Technical Manual no. 4

Climate Prediction for Sustainable Production of Rainfed Groundnuts in SAT

Crop Establishment Risks in the Anantapur Region

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

Groundnut is an important crop around the globe for its nutritional and trade values. As a result of diverse farming situations, there is a large variation in the productivity levels of groundnut around the world. In countries such as USA where the crop is grown on large farms with assured inputs, productivity levels are very high in comparison to a country such as India where the crop is traditionally grown by small-holding farmers, on less fertile soil, in rainfed conditions, with low inputs. In 1998, although the groundnut area in China was about half of that in India, the production exceeded that of India by nearly 10%. Groundnut productivity in India is low due to moisture stress, poor soil fertility, pests and diseases, and low inputs, and cultivation of the crop on marginal and submarginal lands.

Nearly 80% of the area sown to groundnuts in India is rainfed and relies entirely on summer monsoon rainfall. The rainfall in most of the groundnut-growing regions is low and erratic. There is a high variability in the onset of monsoons, annual rainfall, and distribution of rainfall over the growing season. Moreover, such high variability in precipitation is generally associated with a high probability of an early season drought. Thus, rainfed agriculture in India is a risky proposition. One of the decision-making problems confronting the farmers at the onset of the cropping season is choice of an optimum sowing window.

With the above in view, a research project was undertaken at ICRISAT to examine the trends in groundnut production in India over the past few decades in the global context, characterize the groundnut production environment of the Anantapur region, and to provide a first approximation "decision support system" to the farmers of the Anantapur region in the state of Andhra Pradesh and thus aid them in deciding an optimum "time window" for sowing the groundnut crop.

The first section examines the trends in world groundnut area, production, and productivity from 1961 to 1998. Similar trends for China and India, the world's leading groundnut producers, are also analyzed. As an example of precision agriculture, the area and production trends in USA are discussed. The second section takes a closer look at the groundnut production scenario in India. In the third section, groundnut production environment in the Anantapur region (the target benchmark region chosen for this research activity) is characterized, and constraints to sustainable production are identified. The results of groundnut yield simulations using CROPGRO-Peanut model and historical weather data from the Anantapur region are presented in the fourth section. The report is summarized and relevant inferences are drawn from the results of this research activity in the fifth section. A first approximation decision support system for choosing an optimum "time window" for sowing the crop in the region based on model simulation results and rainfall probabilities is also presented. In view of the findings of the project, a research project that aims to enhance and sustain groundnut productivity in India is proposed in the last section.

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1999

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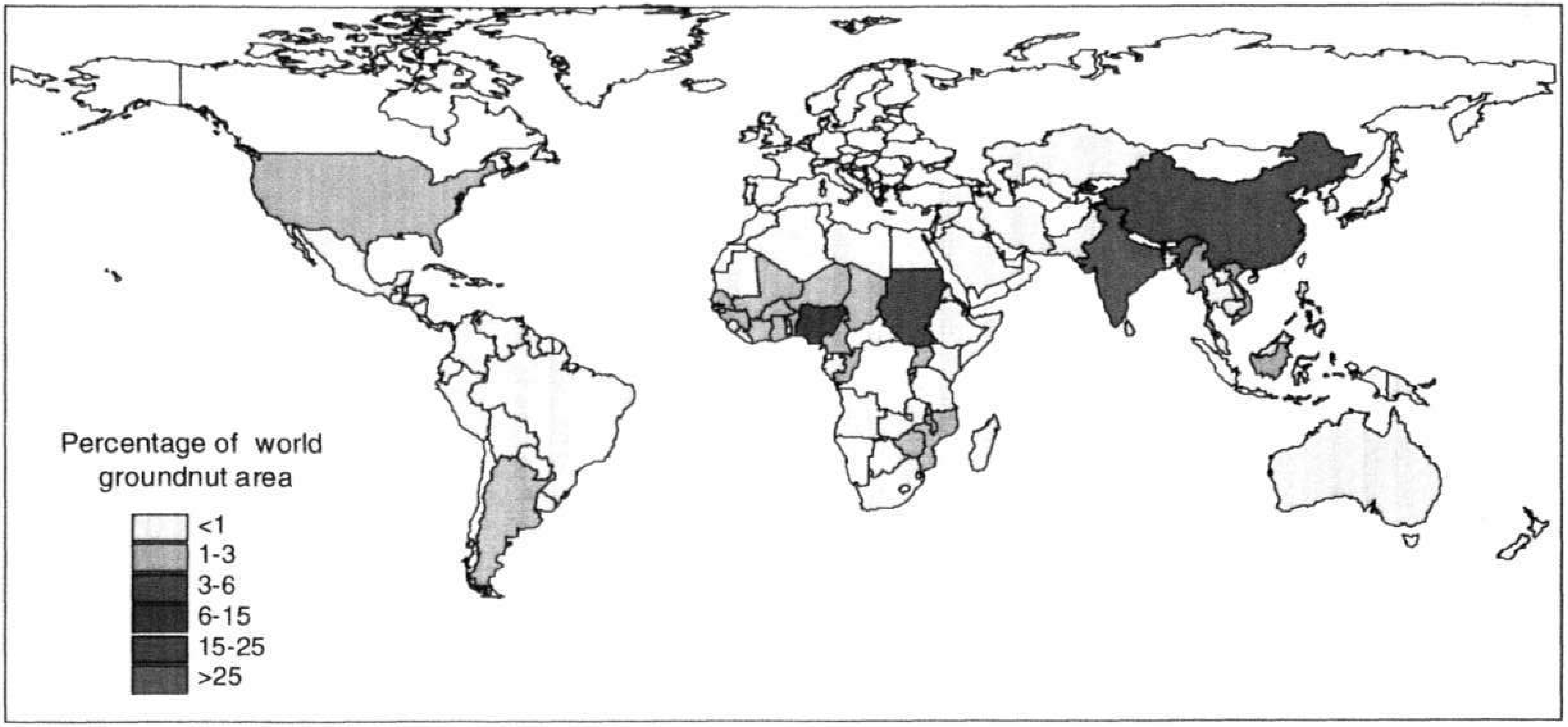

Figure 1.1. World distribution of groundnuts during 1998 (Data Source: FAO Statistical Databases).

World Groundnut Production

World Groundnut Area, Production, and Yield

Groundnut (Arachis hypogaea L) is one of the five most important oilseed crops produced in the world. Until recently, it ranked third in the world oilseed production. However, due to unstable production, its ranking has since declined. Sunflower (Helianthus annuus L) and canola (Brassica napus L; rape) have gained importance as oilseeds (Fletcher et al. 1992). Groundnut is produced in six continents, with Asia, Africa, North America, and South America accounting for the majority of the production (Fig. 1.1).

Annual variations in world groundnut production, area under the crop and productivity from 1961 to 1998 are presented in Figure 1.2. World groundnut production was 14 million t during 1961 and it increased gradually to 18 million t during the late 1970s. Subsequently, the production increased sharply to 31 million t in 1998, with a peak production of 32 million t during 1996 (Fig. 1.2). Over a span of four decades, the world groundnut production has increased by nearly 2.3 times compared to the production in the 1960s.

As is evident in Figure 1.2, such a change in production has been brought about by an increase in the global area under the crop, but the more significant factor for the increase in production is the increase in groundnut productivity. While the global groundnut area was higher by 18% during 1991-98 as compared to the 1960s, the groundnut productivity was higher by nearly 50%. The world

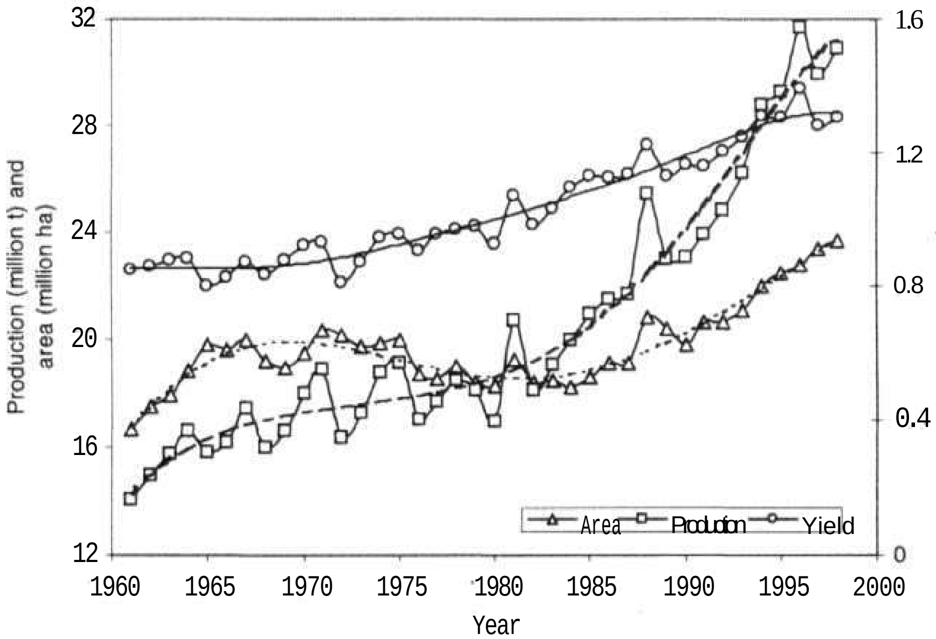

Figure 1.2. World groundnut area, production, and yield during 1961-98 (Note: Sixth order polynomials are fitted to the data) (Source: FAO statistical databases).

groundnut area was 17 million ha during 1961 and peaked at 20 million ha during mid-late 1960s. Adverse climatic conditions, outbreak of pests and diseases, and socioeconomic constraints in Africa and South America led to a steady decline in the global area under the crop (Fletcher et al. 1992), with only 18 million ha during the mid-1980s. Subsequently, the world groundnut area increased steadily to 22 million ha (Fig. 1.2).

In order to better understand the trend in world groundnut production, it is imperative to examine the trends in production, area under the crop, and identify the factors responsible for change in productivity in the major groundnut-growing countries of the world. With this in view, the following discussion focuses on the trends in groundnut production in the world's major groundnut-growing countries.

USA

Seven states account for approximately 98% of all groundnuts grown in USA: Georgia (38%) grows the major proportion followed by Texas (23%); Alabama (11%); North Carolina (9%); Florida (6%); Virginia (5%); and Oklahoma (5%) (Fig. 1.3). There are approximately 40,000 groundnut farms in the major producing regions of USA.

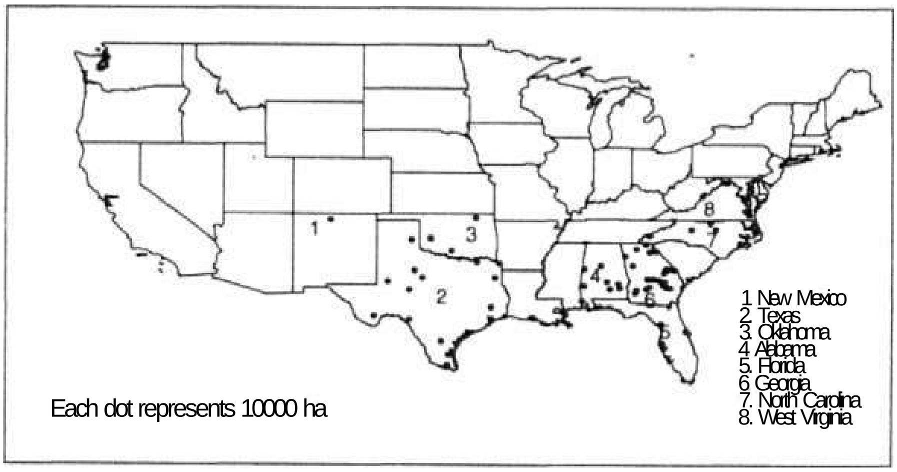

Figure 1.3. Statewise distribution of groundnut in USA in 1997 (Source: US Department of Agriculture).

The area sown to groundnuts in USA has remained fairly constant over the past few decades at about 0.5 million ha due to several economic controls (Fig. 1.4). Nevertheless, the groundnut production in the country has increased from 0.8 million t in 1961 to 1.7 million t in 1998 (220% increase). The compound growth rate of groundnut production in USA is estimated at 1.8% yr^{-1}.

In USA, groundnut production is almost completely mechanized; high inputs are used; precision agricultural production is employed and price supports are guaranteed. The increased production is primarily led by a concurrent increase in groundnut productivity. The groundnut yield has increased from 1.3 t ha^{-1} in 1961 to 2.8 t ha^{-1} in 1998

(Fig. 1.4). According to Isleib and Wynne (1992), some of the factors for such an increase in the groundnut productivity are the development of high-yielding varieties suited to mechanical harvesting, mechanized production, appropriate use of fertilizers based on soil tests and plant analyses, use of high quality certified seed, integrated disease, pest, and weed control, use of irrigation and timely harvesting, storage, and transport of the produce from farms to markets.

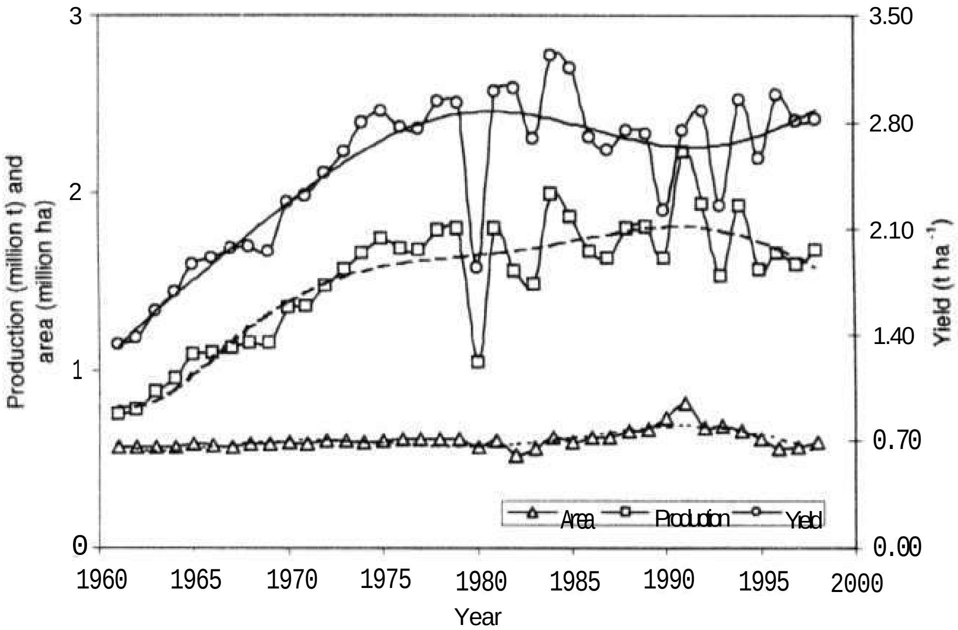

Figure 1.4. Groundnut area, production, and yield in USA during 1961-98 (Note: Sixth order polynomial trendlines are fitted to the data) (Data Source: FAO Statistical Databases).

