AGROMETEOROLOGICAL ASPECTS OF CROP YIELD MODELING: DATA NEEDS AND LIMITATIONS*

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Introduction

Agrometeorological analysis and crop modeling can help determine operations aimed at increasing and stabilizing agricultural production. The objectives of this paper are to illustrate, using a pearl millet model, (i) the utility of agrometeorological data in assessing sowing dates and in estimating probabilities of production potential of pearl millet in rainfed agriculture, and (ii) the limitations experienced in using the model to simulate crop yields over large areas.

A Millet Model

A millet model developed at ICRISAT (Huda, 1987) is based on information of crop, climate, and soil; it operates on a daily basis. The durations of growth stages are determined from cultivar coefficients of the effects of temperature. Daily leaf area progression is calculated by an input of maximum leaf area index at anthesis. The durations (t) of three growth stages: emergence to panicle initiation (GS1), panicle initiation to

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anthesis (GS2), and anthesis to physiological maturity (GS3) simulated by

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

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

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

T = average air temperature,

Tb = base temperature ($10^{o}C$),

Tm = maximum temperature ($45^{o}C$),

To = optimum air temperature ($30^{o}C$),

θ = thermal time for a developmental stage (310 for GS1, 530 for GS2, 450 for GS3)

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:

$$WATDCO = 1.0, \text{ when } (1 - \frac{SW}{UL}) \leqslant 0.25,$$

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

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

Where, SW = Simulated available soil water on any day

UL = Available water holding capacity of the root zone.

Grain yield is simulated by using input on cultivar-specific harvest index.

Assessing Sowing Dates

Daily climatic data from 1930 to 1987 were used to assess sowing dates and to simulate pearl millet yield under rainfed conditions, as an illustration, for one representative pearl millet area of India (Jodhpur, 26°N, 73°E). In Jodhpur, monsoon rains normally set in during the first week of July and their withdrawal occurs during the first week of September; thus there are only two rainy months. However, there was a large variation among years, particularly in the onset of rain for sowing. To start a cropping season, we chose a sowing date after 1 June when at least 30 mm rain fell within three consecutive days. The probability of sowing millet is 28% by 1 July, 65% by 15 July (Figure 1). Simulated sowing dates matched the actual sowing dates in Jodhpur during 1971 to 1985, with one exception. We estimated from long-term climatic analysis that crops should have been resown in 6 of the 58 years because there was no rain for more than 20 days after the first sowing, the criterion for failure of crop establishment.

Figure 2 shows the probability of receiving less than a specified amount of rain during the simulated growing period based on data from 1930 to 1987. Rainfall ranged from 71 mm to 710 mm with a mean of 278 mm. In 70% of the years, rainfall during the growing season was less than 320 mm.

Yield Simulation

Grain yields of a standard pearl millet cultivar (75 days to maturity) were simulated using climatic data of Jodhpur from 1930 to 1987, and assuming optimum plant stand, adequate nutrients, and plant protection. The simulated yield ranged from nothing to 3.2 t ha^{-1}, matching the range of actual yields obtained at Jodhpur from 1971 to 1985 (Figure 3). Though the simulated yield matched the actual yield in very dry years and in well distributed rainfall years, in 80% of the years simulated yields were greater than actual yields. These comparisons suggest that though the model simulated the effects of water deficits reasonably well, some of the assumptions made in this simulation study are not correct, and the model needs refining.

Model Refining

(i) The assumption of the optimum plant stand resulting in 90% or more light interception at anthesis may be obtained in well distributed rainy seasons, but for those years when long dry spells occur, appropriate correction in the model computation of daily leaf area progression needs to be made (light versus water as limiting factor).

(ii) The use of 45% harvest index to convert simulated total dry matter to grain yield may be correct in years where rainfall is well distributed, but appropriate changes in the modelled distribution of the dry matter to grain needs to be made for those years when severe drought stress occurs during the grain-filling period.

(iii) Ratio of dry-matter accumulation and water supply needs to be computed by accounting for saturation deficit of the air. Saturation deficit is linked with seasonal rainfall (Monteith, 1986).

(iv) The model should account for nutrient and biotic stresses and their interactions with environments. For example, if there is not enough soil moisture in the top soil, nutrients applied through fertilizer would not have been available to the plants.

Implications

(i) To assess the effects of dates of sowing on final grain yield of pearl millet (e.g., risks in abandoning first planting, if it is followed by a long dry spell, versus planting again upon receiving sufficient subsequent rain).

(ii) Adopting appropriate management practices to improve the actual yields.

(iii) To carry out preliminary studies on genotype x environment interaction by assessing both potential yield and stability of yield over years.

