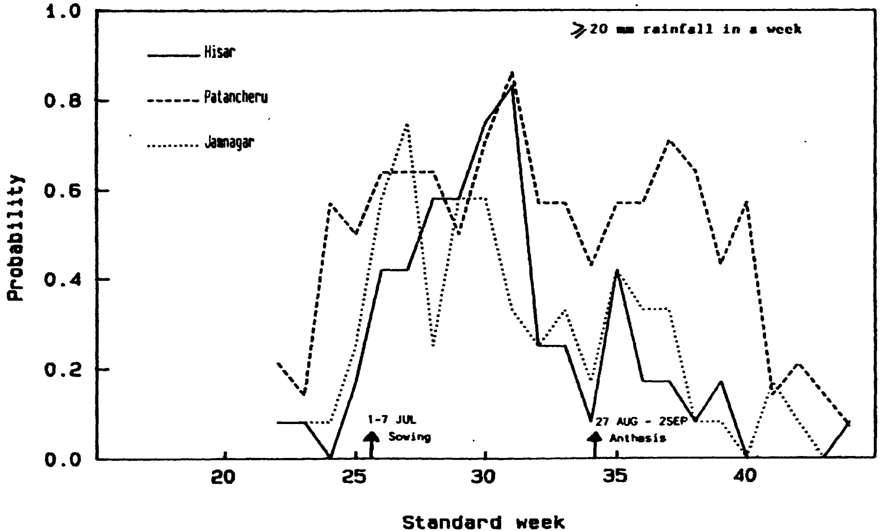


Figure 4. Probabilities of receiving at least 20 mm rainfall in a week during June to October for three locations in India.

period (particularly during the 30th to 40th week, which would coincide with flowering events for crops sown at different time intervals) than Jamanagar and Hisar.

Weekly rainfall data provide a good first approximation for screening environments for ergot severity. However, Thakur and King (1988) reported that pearl millet flowers are susceptible to infection only after stigma emergence and before pollination, as shown in Figure 1. Therefore, daily weather data would be more helpful in characterizing environments for ergot occurrence. A simulation model based on information regarding crop, soil, and climate could be useful in (i) identifying a susceptible growth stage (e.g., preanthesis) for infection, and (ii) estimating probabilities of yield loss, as a result of disease occurrrence, when quantified relations between weather and diseases are available.

Crop Modeling: A pearl millet model developed at ICRISAT (Huda, 1987) is based on information regarding crop, climate, and soil, gathered on a daily basis. The durations of growth stages are determined from cultivar coefficients of the effects of temperature. The durations (t) of three growth stages: emergence to panicle initiation (GS1), panicle initiation to anthesis (GS2), and anthesis to physiological maturity (GS3) were simulated by

$$\frac{1}{t} = (T - Tb) / \theta 1, \text{ when } T \leq To \quad \text{or,}$$

$$\frac{1}{t} = [(Tm - T)\ \theta 1/\theta 2] / \theta 1, \text{ when } To < T \leq Tm$$

where, $\theta 1/\theta 2 = (To - Tb) / (Tm - To)$,

T = average air temperature,

Tb = base temperature (10 °C),

Tm = maximum temperature (45 °C),

To = optimum air temperature (30 °C),

θ = thermal time for a developmental stage.

Daily leaf-area progression is calculated by an input of maximum leaf-area index at anthesis. Daily potential dry-matter production is calculated based on light-use efficiency and light interception (2.2 g of dry matter per MJ of photosynthetically active radiation intercepted). Daily net dry-matter gain is calculated by accounting for soil water deficits. The water deficit coefficients (WATDCO) were derived from field experiments conducted at ICRISAT Center (Jarwal, 1984), and the algorithms used in the model are as follows:

$$WATDCO = 1.0, \quad \text{when } \left(1 - \frac{SW}{UL}\right) \leq 0.25,$$

$$\text{or} \quad = 1.48 - 1.97 * \left(1 - \frac{SW}{UL}\right), \quad \text{when } 0.25 < \left(1 - \frac{SW}{UL}\right) \leq 0.75,$$

$$\text{or} \quad = 0, \quad \text{when } \left(1 - \frac{SW}{UL}\right) > 0.75$$

Where, SW = Simulated available soil water on any day

UL = Available water holding capacity of the root zone.