People's Republic of China

Area under groundnut in Shangdong province of China during 1987 was 0.85 million ha (Fig. 1.5). From the early to mid-1960s, groundnut production and area showed an increasing trend with a peak production of 2.4 million t from 2 million ha of area in 1966 while the productivity was 1.2 t ha^{-1} (Fig. 1.6). Subsequently, the production and area began to decline and fluctuated until 1980.

The 1980s saw a sharp increase in production, area and productivity. An exponentially increasing trend in production is evident in Figure 1.6. A peak production of 10.3 million t of groundnut was observed in the mid-1990s from 3.7 million ha area sown to the crop and yield levels were as high as 2.8 t ha^{-1}. Groundnut area, production, and productivity in China in 1998 were 3.8 million ha, 9.6 million t, and 2.6 t ha^{-1} respectively. The compound growth rate of groundnut production in China is estimated at 5.8% yr^{-1}.

Figure 1.5. Distribution of groundnut in the provinces of China during 1987.

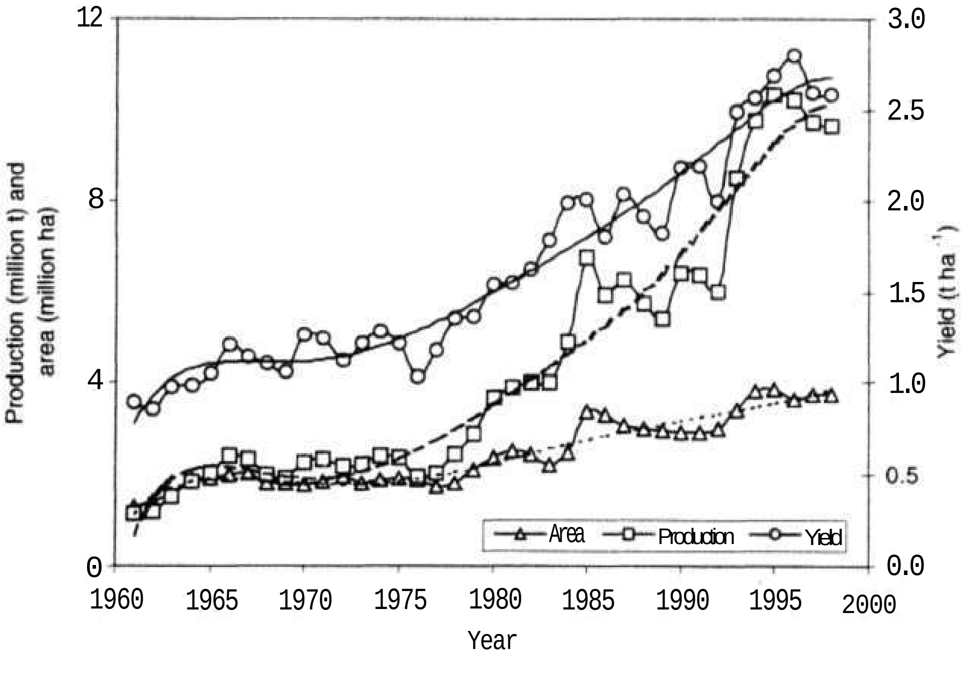

Figure 1.6. Groundnut area, production, and yield in China during 1961-98 (Note: Sixth order polynomial trendlines are fitted to the data) (Data Source: FAO statistical Databases).

The rapid increase in groundnut production in China has been brought about by a combination of extensive and intensive cultivation measures- Increase in production resulting from increase in area under the crop has been accomplished through stimulating agricultural reforms in the country, such as better marketing facilities and provision of stable price supports (Xu 1992). Technological advances in production such as the use of plastic mulch, narrow-bed cultivation, increased plant density, adoption of improved varieties, changes in cropping systems, development of summer crop in northern China, rational and intensive use of fertilizers, and effective control of pests and diseases have led to sharp increases in the productivity (Shuren Gai et al. 1995).

India

India has the largest area under groundnut in the world (Fig. 1.1). However, it ranks second in production next to China. Area under groundnut in India has remained stagnant at 6.5-7.0 million ha from 1961 until 1987. Subsequently, it increased and touched about 8 million ha in 1998 (Fig. 1.7). Groundnut production in India has shown a marked interannual variation. It increased from nearly 5 million t in 1961 to about 8 million t in 1998 with a peak of about 9.5 million t in 1987 (Fig. 1.7). This variation in production is attributed to variation in the amount of rainfall received and distribution of rainfall during the growing season.

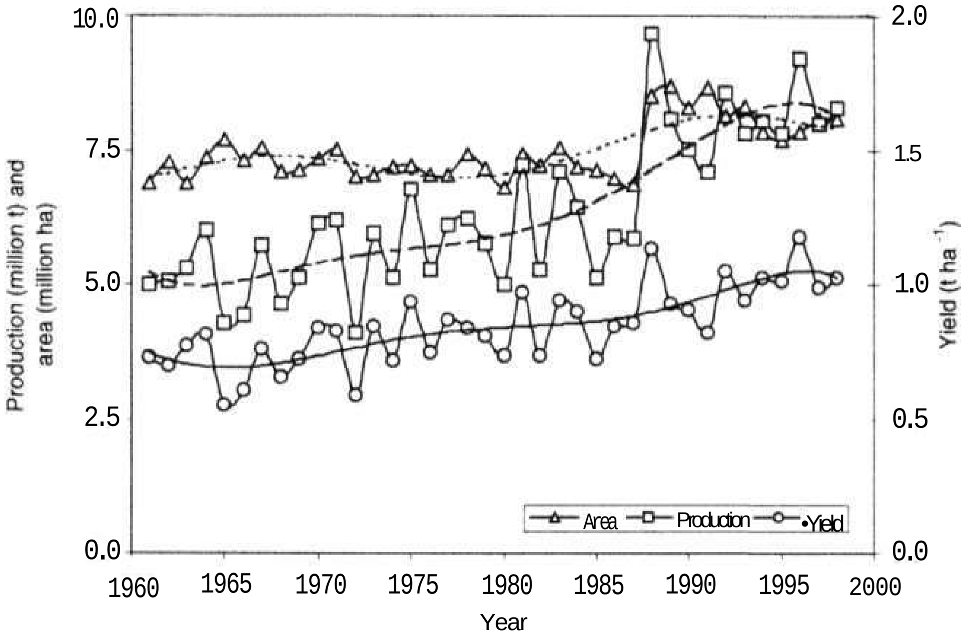

Figure 1.7. Groundnut area, production, and yield in India during 1961-98 (Note: Sixth order polynomial trendlines are fitted to the data) (Data Source: FAO Statistical Databases).

In 1998, India had more than twice the area sown to groundnut compared to China. Despite such a large area, groundnut production in India was lower than that in China by nearly 10%. This is attributed to the differences in the productivity levels. The productivity in China is nearly 2.5 times higher than that in India. Groundnut production in

India is constrained by several factors such as cultivation of the crop on marginal and submarginal lands (mainly under rainfed conditions), uncertain monsoons leading to frequent droughts, poor adoption of improved agronomic practices, low fertilizer usage, use of low-yielding and late-maturing varieties, widespread losses due to pests and diseases, inadequate availability of quality seeds, and many socioeconomic factors (Reddy et al. 1992). Nevertheless, owing to a large area under the crop, India holds the potential of being the world's lead groundnut producer with the ongoing research efforts to develop technologies for rainfed groundnut farming.

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Groundnut Production in India

Groundnut-growing Areas

Groundnut is a major oilseed crop in India. It accounts for 45% of the area and 55% of the production of total oilseeds in the country (Patel 1988). It is cultivated in all the three cropping seasons, i.e., rainy (June-October), postrainy (November-February), and summer (March-May) with nearly 80% of the annual area under the rainy season crop. The states of Andhra Pradesh, Gujarat, Karnataka, Maharashtra, and Tamil Nadu are the major producers of the rainy season crop (Fig. 2.1). In Andhra Pradesh, Karnataka, and Tamil Nadu, groundnut is grown in the postrainy season on rice-fallows. Summer groundnut accounts for about 5% of the total annual area in the country.

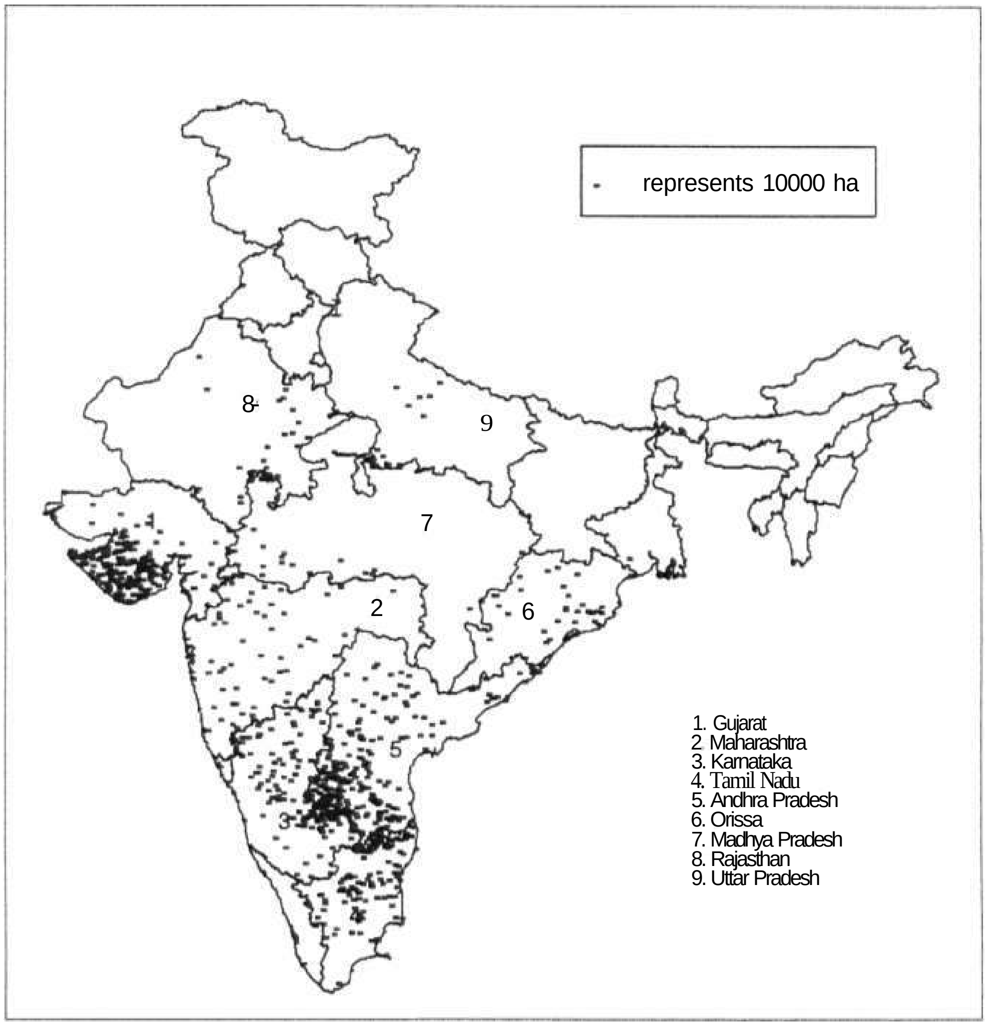

Figure 2.1. Statewise distribution of groundnut in India during 1990-95 (Data Source: ICRISAT Districtwise Crop Database).

Groundnut Production and Seasonal Rainfall

Groundnut production in India has shown a marked interannual variation and a gradual increasing trend during the past three decades (Fig. 2,2). The production increased from nearly 4 million t in 1966 to about 7.6 million t in 1993 with a peak of about 8.9 million t in 1988. Edaphic, plant, and meteorological factors control production of groundnuts.

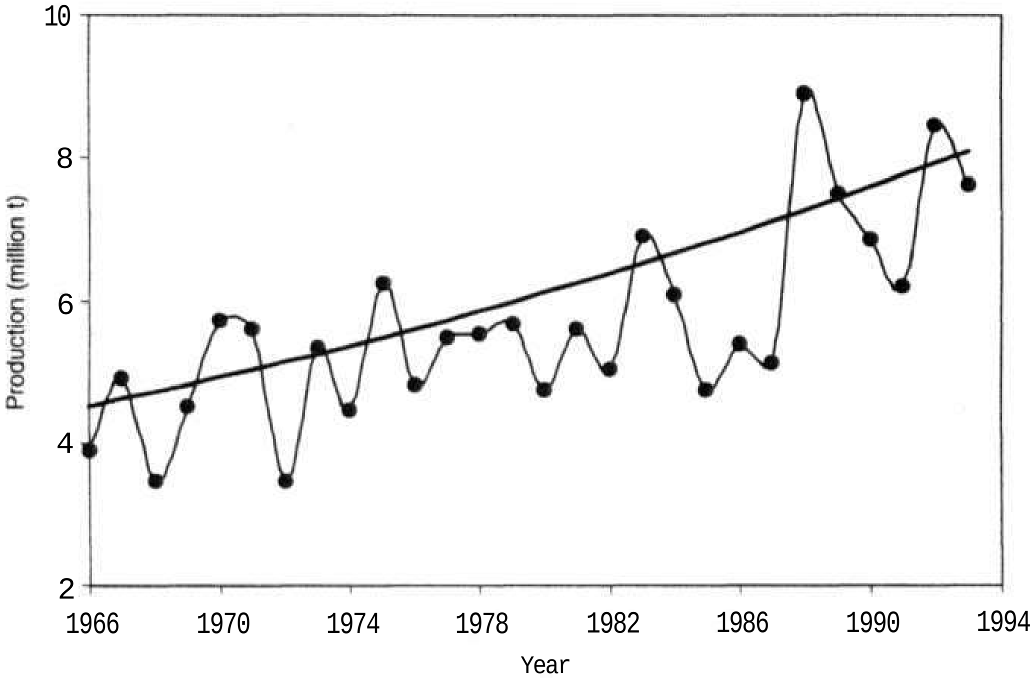

Figure 2.2. Annual groundnut production in India during 1961-1993 (Note: An exponential trendline is fitted to the data) (Data Source: ICRISAT crop databases).