Difficulties in Extending Yield Simulation Over Large Areas

(i) The need for model refinement, as already discussed.

(ii) Among the climatic data, only daily rainfall data are normally available for longer terms; data on other aspects are usually insufficient. Data needs are given in table 1.

(iii) Spatial variability of rainfall and soils.

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References

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Table 1. Data needs for development and testing of a pearl millet model.

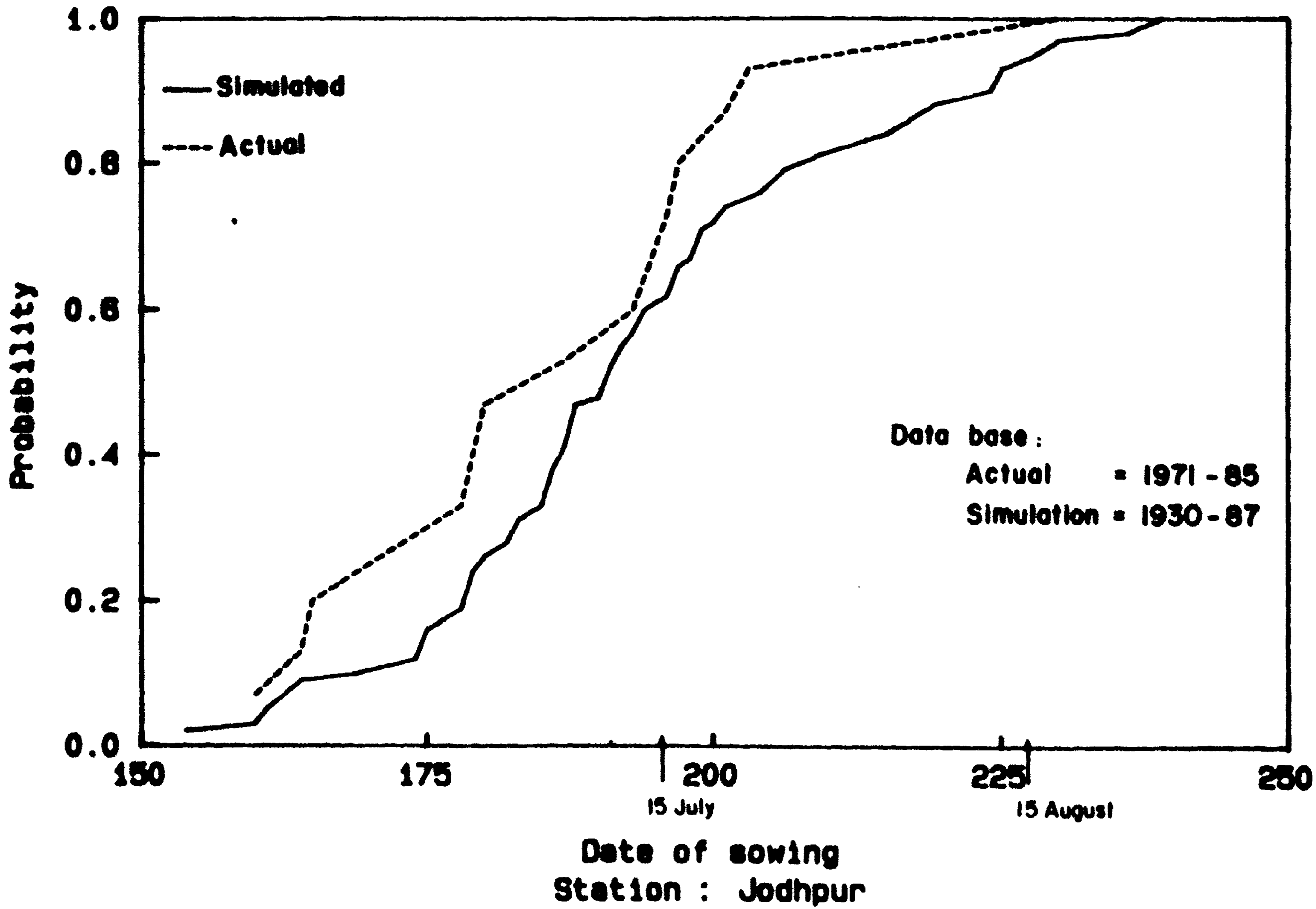
<u>Climate (Daily)</u>	Rainfall Temperature Radiation Open pan Relative humidity Saturation deficit
Soil information	Type Depth Water - holding capacity Special problem
<u>Management</u>	Plant stand Nutrients Biotic Irrigations Crop yields

Figure captions

Figure 1. Comparison between actual and simulated probabilities of sowing pearl millet (on a day) between 1 June and 31 August in Jodhpur.