Grain yield is calculated by using a cultivar-specific harvest index.

APPLICATIONS OF THE MILLET MODEL

We demonstrate the utility of the millet model, described above, in assessing sowing and anthesis dates, and in simulating potential crop yields with adequate management for selected locations.

Sowing dates: To start a cropping season, we chose the sowing dates after 15 June when at least 30 mm rain fell within three consecutive days; these dates are termed the early sowing opportunities. Realizing that farmers often would not be able to sow crops with the first rain, we chose a second sowing date (termed the late sowing opportunities) after 15 July when 30 mm rain fell within three consecutive days.

The probability of sowing pearl millet by 30 June or earlier is 92% at Patancheru, 42% at Jamnagar, and 40% at Hisar. But for late cropping (i.e., sown after 15 July), the probability of sowing by 31 July or earlier is 85% at Patancheru, 58% at Jamnagar, 58% at Hisar.

Simulated sowing dates at Patancheru ranged from 16 June to 22 July for early-sown crops, while they ranged from 17 July to 3 September for late-sown crops. Simulated sowing dates at Jamnagar ranged from 20 June to 2 August for early-sown crops while they ranged from 18 July to 17 August for late-sown crops. At Hisar simulated sowing dates ranged from 19 June to 1 September for early-sown crops, while they ranged from 18 July to 1 September for late-sown crops.

These results illustrate the importance of timeliness of operations in rainfed agriculture. For example, at Patancheru, if crops were not sown with the beginning of rains in June, one had to wait up to 9 August in 1974 and 3 September in 1987 to receive sufficient rains to begin the cropping season.

Anthesis dates: Anthesis dates were calculated for a pearl millet cultivar, BJ 104, based on its thermal time requirement (310 degree days for GS1, 530 for GS2, and 450 for GS3). The average duration from emergence to the anthesis (main culm + tillers) is about 50 days. Because of variations in air temperature among years, the durations from emergence to anthesis ranged from 45 to 55 days across locations and seasons.

Weather conditions during anthesis: The percentage of years when weather conditions during the 4-day preanthesis stage met the assumed requirements of ergot disease development are shown in Table 2. We would like to clarify that the criteria chosen here are somewhat arbitrary because of insufficient understanding of weather and disease interactions. Assuming that at least one day with $\geq$ 5 mm rain, $\geq$ 90% relative humidity in the morning, $\geq$ 70% relative humidity in the afternoon, or $\leq$ 1 h sunshine would cause disease infection, the percentage of such years meeting one or more of the above conditions is usually greater at Patancheru than at Jamnagar and Hisar. We have also assessed the probability of meeting such weather criteria for at least 2 days during the 4-day preanthesis period. These results indicate that for ergot disease development Patancheru provides a more conducive environment, followed by Jamanagar and Hisar. Comparison of actual disease severity data from early- and late- sown crops within a location would be very useful. For example, at Patancheru, late-sown crops would flower in most years during wet and highly humid environments, which might cause more disease occurrence.

Table 2. Percentage of years when weather conditions meet the assumed requirements for ergot disease development at least for (a) 1 day and (b) 2 days in a 4-day preanthesis stage (including the anthesis date), simulated by a pearl millet simulation model for two sowing dates in each of three selected locations in India.

Location	Sowing date	a) At least 1 day with $\geq$ 5 mm rain	$\geq$ 90% R.H. in morning	$\geq$ 70% R.H. in afternoon	$\leq$ 1 h sunshine
		— % years —			
Patancheru	Early	36	50	36	46
	Late	57	71	50	31
Jamnagar	Early	25	-*	-	75
	Late	8	-	-	25
Hisar	Early	33	25	25	0
	Late	8	25	8	0

Location	Sowing date	b) At least 2 days with $\geq$ 5 mm rain	$\geq$ 90% R.H. in morning	$\geq$ 70% R.H. in afternoon	$\leq$ 1 h sunshine
		— % years —			
Patancheru	Early	14	29	21	15
	Late	36	64	21	8
Jamnagar	Early	25	-	-	50
	Late	0	-	-	0
Hisar	Early	8	8	16	0
	Late	0	8	8	0

Data base for Patancheru is 1974 to 1987; for Hisar, 1976 to 1987; for Jamnagar, daily rainfall from 1959 to 1970, sunshine hours from 1967 to 1970.