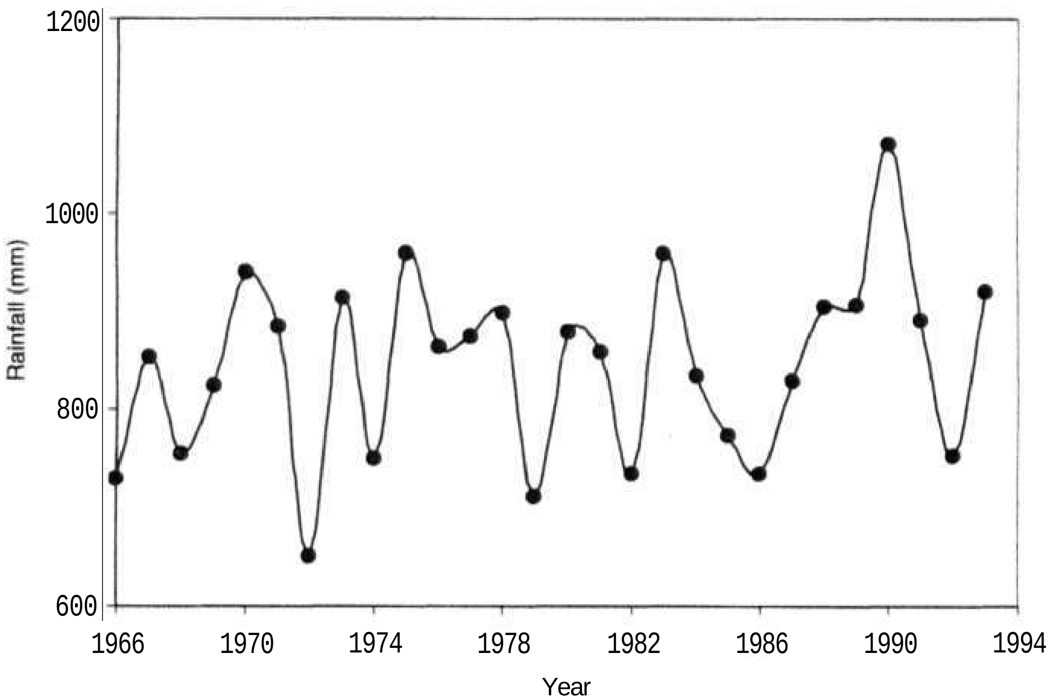

Figure 2.3. Summer monsoon rainfall in Inda, 1966-93.

Among the meteorological factors, total amount of rainfall received and its distribution during the crop-growing season seem to play a pivotal role. Soil fertility status, yield potential of the crop varieties, occurrence of pests and diseases, and management are other important factors.

The weighted average of the southwest monsoon rainfall (June-September) data for the years 1966-1993 is shown in Figure 2.3. As can be discerned from the data in Figures 2.2 and 2.3, groundnut production is dependent on the amount of seasonal rainfall. The cross correlation between the two variables is low probably because of the confounding effect of the management factors and presence of a trend in the production data. Thus, to make the two data series comparable, it is necessary to detrend the production data and normalize the two variables resulting in representative non-dimensional indices.

Following Parthasarathy et al. (1988), the all-India southwest monsoon rainfall (Ri) is expressed as the percent departure (Pi) from the normal rainfall (R):

$$P_i = \frac{(R_i - R)100}{R}$$

The influence of the meteorological variables on groundnut production was separated from the management factors by fitting an exponential trend curve of the following form to the production data:

$$T = ab^x$$

where a and b are constants, T is the trend value, and x is the rate of change of trend in a given year. The logarithms of this series will show a linear trend as:

$$\log T = (\log a) + (\log b)x$$

Thus, the exponential trend is calculated by taking the logarithms of the production data and then fitting a linear trend to the logarithms. The above equation can also be written as:

$$T' = b_o + b_1 x$$

where $T = \log T$, $b_o = \log a$, and $b_1 = \log b$. The trend value T for original series is obtained by taking antilogarithms of T' and the rate of change of trend or growth (g) can be calculated as:

$$g = (\text{antilogarithm of } b_1) — 1$$

The annual groundnut production data from 1966 to 1993 were subjected to this analysis to determine the trend component in the series. The growth rate term so calculated was 2.2% yr^{-1} implying that groundnut production in India has been increasing at a rate of 2.2% yr^{1} from 1966. Parthasarathy et al. (1988) examined the relationship between overall agricultural production in India and rainfall and reported an annual growth rate of food production of 2.8%. Thus, the annual rate of change of groundnut production estimated in this analysis suggests that groundnut production in India has been increasing at a rate in pace with the overall agricultural production in India. The trend values are calculated for each year by taking the antilogarithms of V and these values are plotted as a trend line passing through the production data points (see Fig. 2.2). Finally, groundnut production indices (G_i) are calculated as follows:

$$G_1 = (Y_i/T_i)\ 100$$

where Yi represents the annual groundnut production. Thus, both Pi and Gi series are expressed as percentage quantities and therefore, are easily comparable with each other.

A scatter plot of Gi against Pi is shown in Figure 2.4. Despite some scatter, the data indicate a high positive relationship between the two variables. A simple linear regression of annual groundnut production indices on percentage departures in rainfall resulted in a r^2 value of 0.60 significant at 5% level. These results imply that soil moisture status during the crop-growing season is the most dominant factor and contributes to 60% of variation in groundnut production. Hence, it can be concluded that natural resource management (NRM) practices aimed at increasing the soil moisture availability hold the key for increasing groundnut production and hence, improving groundnut productivity in the country.

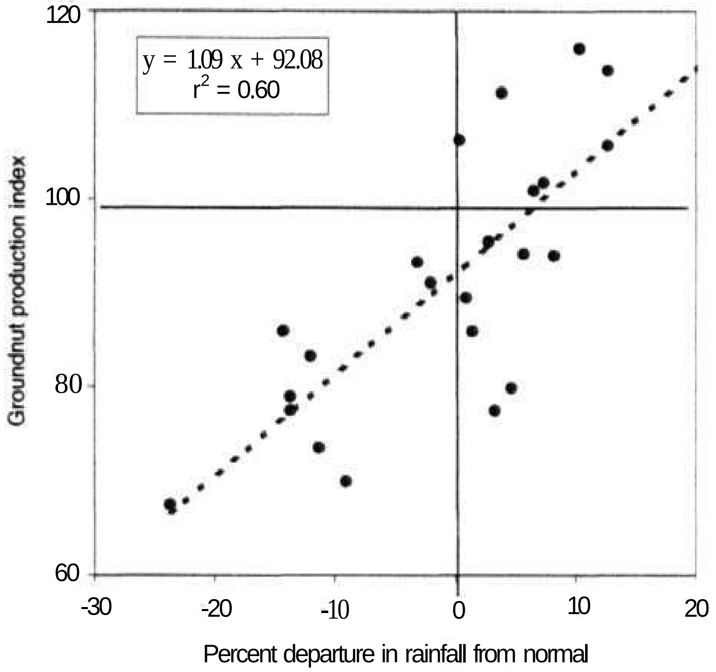

Fig. 2.4. Groundnut production against summer monsoon rainfall in India. 1966-93.

Major Groundnut-growing States of India

Andhra Pradesh, Gujarat, Karnataka, Maharashtra, and Tamil Nadu are the major groundnut-growing states in India (see Figure 2.1). These five states alone have contributed 92% of the area under groundnuts and nearly 95% of the production in the country from 1966 to 1993 (Fig. 2.5; Table 2.1).

During 1966-70, Gujarat led the country in groundnut production (1.2 million t) and area (1.8 million ha) contributing 27% to the country's total production. The yield levels were comparable to the national average. Following Gujarat, Andhra Pradesh contributed 22%, Tamil Nadu 19%, Karnataka 13%, and Maharashtra 13%. In the subsequent years, however, a general increasing trend was observed in the area and production in these major states. During 1976-80, except for Gujarat, all the states showed a decline in area and production. However, with the Government's decision to lay special emphasis on oilseed production in the country during the Sixth Five-Year Plan (Patel 1988), groundnut area and production have continued to increase. During 1991-93, Andhra Pradesh surpassed Gujarat and led the country with a production of 2.1 million t from an area of 2.3 million ha; but the productivity was lower than the national average. Yields in Tamil Nadu and Maharashtra were higher than the national average during 1991-93 (Table 2.1).

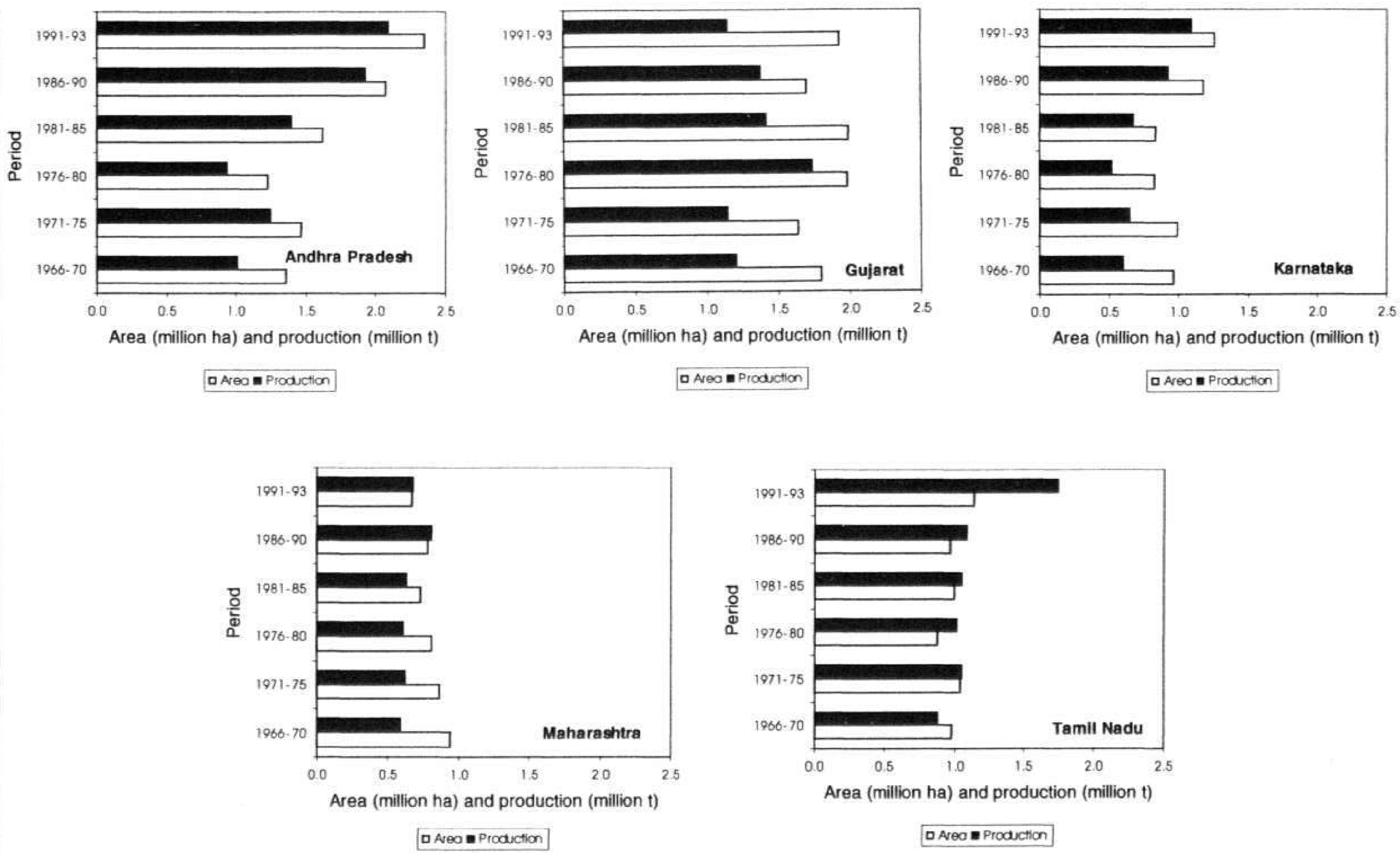

Figure 2.5. Groundnut area and production in the major groundnut-growing states of India during the 5-year periods from 1966 to 1993.

Table 2.1. Groundnut area, production, and yield in the major groundnut-growing states of India during the 5-year periods from 1966 to 1993.

State	Year	Area (million ha)	Production (million t)	Yield (t ha^{-1})	Contribution (%) to national production
Andhra Pradesh	1966-70	1.4	1.0	0.74	22
	1971-75	1.5	1.2	0.85	25
	1976-80	1.2	0.9	0.77	18
	1981-85	1.6	1.4	0.87	25
	1986-90	2.1	1.9	0.93	28
	1991-93	2.3	2.1	0.89	28
Gujarat	1966-70	1.8	1.2	0.67	27
	1971-75	1.6	1.1	0.69	23
	1976-80	2.0	1.7	0.85	33
	1981-85	2.0	1.4	0.70	25
	1986-90	1.7	1.4	0.76	20
	1991-93	1.9	1.1	0.60	15
Karnataka	1966-70	1.0	0.6	0.63	13
	1971-75	1.0	0.7	0.65	13
	1976-80	0.8	0.5	0.63	10
	1981-85	0.8	0.7	0.80	12
	1986-90	1.2	0.9	0.79	14
	1991-93	1.3	1.1	0.86	15
Maharashtra	1966-70	0.9	0.6	0.63	13
	1971-75	0.9	0.6	0.70	12
	1976-80	0.8	0.6	0.76	11
	1981-85	0.7	0.6	0.86	11
	1986-90	0.8	0.8	1.01	12
	1991-93	0.7	0.6	1.02	9
Tamil Nadu	1966-70	1.0	0.9	0.90	19
	1971-75	1.0	1.1	1.01	21
	1976-80	0.9	1.0	1.16	19
	1981-85	1.0	1.1	1.05	18
	1986-90	1.0	1.1	1.12	16
	1991-93	1.1	1.7	1.52	23
India	1966-70	6.6	4.5	0.68	
	1971-75	6.5	5.0	0.77	
	1976-80	6.2	5.3	0.84	
	1981-85	6.8	5.7	0.84	
	1986-90	7.4	6.8	0.91	
	1991-93	8.0	7.4	0.93	

Seasonal Groundnut Production in the Major States

The data on average area, production, and yield of groundnut in Andhra Pradesh, Karnataka, and Tamil Nadu during rainy and postrainy cropping seasons in 5-year periods from 1971 to 1990 are presented in Table 2.2. For each state, the average area and production data of each of the 5-year periods are partitioned to reflect the relative distribution of area and production during rainy and postrainy seasons. The area under rainy and postrainy season groundnut crop during 1971-90 is mapped in Figure 2.6.