Figure 2. Probability of less than a specified amount of rainfall during the simulated growing season of pearl millet in Jodhpur.

Figure 3. Probabilities of less than a specified amount of actual and simulated pearl millet grain yield in Jodhpur.


Simulated
Actual
Probability
1.0
0.8
0.6
0.4
0.2
0.0
150
175
200
225
250
15 July
15 August
Date of sowing
Station : Jodhpur
Data base :
Actual = 1971 - 85
Simulation = 1930 - 87

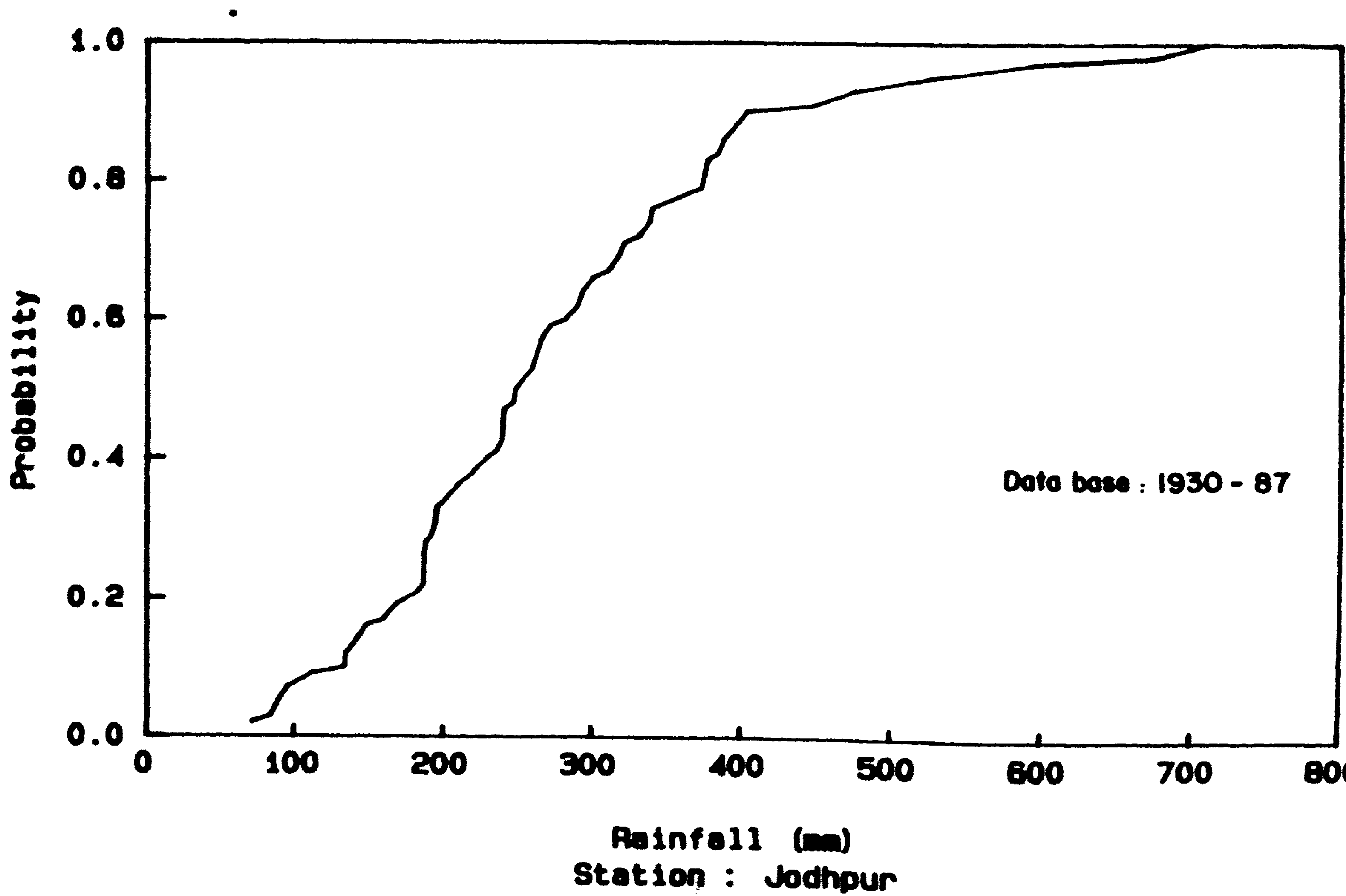

1.0
0.8
0.6
0.4
0.2
0.0
Probability
0
100
200
300
400
500
600
700
800
Data base : 1930 - 87
Rainfall (mm)
Station : Jodhpur

FIGURE 2.