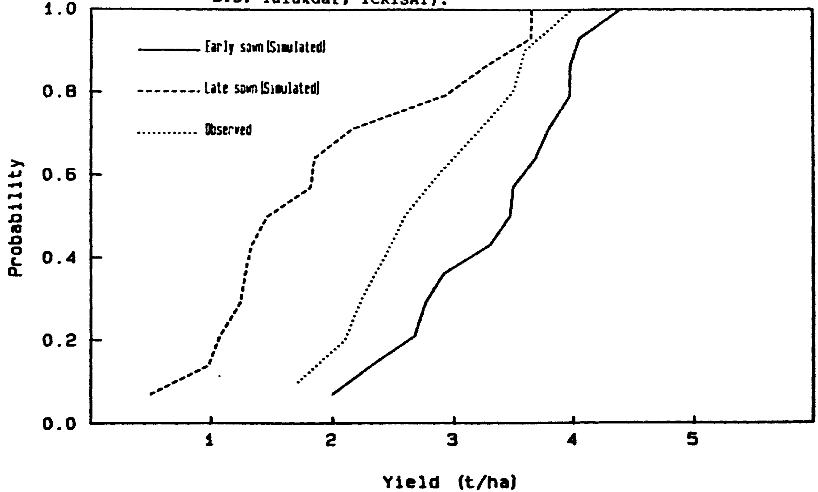
* - Data not available.

Rainfall, relative humidity, and sunshine hours are somewhat interrelated to each other and, therefore, the effect of each of these factors (individually or in combination) on disease development needs to be studied under controlled environments. From Table 2, it is apparent that daily rainfall of 5 mm might not be a good criterion for disease assessment, while relative humidity of 90% in the morning, and $\leq$ 1 h sunshine per day could be a better criteria. Therefore, though the somewhat arbitrary criteria chosen in this study showed the correct trend in disease occurrence across locations, further studies to quantify the relationship between weather and ergot development would be needed.

Grain yields: Grain yields of a pearl millet cultivar (BJ 104) were simulated, using climatic data from 1974 to 1987 for Patancheru, and from 1976 to 1987 for Hisar. To estimate potential yields, assumptions of optimum plant stand, adequate nutrient and plant protection were made. Yields were simulated for two sowing dates (early-sown with the onset of rains after 15 June, late-sown with rains after 15 July). Simulated yields were compared with observed yield data (Figs. 5a and 5b).

Simulated yields for early-sown crops at Patancheru ranged from 2 to 4.4 t ha^{-1}, while they ranged from 0.4 to 3.7 t ha^{-1} for late-sown crops. Observed yields (from different years--sowing dates varied from late June to mid July) ranged from 1.7 to 4.0 t ha^{-1} (Fig. 5a). Simulated yields, for the early sown crops were greater than observed yields, and this is partly because the model does not account for nutrient and biotic

Figure 5a. Probabilities of less than a specified amount of pearl millet grain yield under rainfed condition at Patancheru. Available water-holding capacity of the soil is 80 mm. Data base is 1974 to 1987. (Data on observed grain yield were supplied by S.P. Wani and B.S. Talukdar, ICRISAT).