In 1971-75, 86% and 89% of the total annual area was under groundnut crop during the rainy season in the states of Andhra Pradesh and Karnataka respectively and 14% and 11% of the area was sown to groundnut during the postrainy season in the two states respectively (Table 2.2). Rainy and postrainy season production accounted for 78% and 22% in Andhra Pradesh and 79% and 21% of the annual production in Karnataka respectively. Tamil Nadu, however, accounted larger area for postrainy season production (24% of its annual area) during 1971-75. During subsequent periods, the area under the crop during postrainy season showed a steady increasing trend in the states of Andhra Pradesh and Karnataka. The trend in Tamil Nadu was, in general, constant over the years. Andhra Pradesh and Karanataka contributed 30% of their annual area for groundnut crop during 1985-90.

The productivity levels during postrainy season are higher in the three states as compared to the rainy season crop (Table 2.2). In general, in most groundnut-growing regions of India, the rainy season crop experiences moisture stress during the crucial crop establishment stage and at the yield determining reproductive stages of flowering, peg initiation, and pod formation. However, the protective irrigation reduces drought risk considerably during the postrainy season. The observed increasing trend in postrainy groundnut area and productivity is a positive development. Therefore, future research efforts should focus on disseminating existing technology and providing improved methods to the farmers of these regions to sustain the incentive to bring more area under postrainy groundnut cultivation.

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Table 2.2. Average area, production, and productivity of groundnut during rainy and postrainy seasons in the 5-year periods from 1971 to 1990 in Andhra Pradesh, Karnataka, and Tamil Nadu states of India.

	Rainy season					Postrainy season					Annual		
State/Years	Production (million t)	Percentage of annual production	Area (million ha)	Percentage of annual area	Yield (t ha^{-1})	Production (million t)	Percentage of annual production	Area (million ha)	Percentage of annual area	Yield (t ha^{-1})	Production (million t)	Area (million ha)	Yield (t ha^{-1})
Andhra Pradesh													
1971–75	0.97	78	1.26	86	0.77	0.27	22	0.21	14	1.33	1.24	1.47	0.87
1976–80	0.68	72	1.04	85	0.65	0.26	28	0.18	15	1.44	0.94	1.22	0.77
1981–85	0.98	70	1.31	81	0.75	0.42	30	0.31	19	1.36	1.40	1.62	0.88
1986–90	1.35	70	1.68	81	0.80	0.58	30	0.39	19	1.47	1.92	2.07	0.94
Karnataka													
1971–75	0.51	79	0.88	89	0.58	0.14	21	0.11	11	1.25	0.65	0.99	0.73
1976–80	0.35	67	0.70	85	0.50	0.17	33	0.12	15	1.39	0.52	0.82	0.70
1981–85	0.46	68	0.70	84	0.66	0.22	32	0.13	16	1.62	0.68	0.84	0.87
1986–90	0.65	70	0.96	81	0.68	0.28	30	0.22	19	1.24	0.92	1.18	0.82
Tamil Nadu													
1971–75	0.69	66	0.79	76	0.88	0.36	34	0.25	24	1.43	1.05	1.04	0.97
1976–80	0.68	67	0.67	76	1.01	0.33	33	0.21	24	1.58	1.01	0.88	0.99
1981–85	0.70	67	0.73	74	0.95	0.34	33	0.25	25	1.39	1.05	0.99	1.03
1986–90	0.75	69	0.72	75	1.04	0.34	31	0.24	25	1.40	1.09	0.96	1.11

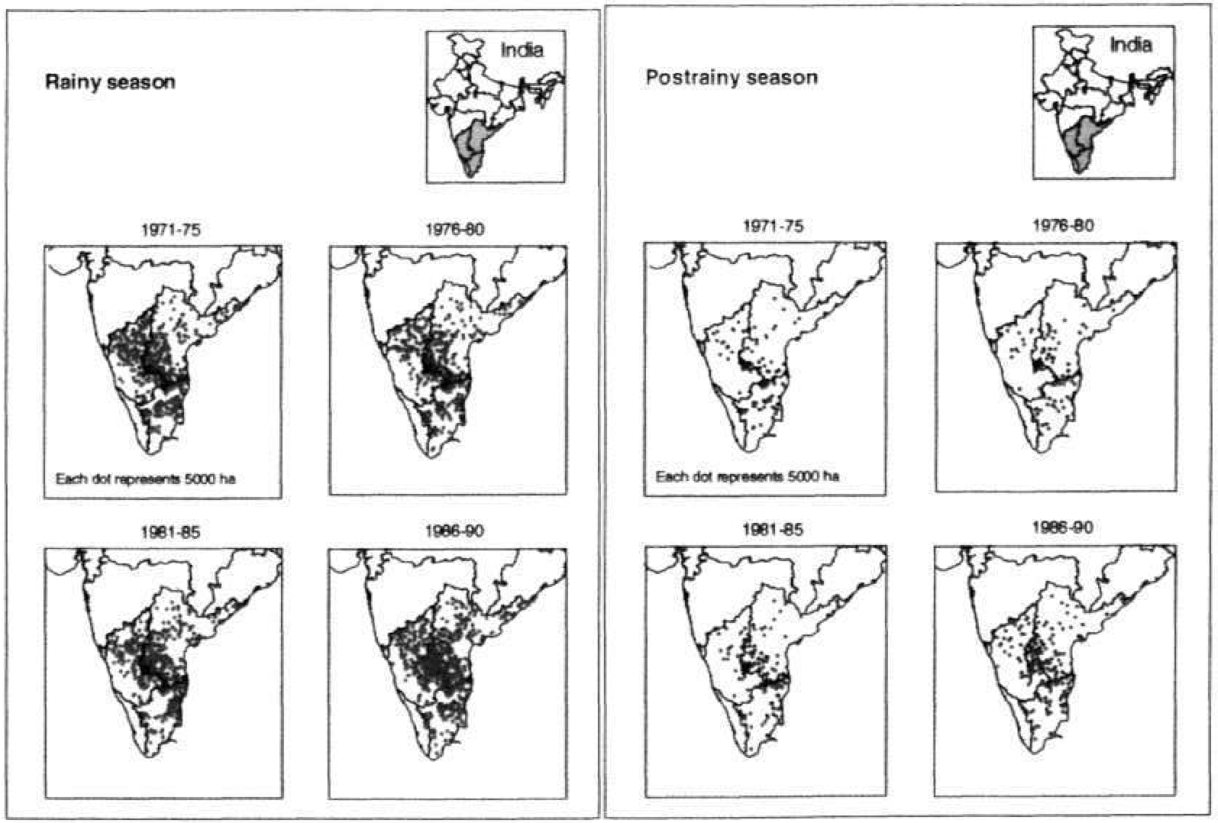

Figure 2.6. Area under rainy and postrainy season groundnut crops in the states of Andhra Pradesh, Karnataka, and Tamil Nadu in India during 1971–90 (Data Source: ICRISAT Districtwise Database).

Agroclimatic Conditions

As per the agroclimatic classification adopted for India, Anantapur region is described as the scarce rainfall zone of Rayalseema in the state of Andhra Pradesh in the Indian southern plateau and hills region (Rastogi 1991) (Fig. 3.1).

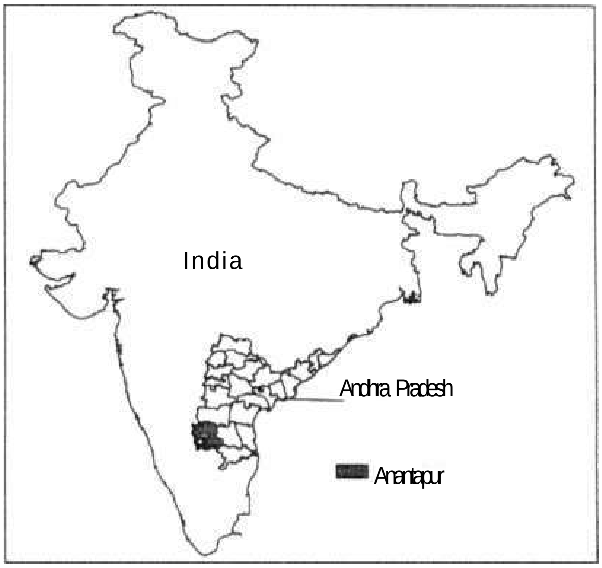

Figure 3.1. A map of India showing the geographical location of Anantapur district in the state of Andhra Pradesh.

Climate

The annual average (averaged over a period from 1980 to 1990) amount of solar radiation received is 22.1 MJ nr^{2} d^{-1} with a standard deviation of 3.1 MJ m^{-2} d^{-1}. While the annual average maximum temperature is 31℃ (±3.4℃), the minimum temperature is 19℃ (±2.4℃). The annual total rainfall is 566 mm (±6.3 mm). This compares favorably well with the 30-year average annual rainfall of 565 mm.

During January, the radiation intensity is low at about 17 MJ m^{-2} d^{-1} (Fig. 3.2). The incident solar radiation increases steadily and reaches a peak of about 27 MJ m^{-2} d^{-1} during April and May. With the onset of the southwest monsoon activity during early June, the radiation intensity decreases sharply. Subsequently, a gradual decline is observed. The amount of radiation (~ 16 MJ nr^{2} d^{-1}) incident on the surface is as low in December as in January (Fig. 3.2).

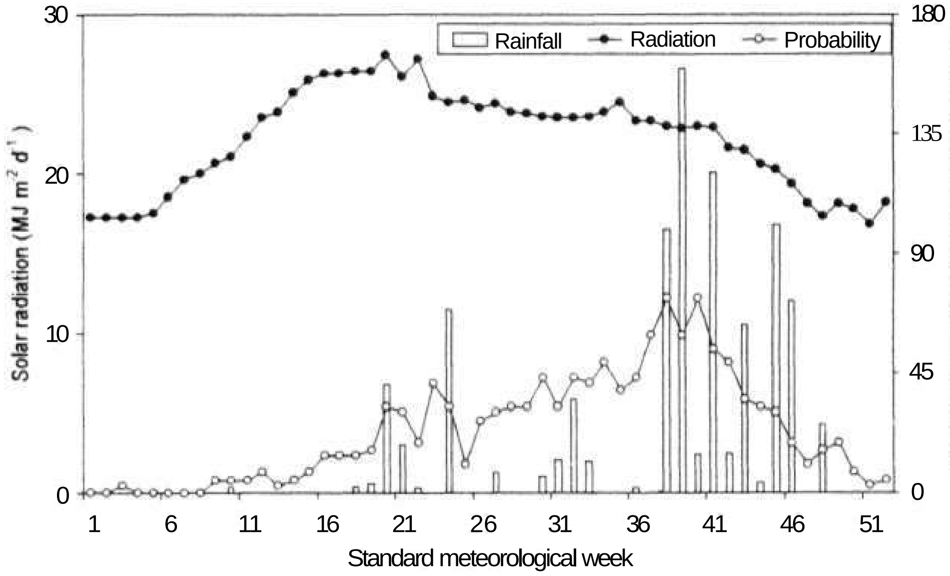

Figure 3.2. Weekly average solar radiation, rainfall, and probability of >10 mm rainfall at the Dryland Agricultural Research Station, Anantapur, India during 1980-90.

Since the annual temperature cycle is primarily governed by the solar energy input, maximum and minimum temperatures exhibit a pattern similar to that of incident radiation. Temperatures are low with maximum at 30℃ and minimum at 17℃ during January and increase with increasing radiation input; and these reach peak values during April-May (40℃ maximum and 22℃ mimimum). Subsequent ly, maximum and minimum temperatures gradually decrease to about 29℃ and 16℃ respectively towards the end of December (Fig. 3.3).

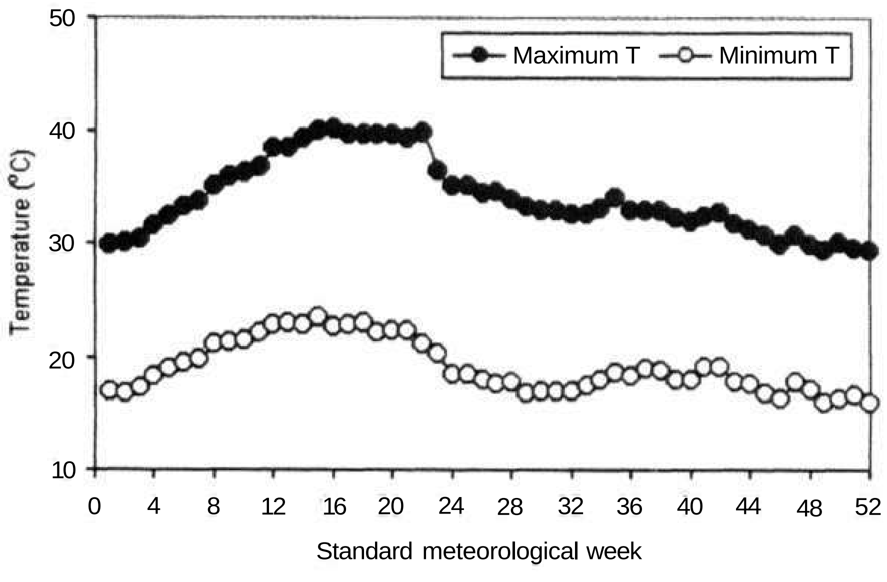

Figure 3.3. Weekly average maximum and minimum temperature at the Dryland Agricultural Research Station, Anantapur, India during 1980-90.

The rainfall amount and distribution patterns during three contrasting years at the Dryland Agricultural Research Station, Anantapur indicated that 1972 was a normal rainfall year with about 557 mm (Fig. 3.4); normal rainfall for Anantapur region is 565 mm. While 1998 was a wet year with 920 mm of rainfall (63% above normal rainfall), 1984 was a dry year with 176 mm (69% below normal). The rainfall patterns of 1972 and 1998 indicate that the distribution is bimodal in nature. Even during normal or high rainfall years, intermittent dry spells occur in the initial and mid-periods of the rainy season (Fig. 3.4). Ample rains are received in late August, September, and early October. Generally, dry conditions prevail thereafter. In 1984 (a dry year), drought conditions prevailed throughout the year resulting in a total crop failure (Fig. 3.4).

The Anantapur region receives the least amount of rain in the state. Also, rain is highly uncertain and erratic. This leads to occurrence of severe droughts and crop failures. The region, in fact, represents a chronically drought-prone area in the state.

Soils

Anantapur is the driest district in the scarce rainfall zone of Andhra Pradesh with a predominance of Alfisols. These soils are shallow and have low fertility and low moisture-holding capacity. Soil erosion including sheet, gully, and wind erosion in some areas is a serious constraint.