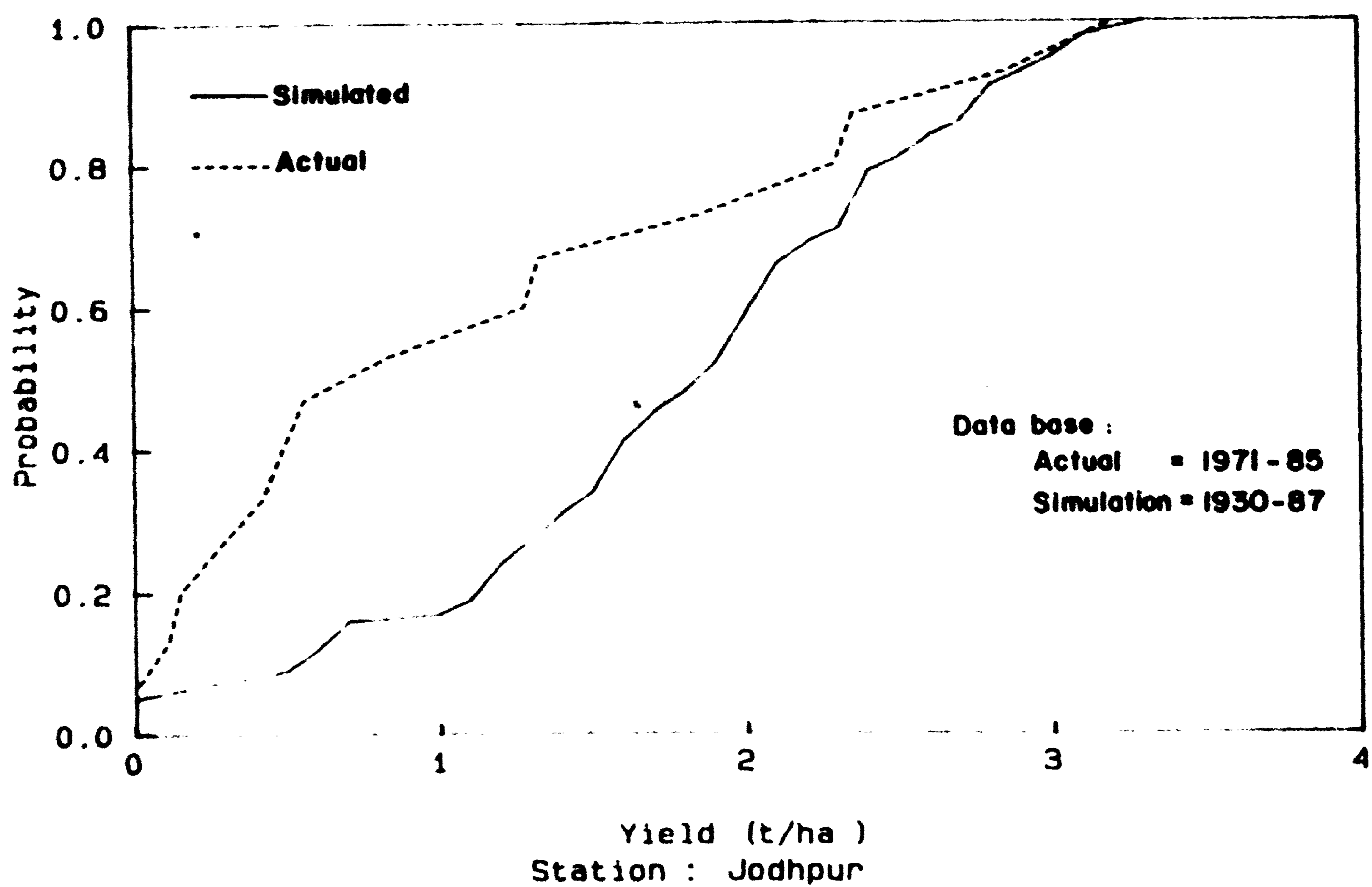

1.0
0.8
0.6
0.4
0.2
0.0
Probability
Simulated
Actual
Data base :
Actual = 1971-85
Simulation = 1930-87
0
1
2
3
4
Yield (t/ha)
Station : Jodhpur

FIGURE 3.

APPENDIX

Simulated Grain Yield of Pearl Millet and Seasonal Rainfall

Station : Jodhpur

Year	Seasonal rainfall mm	Grain Yield t/ha
1930	135	0.5
.	.	.
.	.	.
.	.	.
1943	596	3.0
1944	710	3.1
1945	475	3.3
.	.	.
.	.	.
.	.	.
1959	249	0.6
1960	89	0.0
1961	311	0.7
.	.	.
.	.	.
.	.	.
1987	71	0.0

. = Data not shown