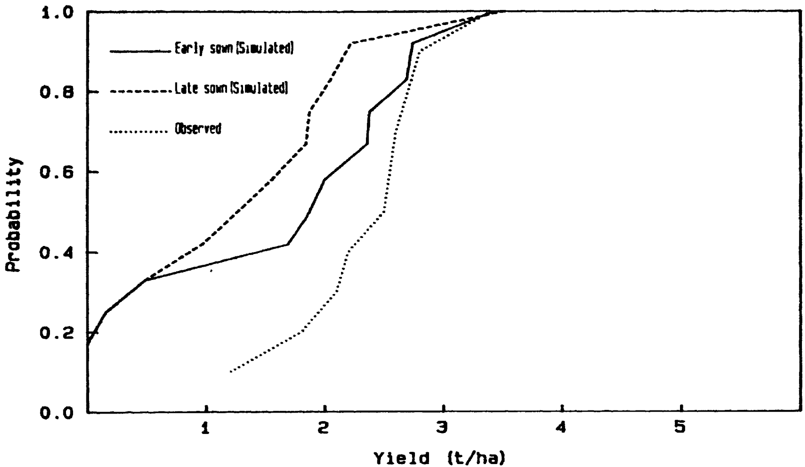


Figure 5b. Probabilities of less than a specified amount of pearl millet grain yield under rainfed conditions at Hisar. Available water-holding capacity of the soil is 150 mm. Data base for simulation is 1976 to 1987, and for actual yield 1975 to 1984. (Data on observed grain yield were obtained from Pearl Millet Adaptation Trial

stresses, including ergot infection. Therefore, simulated yields from early-sown crops could be treated as potential yields achieveable at Patancheru with better management practices. One reason for lower simulated yields in late-sown crops, compared to the early-sown crops at Patancheru, could be that the grain-filling period of the late sown crops coincided with low rainfall (Table 3), at least in some years. Increased saturation deficits of the air associated with low rainfall also affect crop growth (Monteith, 1986). Simulation results are in agreement with the common experience that yields of late-sown crops are substantially lower than those of early-sown crops.

Interestingly, the simulated yields in 50% of the years at Hisar (Fig. 5b), when rainfall was insufficient, were lower than observed yields. This may be because of supplementary irrigations that would have been given in the field experiment in dry years. The model needs irrigation dates and amounts as input data. Because, these data were not included in the reports from which observed yield data were collected, yields were simulated for rainfed conditions. This further emphasizes the need for collection of minimum data (Table 4) from experiments to generalize the research results.

DISEASE AND WEATHER INTERACTION STUDIES

In most crop simulation models, results are simulated by assuming no biotic stress, but this is not the reality. In view of this, it is essential that quantified information on weather and the development of some important diseases should be generated. Therefore, interdisciplinary efforts should be made to carry out

Table 3. Rainfall statistics in different growth stages of pearl millet at three locations in India.

		Locations			
		Patancheru		Hisar	
Growth stages	Statistics	Early sowing	Late sowing	Early sowing	Late sowing
		— mm —			
Emergence	Minimum	11	2	0	0
to panicle	Mean	84	118	53	51
initiation	Maximum	209	241	100	92
Panicle	Minimum	63	63	2	0
initiation	Mean	194	233	83	37
to anthesis	Maximum	317	490	150	69
Anthesis to	Minimum	17	5	0	0
physiological	Mean	196	129	23	7
maturity	Maximum	451	286	53	50

Data base for Patancheru is 1974 to 1987; and for Hiśar, 1976 to 1987.

Table 4. Data needs for development and testing of a pearl millet model.

Climate (Daily)	:	o Rainfall
		o Temperature
		o Radiation
		o Open pan
		o Relative humidity
		o Saturation deficit
Soil information	:	o Type
		o Depth
		o Water-holding capacity
		o Special problem
Management	:	o Plant stand
		o Nutrients
		o Biotic
		o Irrigations
		o Crop yields
Disease	:	o Intensity
		o Time of appearance
		o Wetness
		o Rate of disease spread
		o Biological yield loss
		o Climatic data (hourly values), including sunshine and wind speed

in-depth studies under controlled environments, to collect the relevant data on physical and biological aspects. Data needs are suggested in Table 4. Details of experimentation, data collection, and analysis need greater attention. The results obtained from such studies can be used more effectively in crop simulation models.

The difficulties experienced in using crop simulation models are as follows:

(i) The models usually do not account for nutrient and biotic stresses and their interactions with environments.

(ii) Among the climatic data, only daily rainfall data are normally available for a long term; data on other aspects of the climate are usually insufficient. Data needs are given in Table 4.

(iii) Spatial variability of rainfall and soils.

IMPLICATIONS

Agroclimatic analysis and crop modeling can help:

i) To screen environments in terms of high, medium, and low susceptible areas for ergot occurrence areas, and to thereby identify areas where disease resistant/tolerent cultivars could be tested.

ii) To suggest alternate management practices (e.g., sowing dates, maturity duration of cultivars, cropping systems, etc.) for economic control of ergot.

iii) To estimate occurrence of other diseases, using similar agroclimatic data.

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