Crops

Most of the cultivated area is rainfed and is dependent on the southwest monsoon. Due to high variability of monsoons, crop productivity is low, uncertain, and unstable. The major crops grown in the region are groundnut, sorghum (Sorghum bicolor (L.) Moench), pearl millet (Pennisetum glaucum (L.) R. Br.) (and other millets), rice (Oryza sativa L), cotton (Gossypium sp), and coriander (Coriandrum sativum L). Hence, groundnut-, sorghum-, millet-, rice-, and cotton-based cropping systems predominate. Amongst the cereals, sorghum and rice are the dominant crops each occupying 75,000 and 55,000 ha respectively (Table 3.1). Groundnut is the most dominant oilseed crop grown in the region. Crop production in this low rainfall area is a high-risk proposition. Hence, many of the small and marginal farmers combine crop production with a livestock base such as sheep or goat rearing. Cereal, oilseed, and pulse crops are common in the region.

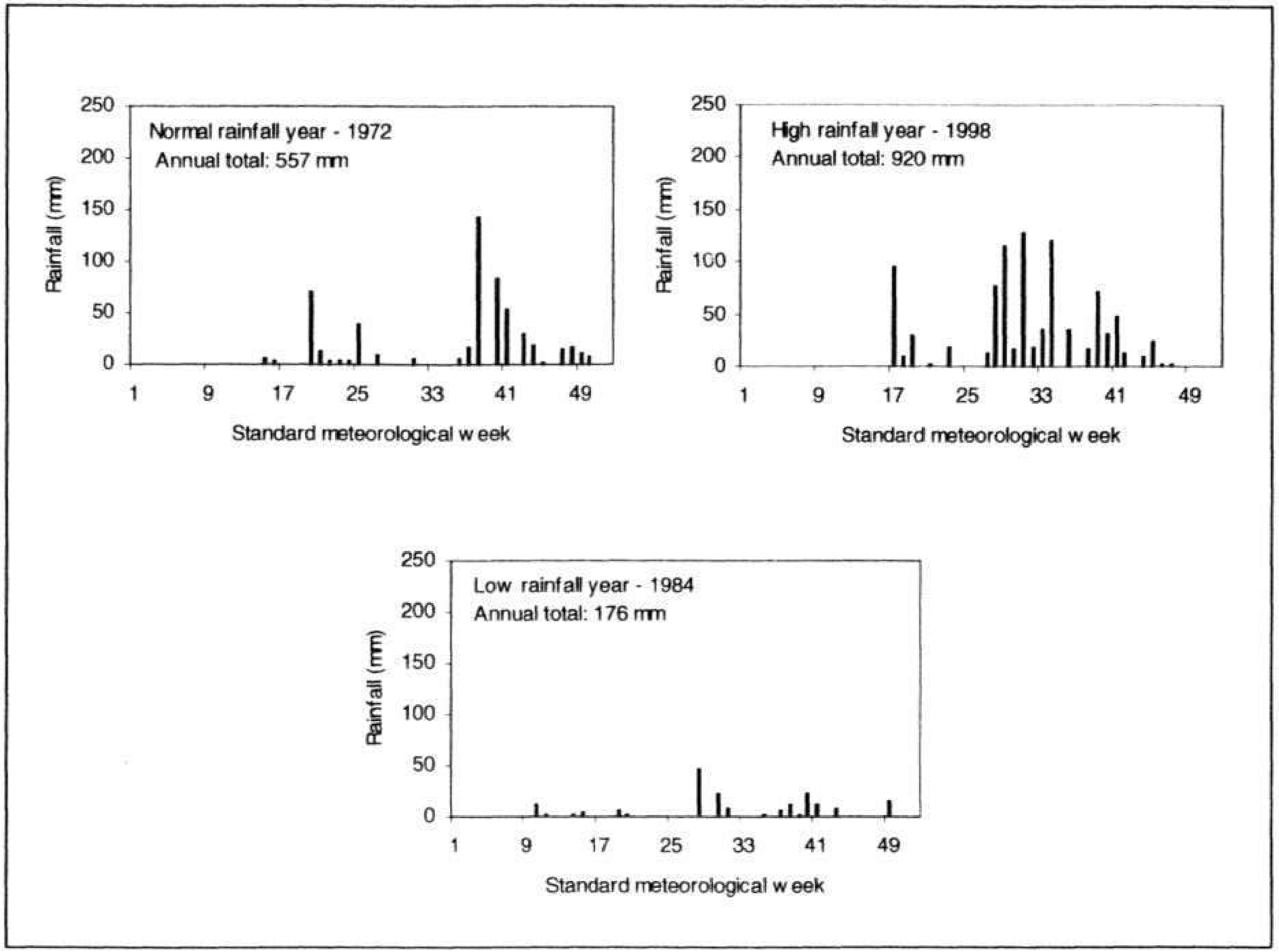

Figure 3.4. Weekly rainfall patterns in three contrasting years at Anantapur, India.

Table 3.1. Area (averaged over a period from 1966 to 1993) under major crops grown in the Anantapur region, India.

Crop	Area (mean) ('000 ha)	Area (standard deviation) ('000 ha)
Cereals	253	189
Rice	55	24
Wheat	1	1
Sorghum	75	55
Pearl millet	34	25
Maize	1	0
Finger millet	21	12
Oilseeds	414	233
Groundnut	389	216
Sesame	4	4
Safflower	3	1
Castor	5	2
Pulses	59	32
Chickpea	5	6
Pigeonpea	19	9
Minor pulses	44	27

Groundnut Area and Production

While the state of Andhra Pradesh has led the country in groundnut production and area in recent years, the Anantapur region is the leading producer and has the largest area under the crop in the state. The region accounted for 16% of the area in the state and 3% of the area in the country during 1966-70. Its contributions to groundnut production was 14% in the state and 3% in the country during this period (Table 3.2). Groundnut was cultivated on 0.22 million ha during 1966-70 with a production of 0.14 million t. The area under the crop increased to 0.73 million ha and the production to 0.58 million t during 1991-93. This region represented 31% of the area under the crop and 28% of the production in the state and 9% of the area and 8% of the production in the country.

Table 3.2. Groundnut area, production, and yield in the Anantapur region, India during 1966-93.

Year	Area (million ha)	Contribution (%) to area in the state	Contribution (%) to area in the country	Production (million t)	Contribution (%) to state production	Contribution (%) to national production	Yield (t ha-1)
1966-70	0.22	16	3	0.14	14	3	0.62
1971-75	0.28	19	4	0.22	17	4	0.77
1976-80	0.33	27	5	0.20	22	4	0.62
1981-85	0.44	27	7	0.35	25	6	0.80
1986-90	0.64	31	9	0.53	27	8	0.83
1991-93	0.73	31	9	0.58	28	e	0.79

Despite the agroecologically marginal conditions for rainfed groundnut production and the consequent poor performance of the crop from year to year in terms of final yield, the area and production in the region have shown an increasing trend over the years (Fig. 3.5; Table 3.2). This region, as such, does not provide optimal conditions for a sustained production of groundnuts. Nevertheless, the farmers of the region continue to adopt groundnut-based cropping systems. Thus, the reasons for an increasing trend, unfortunately, appear to be related more to the lack of awareness of the farmer on the availability of better performing, more profitable, alternate cropping systems suitable for the region than to the motivation a sustained production would otherwise offer. Despite its shortcomings, this region represents a potential area for concerted efforts of interdisciplinary research for improving groundnut productivity.

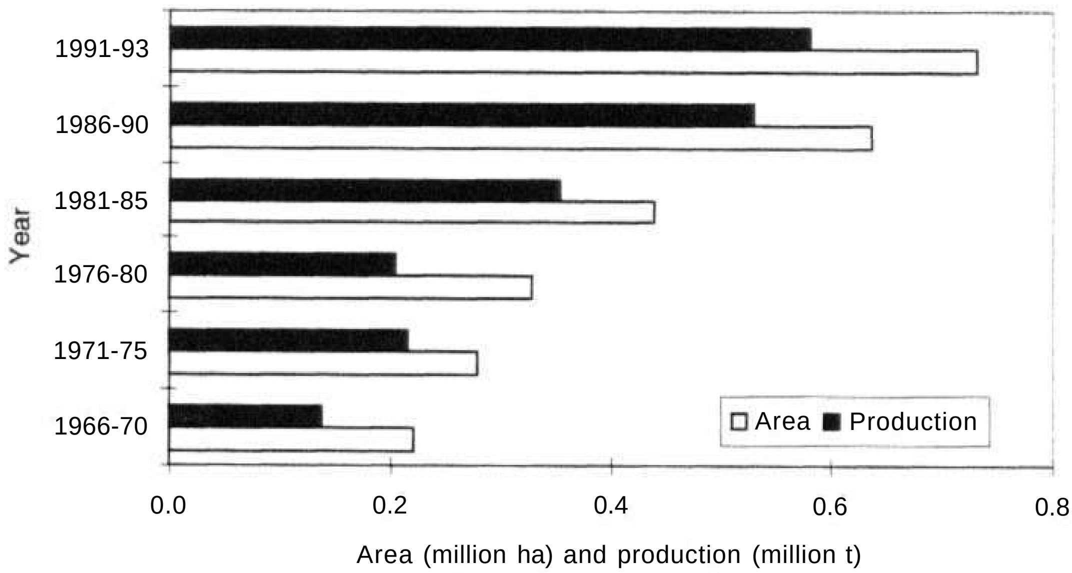

Figure 3.5. Groundnut area and production in the Anantapur region, India during 1966-1993 (Data Source: ICRISAT Districtwise Crop Database).

In general, the yield levels in the Anantapur region are lower by 10% when compared to the state and national yields under the best case scenario (Table 3.3). Under the worst case scenario, the yields are lower by 25% of the state and national yields. The situation is much worse when compared to the yield levels of some of the leading groundnut producers in the world, e.g., China and USA where the yield levels are five-fold high. Such low yields in the Anantapur region are attributed to severe production constraints posed by the natural resources as well as the socioeconomic conditions of the farming community.

Constraints to Groundnut Production

As discussed earlier, groundnut productivity in the Anantapur region is low when compared to the state and national levels. This is due to various constraints to production. During certain severely constrained years, the farmers fail to recover even the minimal cost incurred on production. The following constraints to production were identified based on a socioeconomic survey of the groundnut farmers from the region during the 1998 cropping season.

Cultivation of the crop on marginal and submarginal lands

The Anantapur region is a chronically drought-prone area with soils that are low in fertility and water-holding capacity. The rainfall pattern is erratic as the amount and distribution of rainfall varies greatly from year to year. Groundnut is cultivated on marginal and submarginal lands under rainfed conditions. Using conventional methods, the farmers choose a certain "time window" (with some amount of assured rainfall) during the cropping season to sow the crop. In general, the initial crop establishment itself meets with failure due to lack of sufficient soil moisture. Even if the crop manages to establish, there is no assurance that the crop will attain normal maturity as the crucial phenological stages subsequent to crop establishment generally coincide with dry spells in the region. Hence, the application of landscape watershed

Table 3.3. A comparison of groundnut yields at national, state, and regional levels in Anantapur region in the state of Andhra Pradesh, India during 1966-1993.

Year	National yield (t ha^{-1})	State yield (t ha^{-1})	Regional yield (t ha^{-1})	Percentage of national yield	Percentage of state yield
1966-70	0.68	0.74	0.62	90	83
1971-75	0.77	0.85	0.77	100	91
1976-80	0.84	0.77	0.62	74	81
1981-85	0.84	0.87	0.80	96	93
1986-90	0.91	0.93	0.83	91	90
1991-93	0.93	0.89	0.79	85	89

management system is crucial to the sustainability of groundnut production (see Virmani 1999 for a review on watershed management).

Low levels of inputs and poor agronomic practices

The main reason for low levels of inputs is that resource-poor farmers cultivate the crop. In addition, with intensification of agriculture, soil fertility is fast degrading. Soils that were deficient in nitrogen some decades ago have now begun to show deficiency in major, secondary, and micronutrients. Despite the fact that Indian soils in general are deficient in organic matter content, with the increased use of chemical fertilizers, use of organic manure is being overlooked. There is an urgent need for a balanced use of nutrients based on continuous soil fertility evaluation in view of multiple cropping and growing high-yielding varieties in various sequences and cropping systems. The farmers lack awareness about important cultural practices such as seed treatment, method and time of sowing, application of proper quantities of plant nutrients, and plant protection measures. The present agrarian infrastructure lacks appropriate agronomic technology for different agroclimatic regions and location-specific technology for high and low input conditions to suit the socio-economic environments of big and marginal farmers.

Insect pests, diseases, and weeds

Insect pests, diseases, and weeds are a serious menace to the groundnut crop in the region. The region suffers from a serious incidence of insect pests such as aphids, white grub, and diseases such as late leaf spot (caused by Phaeoisariopsis personata) and rust (caused by Puccinia arachidis). Even when the seasonal weather appears to favor high crop yields, the farmers are still not assured of a bumper crop due to severe disease and pest attack. The resource-poor farmers do not employ any integrated pest management (IPM)-based plant protection measures.

Use of low-yielding and late-maturing varieties

Another reason for low productivity in the region is the non-availability of high-yielding and biologically-efficient varieties tested and suited to the specific region. Farmers use low-yielding and late-maturing varieties. Some of the high-yielding groundnut varieties known to have performed well in other groundnut-growing states of the country are not available for distribution in the region. Since farming in the region is a risky proposition, early-maturing varieties with high yield potential, harvest index, resistance to drought, insect pests, and diseases, and high oil content are needed.

Inefficient labor use

Despite moderately high cost efficiency in groundnut production, there appears to be inefficiency in labor use. This is primarily due to non-availability of farm labor and partly due to high wage rates prevailing in the area, resulting in less than optimal availability of labor required in the production process.

High cost and non-availability of inputs

Inputs such as seed and fertilizers are not easily available or are highly priced. There is a lack of credit facility for purchase inputs and a lack of marketing facilities for efficient distribution of inputs. Non-availability of quality seeds at affordable prices has been a serious problem for small and marginal farmers. Hence the farmers resist using new varieties with high yield potential. In addition, the absence of an organized certified seed production and distribution system in the region is strongly felt. To cite an example of the inadequacy of the present setup, the seed requirement for 7.2 million ha of groundnut crop during 1984-85 was 1.1 million t, while only 26,000 tons of certified seed (2.5% of the requirement) were produced in the country during that year (Umesh 1991).

Anantapur Farmer Profiles

Based on the socioeconomic survey of groundnut-producing farmers conducted during the 1998 cropping season, from nearly 30 villages in the Anantapur region, farmer profiles have been developed. The farmers were classified as 'big" or "small" farmers depending on the size of their land holding. The farmers cultivating <4 ha of total agricultural land were classified as "small farmers" and farmers cultivating >8 ha of land as "big farmers" (Table 3.4).

Size of land holding

It has been noted from the survey analysis that a "small farmer" with less agricultural land is restricted to allocate the available piece of land to the cropping pattern generally adopted in the region. A "big farmer" with relatively more agricultural land at his disposal, however, has the option to allocate land to other land-uses. Generally, the "big farmers" of the Anantapur region allocated a part of their total land holding to the cultivation of horticultural crops such as mango (Mangifera indica L) and arecanut (Areca catechu L), and to mulberry (Morus alba L.) cultivation for sericulture. Thus, a "big farmer" is more diversified and is less likely to depend solely on groundnut-based agriculture for his family income.

Family size

"Small farmers" have medium- to small-sized families, while the "big farmers" of the region generally have medium- to big-sized families. As discussed earlier, availability of farm labor is one of the severe constraints to groundnut production in the region. With a bigger family size, "big farmers" are at an advantage as they can meet their farm labor requirement through their own family members.

Education level

"Big farmers" of the region have a higher education level compared to the "small farmers". Some of the "big farmers" have held scientific research positions in the local agricultural universities.

Financial status

The financial status of "big farmers" of the region is higher than that of the "small farmers". Many of the "big farmers" of the region own tractors, several pairs of bullocks, and other farm equipment. In contrast, some of the "small farmers" are so resource-poor that they do not own even a single pair of bullocks and thus have to depend upon other farmers for their routine farming needs.

Alternate sources of income

Realizing the uncertainty in income from the severely constrained groundnut-based agriculture, the "big farmers" of the region utilize their resources to diversify into other sources of income such as horticulture, sericulture, dairying, poultry farming, and sheep/goat rearing. Thus, the "big farmers" are less dependent on groundnut cultivation in particular or agriculture in general and income from groundnut cultivation has a smaller share in the total family income. On the contrary, the "small farmers" solely depend on agriculture for their family income. Since their options are limited, they opt for the regionally adopted groundnut-based cropping pattern. Weather permitting, they harvest yields barely enough to recover the high cost of groundnut cultivation and hardly make both ends meet. Thus, for many "small farmers", uncertain income from groundnut cultivation is the only source of family income.

Irrigation facilities

The "big farmers" of the region have developed irrigation facilities on their farms. They employ open and bore wells for irrigation. Since irrigation facilities are available, many of these farmers take up groundnut cultivation during the postrainy season and summer in addition to cultivation of rice. The ratio of irrigated to total land owned by a "big farmer" of the region was 0.3 to 0.4. The "small farmers" of the region generally did not have any irrigation facilities.

Application of fertilizers and plant protection measures

Groundnut is cultivated primarily under rainfed conditions during the rainy season. Due to lack of a proper long-term weather forecasting system, the farmers are ill-equipped to predict the crop performance, occurrence of pests and diseases, and the final yield in advance. Even if the "big farmers" of the region can well afford, in light of the uncertain returns, they are less willing to invest more money on inputs for plant protection. Thus, fertilizer application for groundnut cultivation in the region is rather low and no IPM-based plant protection measures are adopted to control yield losses due to pests and diseases.

Preferred farming strategy

Both "big" and "small farmers" prefer to optimize groundnut yields with some risk avoidance technologies.

Table 3.4. Profiles of a big and small farmer in the Anantapur region, India.

Criterion	Big farmer	Small farmer
Land holding size	>8ha	<4 ha
Family size	Medium to big	Medium to small
Education level	High	Low
Purchasing power	High	Low
Dependence on agriculture for family income	Low	High
Alternate sources of income	Available	Not available
Crops grown during rainy season	Groundnut, pigeonpea, horse gram, mung bean	Groundnut, pigeonpea, horse gram, mung bean
Crops grown during postrainy season	Rice, millets, groundnut	None
Ratio of irrigated to total land area owned	0.3-0.4	0-0.05
Irrigation facilities	Available	Not available
Cost of groundnut cultivation	Low	High
Groundnut productivity rating	Low	Low
Share of income from groundnut cultivation in the total family income	Low	High
Fertilizer application	Low to moderate	Low to moderate
Application of plant protection measures	Not followed	Not followed
Awareness about improved methods of cultivation	Aware	Not aware
Preferred farming strategy	Maximize yields with some risk of low yields	Maximize yields with some risk of low yields

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Simulation of Groundnut Response to Sowing Date Variation: CROPGRO-Peanut Model

Introduction

Agricultural production is based on complex biological systems. It is further complicated by the uncertainties of weather. Our inability to forecast weather over a season has meant that farming practices are prone to weather risk. Farmers in rainfed areas by and large do not know before they plant their crops, the likely response to fertilizer or other management inputs. The decisions that farmers make are usually based on their own experience, and these are weighted to the likelihood of failures and successes. However, agricultural systems are dynamic in nature and farmers adopt and innovate continuously. Hence, a pertinent question would be: How does one determine the success of the introduction of any new practice? Ideally, to answer this question, the decision-makers (farm managers or farmers) would like to have access to a long-term record of observations from a production system incorporating a new practice which spans a length of growing season over a range of locations. However, such long-term data are seldom available.

Crop models which simulate major biological interactions in agricultural production systems as well as the effects of weather are excellent first approximation tools to study such interactions. Such models can play an important role in providing appropriate information to decision-makers by readily simulating crop responses, on a first approximation basis, to single and multiple inputs. Also, one can simulate the response to a particular practice over many years and compare the results with the other strategies. Once the simulations are made, the results need careful interpretation. Arithmetic mean responses can be calculated from the temporal data. However, good decision-making requires more information (such as the risks associated with a particular strategy) rather than a mere knowledge of the most likely response.

Problem Statement

India has the largest area under groundnut crop in the world and is second in production next only to China. In India, the crop occupies 45% of the area and represents 55% of the total oilseeds produced in the country. Nearly 80% of the area sown to groundnuts is rainfed and relies entirely on summer monsoon rainfall. The rainfall in most of the groundnut-growing regions is low and erratic. There is a high variability in the onset of monsoons, annual rainfall, and distribution of rainfall over the growing season (Gadgil et al. 1998). Moreover, such high variability in precipitation is generally associated with a high probability of an early season drought. Thus, rainfed agriculture in India is a very risky proposition. One of the decision-making problems confronting the farmers at the onset of the cropping season is choice

of an optimum sowing window. When crop establishment is poor, the farmers incur heavy income losses and often, the income from a crop (e.g., groundnut) is less than the cost of cultivation.

With the above in view and as a case study, the Anantapur region in the state of Andhra Pradesh was chosen for simulating the response of groundnut to changing sowing dates. On-farm trials were simultaneously carried out in tandem. The region was chosen for this study for the following reasons:

- The region alone accounts for nearly 10% of the groundnut production in the country and thus plays a major role in the regional economy;
- The soil data and historical weather records from 1962 to 1998 are readily available for this region;
- A number of cooperative farmers from this region were willing to participate in the research activity.

Methods

The soils in the Anantapur region are Alfisols and associated soils. These hold about 100 mm of available water in the top 120 cm soil profile. The simulations were performed for the groundnut cultivar TMV 2, a Virginia bunch type most commonly cultivated in the region. The cultivar matures in about 100 days. The genetic coefficients of this cultivar were calibrated using the crop growth and development data collected at the Dryland Farming Research Station, Anantapur. A plant population of 33.3 plants m^{-2} and 30-cm row spacing were assumed. The simulations were performed for the 10 sowing windows each of 15 days duration starting May 1 to September 30. In a given sowing window, the sowing was considered to have taken place on a day provided the soil water content in the top 30 cm of soil profile had reached at least 40% of available water-holding capacity. Sowing was not done if this condition was not satisfied. The model outputs for each year simulated were sowing date, biomass and seed yields, total rainfall during the crop growth period, and water balance components of groundnut production system. The mean and standard deviations of various output variables and their probability distributions were plotted using the DSSAT software (version 3.1).

Results and Discussion

Simulated mean yield responses

Simulated mean (averaged over 37 years of historical weather data) groundnut yields were plotted against the corresponding sowing dates (Fig. 4.1). The data indicate that sowing groundnuts during the first fortnight of May results in the lowest yields (365 kg ha^{1}). The yields increase with increasing delay in sowing. Maximum yields (1282 kg ha^{1}) are obtained when the seed is sown during the first fortnight of August (Fig. 4.1). The groundnut crop planted during the period from mid-July to the end of August results in yields greater than 1000 kg ha^{-1}. With any subsequent delay in sowing, there is a decline in the seed yield. Groundnut sown during the second half of September yields as low as 649 kg ha^{-1}.

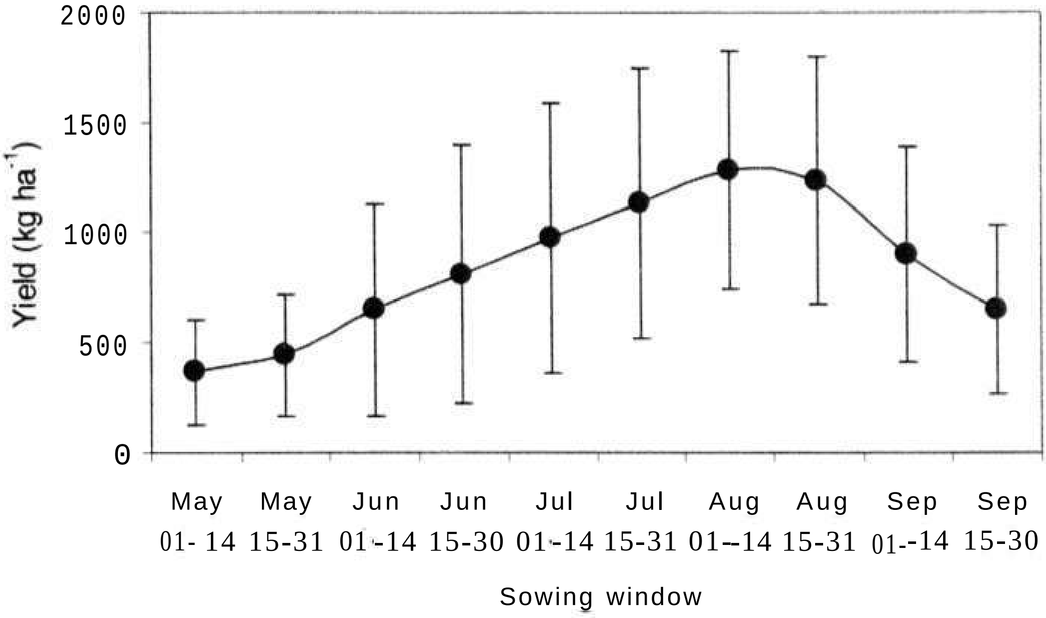

Figure 4.1. Simulated groundnut yields (averaged over 37 years of historical weather data) as a function of crop sowing options from May to September.

Such a response to variations in sowing date is consistent with the pattern of soil moisture availability to the groundnut crop during the growing season. The rainfall during the season corresponding to the sowing window increases with increasing delay in sowing the crop (Fig. 4.2). While the seasonal rainfall is 212 mm for the first sowing

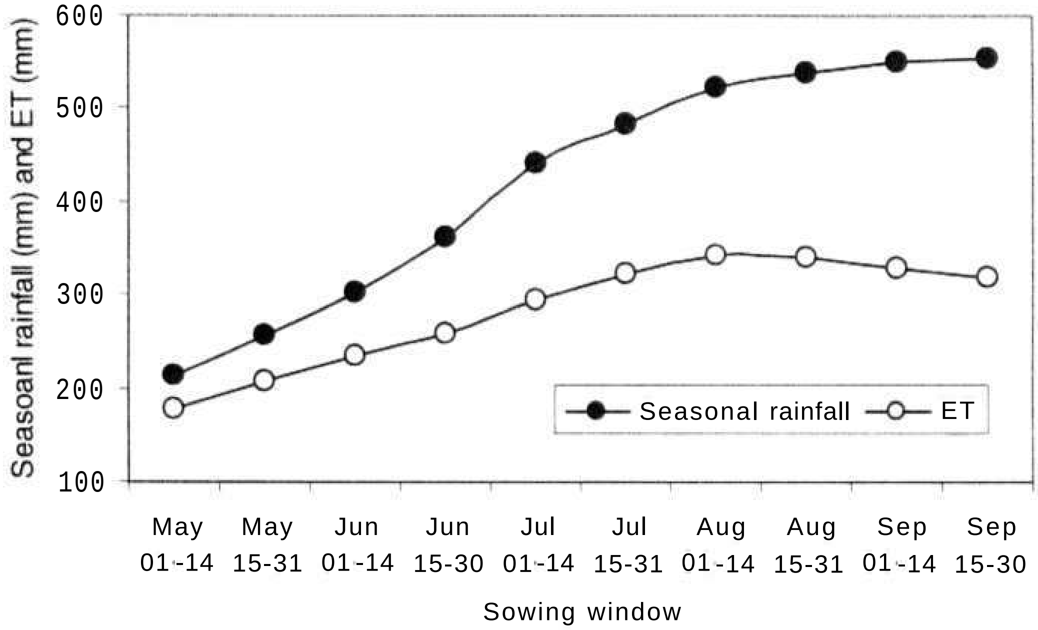

Figure 4.2. Simulated seasonal rainfall and evapotranspiration (ET) from a groundnut cropping system as a function of crop sowing options from May through September.

window, it is 555 mm for the sowing window in the second half of September. Despite high seasonal rainfall during the later sowing windows (from mid-August to end of September), the groundnut crop planted later than the first fortnight of August yields less. This is because excess rain received during the seasons corresponding to later sowing dates is not available to the crop at maturity, as it is lost through drainage. This is seen clearly in the pattern of seasonal evapotranspiration (ET) losses. The ET values show a pattern similar to that of groundnut yields (Fig. 4.2).

Groundnut yield and moisture deficit at various phenological stages

Rainfall is the most significant climatic factor affecting groundnut production in the dry tropical Anantapur region where the crop is raised mostly under rainfed conditions. The crop water status invariably affects plant growth and development since about 80% of plant fresh weight is water. Several stages in the groundnut life cycle are sensitive to moisture deficit, particularly early establishment and vegetative growth, flowering and peg formation, and seed development; however, different stages have different sensitivities to water deficit (Reddy 1988). Hence, to better understand the impact of amount and distribution of rainfall on the various phenological stages and groundnut seed yield, typical three years with contrasting rainfall characteristics were selected. The soil water balance was then simulated to study the impact of moisture deficit at various stages using CROPGRO-Peanut model and was analyzed over the season corresponding to several sowing windows in these selected years. These results are presented in the following discussion.

The normal amount of rainfall for the Anantapur region is 565 mm. The year 1972 was a normal rainfall year with 557 mm rainfall. While 1998 was a wet year with 920 mm of rainfall (63% above normal), 1984 was a dry year with 176 mm rainfall (69% below normal) (see Fig. 3.4).

The data on moisture deficit at various phenological stages and groundnut seed yield are shown in eight panels in Figure 4.3. Panels 1 through 7 present crop water status and panel 8 presents seed yield in the selected years with the crop planted during various sowing windows. Moisture deficit factor plotted along the y-axis varies from 0 to 1 with 0 indicating no moisture deficit and 1 indicating maximum stress.

In 1972, the crop experienced low to moderate moisture deficit during the initial stages of flowering initiation, i.e., first visible flower and first peg formation for all the sowing windows; and moderate to high deficit at first pod formation and seed development for the early sowing windows. A high moisture deficit is evident at the end of pod formation and physiological maturity for the early sowing windows.

Although 1972 was a normal year, rainfall distribution during the growing season was such that there was a prolonged dry spell between meteorological Weeks 26 and 38. Most of the rain fell during the latter part of the year following Week 38 (see Fig. 3.4). Thus, lack of available soil moisture during the earlier sowing windows and particularly at the crucial stages of first peg and pod formation and seed development resulted in low yields due to soil moisture deficit

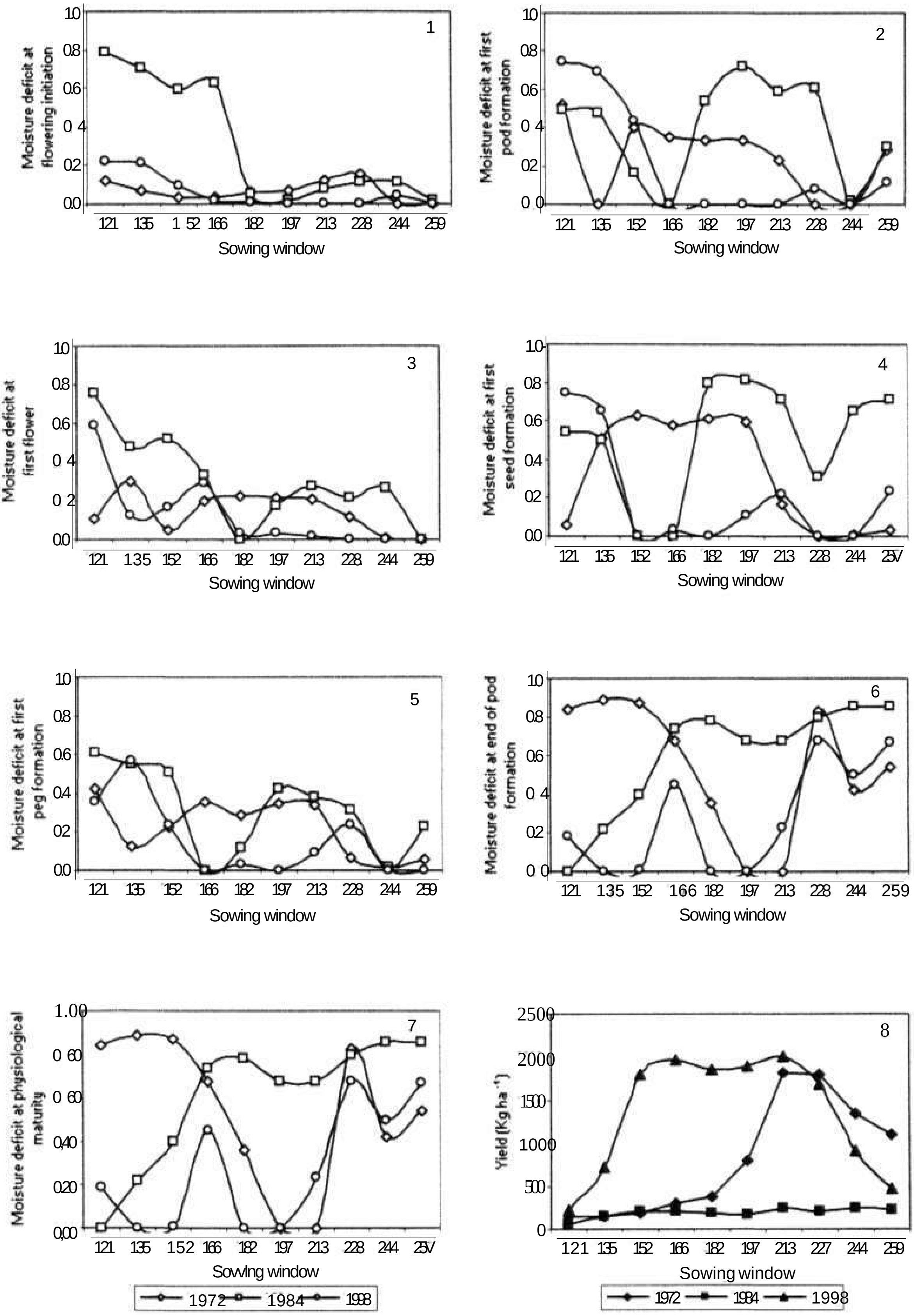

Figure 4.3. Soil moisture deficit at various phenological stages (panels 1-7) and yield of groundnut (panel 8) as a function of sowing window during three contrasting years in Anantapur, India.

(panel 8, Fig. 4.3). Groundnuts sown earlier than the first fortnight of July yielded less than 500 kg ha^{1}. Higher yields (greater than 1000 kg ha^{1}) in years with rainfall distribution pattern similar to 1972 can only be realized by sowing the crop not earlier than the second fortnight of July.

In a dry year (as in 1984), the crop experiences severe moisture deficit at all the stages of its development, no matter in which sowing window the crop is planted. This leads to a significant reduction in the grain yield. None of the sowing window options in 1984 resulted in yields greater than 250 kg ha^{1} (panel 8, Fig. 4.3). In 1984, the total amount of rainfall received during the entire year was so low that it did not meet even 1/3 of the crop water requirement (about 600 mm for the groundnut crop in the Anantapur area). In contrast to this, in a wet year (e.g., 1998), the rain received was well distributed during the growing season barring two short dry spells early in the season.

Model simulations indicate that in a good year (such as 1998), the farmers have a wide choice of sowing window; i.e., from early June to mid-August, and they can harvest a bumper groundnut crop with yields exceeding 1500 kg ha^{1}.

Optimal sowing options

Strategy evaluation using stochastic and mean Gini dominance analyses

From the foregoing discussion, it is apparent that rainfall is a crucial weather parameter in groundnut production in the Anantapur region. It is also apparent that due to the inherent variability in the rainfall characteristics, the crop experiences moisture deficit at one or several crucial phenological stages depending on the amount of rainfall (whether a dry, normal, or wet year) and distribution over the growing season in a given year. The sowing time has a major control on the final yield of the crop. As the crop water status invariably affects seed yield, farmers need to decide in a strategic sense each year as to which sowing option is likely to be the most risk-efficient. This raises a crucial question: How should one decide which strategy is risk-efficient? To answer this question, the risks to final yield due to sowing the crop at different times in a season using CROPGRO-Peanut model were first quantified. Applying the theory of stochastic dominance, the strategies were then evaluated for their robustness under weather uncertainties. The procedure adopted for this analysis is described below.

Theoretical background

The stochastic efficiency rules are an important class of decision criteria, and are particularly suited to the analysis of simulation model output. These rules are used as popular tools for risk analysis applications. The risk analysis procedure involves a pair-wise comparison of random variables. The result of the analysis is an efficient set of treatments. This efficient set contains a subset of treatments that are most risk-efficient (there may be only one or sometimes more than one set of efficient treatments).

Stochastic dominance: For two risky prospects, A and B, A dominates B by first-order stochastic dominance (FSD) if the Cumulative Probability Distribution Function (CPDF) of gains from A lies to the right of the CPDF of B over the entire probability interval 0 to 1. If the

CPDFs of A and B intersect, then no dominance by FSD can be established. If, however, the area between the two CPDFs below the point of intersection is greater than the area between the two CPDFs above the point of intersection, then A dominates B by second-order stochastic dominance (SSD).

Mean Gini dominance: For two risky prospects, A and B, A dominates B by mean Gini dominance (MGD) if:

$$\underline{E}(A) > E(B) \text{ and } E(A)-r(A) > E(B) - T(B)$$

where E(A) and E(B) are the means of A and B and r(A) and T(B) are the mean Gini coefficients. Mean Gini coefficient is half the value of the mean Gini difference (the absolute expected difference between a pair of randomly selected values of a variable). The efficient set of treatments tends to be larger in the stochastic dominance analysis compared to the MGD method.

Analysis results

CROPGRO-Peanut model utilizes MGD method for risk analysis. Among the various sowing dates analyzed, the MGD analysis revealed that treatment 7 is the most risk efficient treatment. Treatment 7 corresponds to the sowing window option of the first fortnight of August. This treatment has the highest mean. Such analytical results, based on 37 years of historical weather data, imply that the best option for sowing groundnuts in the Anantapur region is early to mid-August, because this sowing window coincides with the period with the most appropriate combination of water balance components. Hence, there are assurances of maximum soil moisture availability to the crop.

While it is good to narrow down the efficient set of treatments of sowing window to as low as one with the maximum yield, it may be, at times, worthwhile to consider a larger set of efficient treatments with the risk of slightly lower yields. In the drier parts of semi-arid tropical India, it is primarily the resource-poor farmers who cultivate the land. Apart from the effect of uncertainty due to weather, the socioeconomic conditions of the farmers should also be integrated in any decision-making process. As a part of this study, a socioeconomic survey was conducted and the major socioeconomic constraints to groundnut production in this region have been listed earlier. Availability of credit, labor, and technical knowhow well in advance were found to be major constraints. Therefore, the farmers, should be provided with a sample decision support system that allows to cope with the uncertainty in weather and also gives enough time to garner their meager resources before they embark upon the task of sowing groundnut crop.

With these points in view, CPDFs of grain yield as a function of sowing dates were analyzed (Fig. 4.4). Note that CPDFs of only seven sowing date options are shown in Figure 4.4 to avoid confusion and to facilitate easy interpretation. As per the principle of stochastic dominance, the CPDF of an efficient treatment lies to the right side in the plot. A comparison of the CPDFs in Figure 4.4 shows that treatments 6 (15-31 July), 7 (1-14 August), and 8 (15-31 August) together form an efficient set by FSD. These treatments together correspond to a sowing window ranging from mid-July to end of August. The farmers in the region have observed that with delayed sowing there is an increased risk of pest and disease incidence. Thus, prudence demands that sowing of groundnuts in the Anantapur region be restricted to a window of one-month duration from mid-July until mid-August.

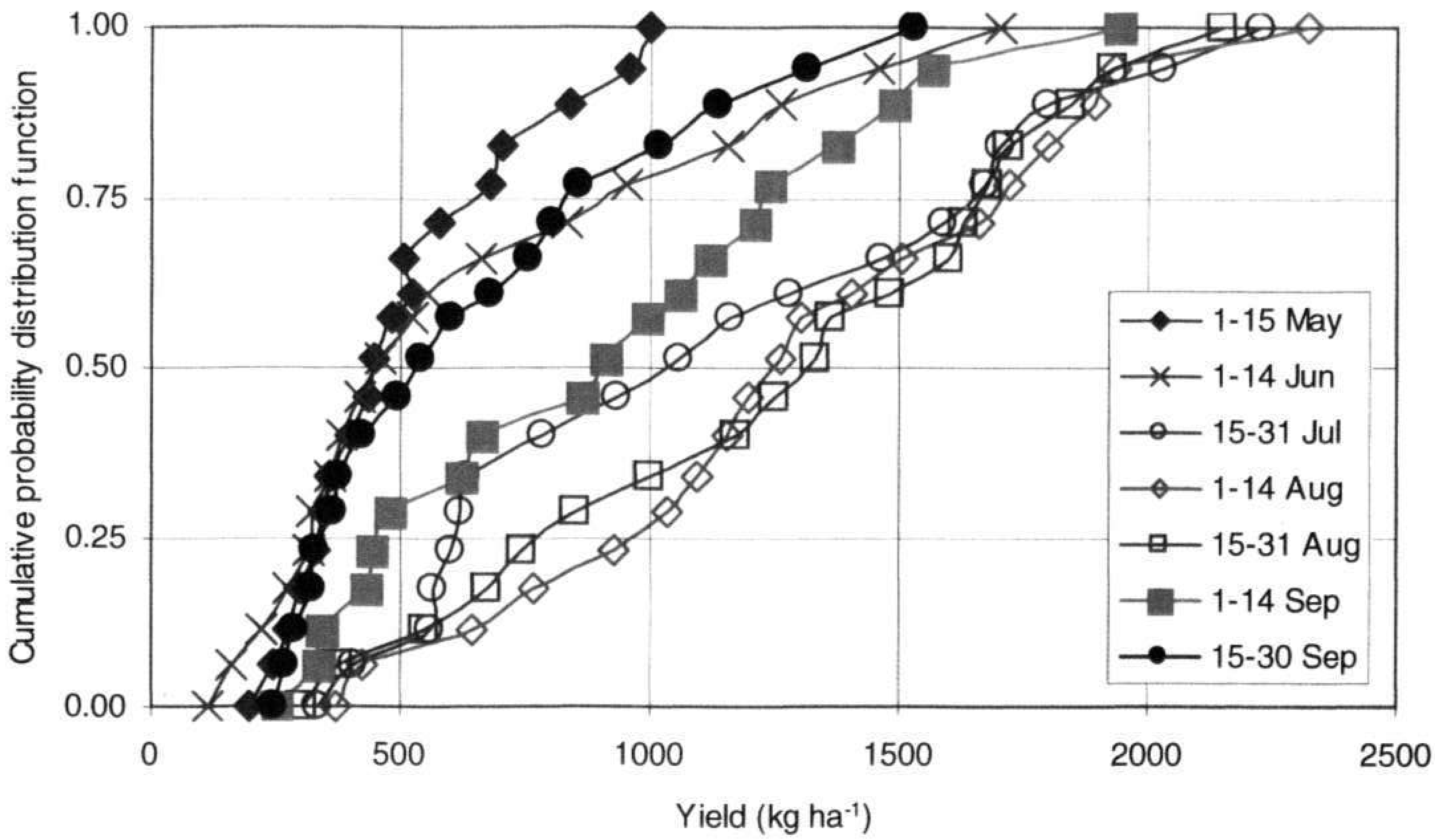

Figure 4.4. Cumulative probability distribution functions for selected sowing date treatments of groundnut in Anantapur, India.

Model Predictions vs. Measured Yields from Benchmark Sites _

Several villages from the Anantapur region were surveyed during the 1998 cropping season to understand the regional socioeconomic constraints on groundnut production. As a part of this exercise, a few villages were chosen as benchmark sites. Meteorological, crop growth and yield, and soil moisture data were collected from these benchmark sites. While rainfall data are available for each one of these sites, temperature and radiation data could not be collected from each site. Hence, .missing data were generated from the meteorological data collected at the Dryland Agricultural Research Station, Anantapur. Using these data, yields from the benchmark sites were simulated for the 1998 cropping season using CROPGRO-Peanut model (Table 4.1).

Table 4.1. A comparison of the simulated and measured yields from the benchmark sites in the Anantapur region.

Site	Measured yield (kg ha^{-1})	Simulated yield (kg ha^{-1})
Arlahalli	970	1880
Bupur	1320	1690
Chikahulikunte	1520	1020
Kotaguda	1470	2301
Mahadevpura	840	1490
Venkatapura	1900	1930

The simulated yields were generally higher compared to the measured yields from the benchmark sites (Table 4.1). The measured yields for some of the sites were lower by as much as 50%. The primary reason for such an anomaly is that the simulated yields represent potential yields. The CROPGROPeanut simulation model does not take into account the biotic stress caused by the incidence of pests and diseases. The current version of the model is best used to understand the variation in the potential crop yields of a region due to the inherent variability in the weather. The measured yields from these sites include losses due to pests and diseases. Groundnut production in this region is known to be susceptible to pest and disease attack. The intensity of incidence in some years is so severe that the farmers fail to reap any harvest. Despite such severe conditions, the farmers of the region do not undertake any control measures as the erratic rainfall patterns fail to offer any assurance of even marginal income returns. Thus, in order to be able to predict yields as measured on the farmers' fields, crop models need to incorporate a biotic stress subroutine that accounts for yield losses by accurately simulating the incidence of pests and diseases.

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Conclusions

Summary

Globally, groundnut is one of the five most important oilseed crops. The world's groundnut production was nearly 31 million t in 1998 from an area of 24 million ha. Over a span of the past four decades, the world groundnut production has increased by nearly 2.3 times compared to its production in the 1960s. Such a change in production has been partially brought about by increased area under the crop; but more significantly by its increased productivity. While the global groundnut area was higher by 18% during 1991-98 as compared to the 1960s, the groundnut productivity was higher by nearly 50%.

China and India are the world's leading groundnut producers together accounting for nearly 60% of the production and 52% of the world area under the crop. In 1998, India had more than twice the area sown to groundnuts than in China. Despite such a large area, the annual Indian groundnut production is lower than the production in China by nearly 10%. This is attributed to the differences in productivity levels. The productivity in China has consistently been nearly 2.5 times higher than that in India. Groundnuts in India are severely constrained by several factors. Some important constraints are cultivation of the crop on marginal and submarginal lands under rainfed conditions; water deficits experienced by the crop due to uncertain monsoons; and low input-use and factors related to socioeconomic infrastructure.

Future Research: Some Lessons

- Among the meteorological factors, total amount of rainfall received and its distribution during the crop-growing season play a pivotal role in groundnut production in the semi-arid tropical agriculture. Hence, NRM practices aimed at increasing the soil-moisture availability so that water deficits during the growing season are reduced, hold the key for increasing groundnut production and thus, increased groundnut productivity.
- The seasonal analysis of the groundnut production scenario in India indicates a steady increasing trend in the area under the crop during the postrainy season in the states of Andhra Pradesh, Karnataka, and Tamil Nadu. Any steps taken to further increase this area in these and other major groundnut-growing states will lead to a significant increase in national production as the postrainy season yields are two- to three-fold higher compared to yields harvested from the rainy season crop.
- In spite of the agroecologically marginal conditions for rainfed groundnut production and the consequent poor final yield performance of the crop from year to year, the area and production of groundnut in the Anantapur region have shown an increasing trend over the years. Presently, this region is one of the leading groundnut producers in the country and thus, it represents a

potential area for concerted efforts of interdisciplinary research for improving groundnut productivity in the nation.

- A socioeconomic survey conducted in the Anantapur area during the 1998 cropping season identified the following factors as the main constraints to groundnut production:
  - Insecurity of length of growing season in rainfed groundnut-growing areas which leads to under-utilization of natural resources.
  - Cultivation of the crop on marginal and submarginal lands under rainfed conditions fraught with frequent droughts.
  - Low levels of inputs and poor adoption of improved agronomic practices due to perpetual risk of crop failure and crop loss due to the incidence of pests and diseases.
  - High cost and non-availability of inputs, lack of credit for the purchase of inputs, and lack of marketing facilities for efficient distribution of inputs.
  - Lack of availability of farm labor and its inefficient use due to high wages.

  An in-depth survey of a large volume of existing literature available at the library in ICRISAT, Patancheru on the topic of constraints to groundnut production in India, has revealed that the semi-arid tropical agriculture itself, in general, is fraught with similar constraints to crop production. One of the major causes for such a sad situation is the neglect of appropriate management of natural resources, particularly rainwater, together with farmers' perspectives and the adoption of the top-down agricultural research and policy approaches that do not match farmers' perceptions or the socioeconomic environment. Hence, the need of the hour is to adopt approaches that are environment friendly and client (farmer)-oriented.

- Meteorological and plant data were collected from selected benchmark farmers of the Anantapur region. Using these data and CROPGRO-Peanut model, simulated yields were compared with the yields from the surveyed villages (or sites). The analysis indicated that the yields from the surveyed villages were generally lower compared to the simulated yields. This is attributed to the fact that the model-simulated yields represented production under optimum soil fertility conditions. The simulations were, however, useful for understanding the variation in yields due to inherent variability in the weather conditions of the Anantapur region. Biotic stress due to pests and diseases is not taken into consideration. In order to bridge the yield gap, the need for crop simulation models that incorporate the impact of biotic stress on yield is strongly felt.

- A first approximation decision support system for choosing an optimum groundnut sowing window was developed using CROPGRO-Peanut model, and risk analysis employing stochastic and mean Gini dominance theories based on 37 years (from 1962 to 1998) of historical weather data. As a case study, the Anantapur region was selected for the analysis. A time-window of one-month

duration from mid-July to mid-August has been found to be optimal for sowing groundnut crop in this region. This window coincides with the most appropriate combination of water balance components and hence, there are assurances of maximum soil availability to the crop over the entire growing season (Table 5.1).

Table 5.1. A proposed decision support system for sowing rainfed groundnuts in the Anantapur region, India.

Component	Description
Variety	TMV2
Soil type	Sandy loam
Plant population	33.3 plants m^{-2}
Row spacing	30 cm
Sowing date	July 15-31: Sow groundnut provided the rainfall amount received during the second week of July (Week 29) is at least 8 mm. If this condition is not met, wait for the next sowing window. August 1-14: If the total rainfall in July is at least 70 mm, sow groundnut during Week 31. The initial and conditional Wet/Wet (W/W) and Wet/Dry (W/D) probabilities of receiving >5 mm of rainfall during the Weeks 35 to 42 is 50-80% for the Anantapur region (Fig. 5.1; see Appendix I). The crop planted in the first week of August (Week 31), in particular, is well suited to utilize the soil moisture available during the high rain probability period. Weeks 35 to 42 coincide with the most crucial reproductive stages of the crop when the crop water requirements are at their peak. If any of the above conditions are not met, the farmers may not sow groundnut crop in the region, as the dry conditions will lead to low returns and loss.
Fertilizers	The soils of Anantapur are deficient in phosphporus. Judicious application of phosphatic fertilizers as recommended by soil tests should be made. The general recommended dosages do not hold good for the needs of individual farms.
Productivity	• Yields greater than 1000 kg ha^{1} can be realized in normal years (which have 75% probability of occurrence of rain based on 98 years of rainfall data for Anantapur; Fig. 5.2) with even distribution during July to November. • During the high rainfall years (8 out of 98 years have 10% probability of occurrence of rain; Fig. 5.2), groundnut yields greater than 1500 kg ha^{-1} can be harvested with a wide sowing window from June 15 to August 15. • In the low rainfall years (13 out of 98 years have 12% probability of occurrence of rain; Fig. 5.2), the farmers are advised not to sow groundnut as the yields realized during such years are less than 300 to 400 kg ha^{1}.

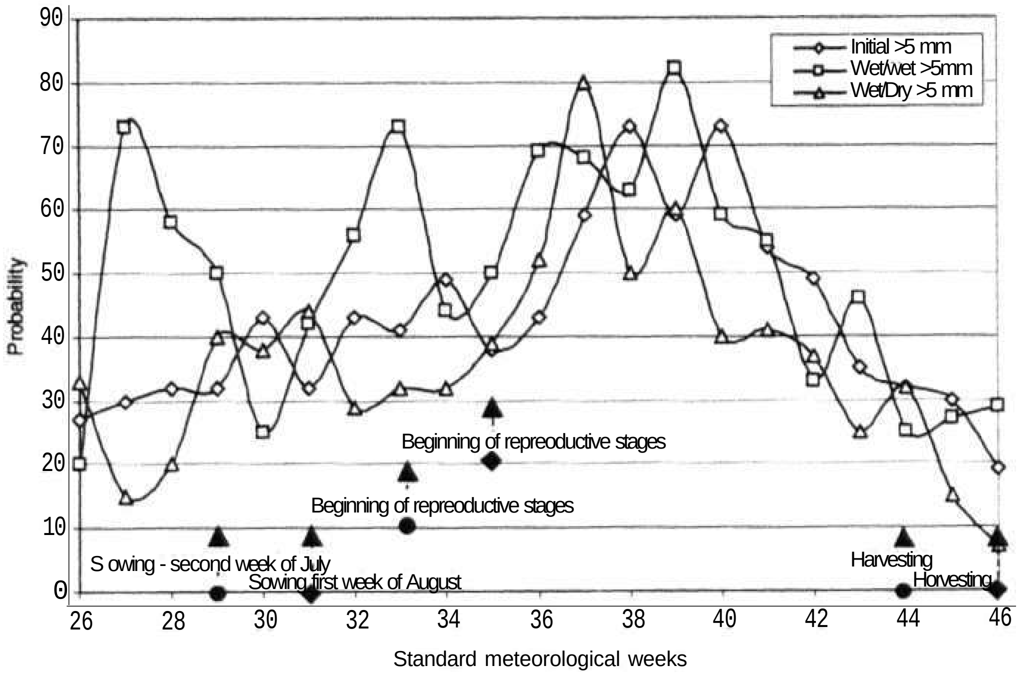

Figure 5.1. Initial and conditional probabilities of greater than 5-mm rainfall for Anantapur region, India.

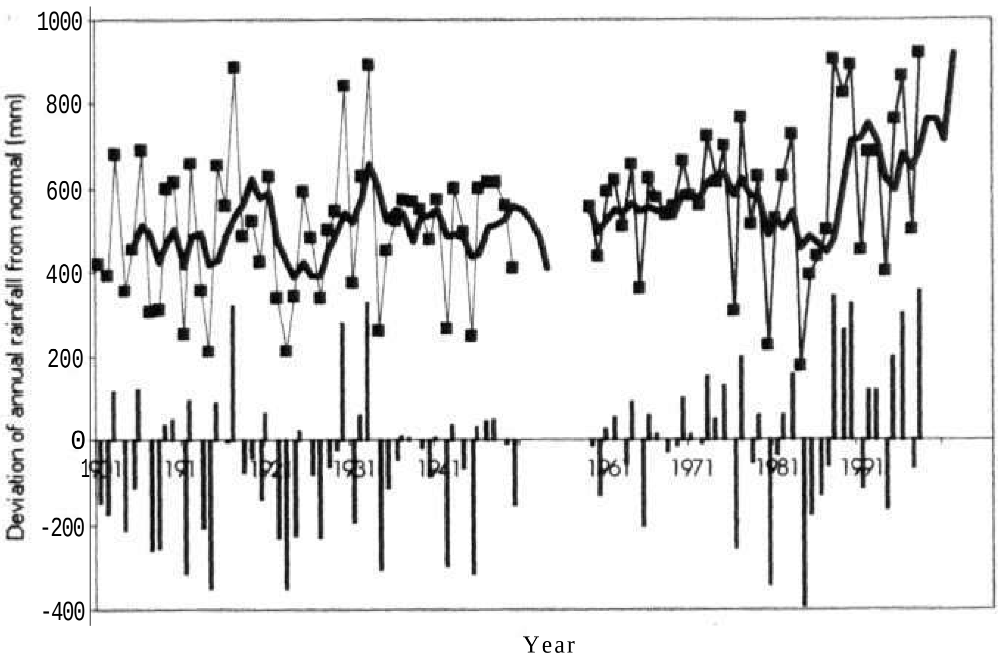

Figure 5.2. Deviation of annual rainfall from normal for Anantapur region, India from 1901 to 1998 (Note: The curve with solid squares represents the annual distribution of rainfall; the black solid curve is the 5-year moving average trendline. The lower histogram represents the deviation of annual rainfall from normal (1901-98). Rainfall data for the years from 1951 to 1959 are missing).

A Proposed Research Project

Introduction

In 1998, the Indian Institute of Science (IISc), Bangalore and ICRISAT initiated the project "Climate Prediction for Sustainable Production of Rainfed Groundnuts in the Semi-Arid Tropics (SAT)" with Drs Sulochana Gadgil (IISc) and S M Virmani (ICRISAT) as the principal investigators. This document is the Final Project Report highlighting the findings of the ICRISAT component of the project. One of the broad objectives of the project was to characterize the groundnut production environment in the semi-arid tropics (SAT) of India. To address this objective, the Anantapur region in the state of Andhra Pradesh was chosen as a representative location. This region is one of the leading groundnut producers accounting for nearly one-tenth of the country's production. A detailed analysis of the production environment of the Anantapur region has given useful insights into several aspects of production that need immediate attention in terms of a multidisciplinary, farmer-oriented, NRM for sustained groundnut productivity in this region in particular, and in SAT of India in general.

The challenges in the coming years before Indian agriculture are immense. As an illustration, an excerpt from the inaugural address of Dr C Rangarajan, a noted economist and the Governor of Andhra Pradesh, at a national seminar on 'New challenges facing Indian agriculture in the context of WTO', held in Hyderabad recently is given below (Source: The Hindu, July 6,1999).

"Calculations show that if the economy is to grow at 7% per annum and also if the export base is to expand, the value of agricultural output must increase at an annual rate of 4.5% between 1997 and 2002. Looking at agricultural crops alone, the required growth rate for 1997-2002 is 3.82% as compared with the actual annual compound growth rate of 2.77% during 1980-94. While the targeted growth rate of food grains is 3.05% per annum as against the actual growth rate of 2.67% in the period 1980-94, a substantial increase in growth rate is required in the case of pulses, oilseeds and fruits and vegetables."

Paying heed to such alarming messages and in view of the findings presented in the final report, we propose a research project as detailed below.

Objectives

The broad objective of the proposed research is to increase and sustain productivity of the groundnut-based production systems in SAT of India. This research activity would aim primarily to introduce precision crop-intensive farming practices for sustained increase in groundnut productivity and increase in farmers' income by better NRM. The specific objectives of the proposed research are given under the "Strategic Research Plan".

Since this research activity is being envisioned to bring about radical changes in the way a farmer thinks about farming, the research project is intended to be carried out in a multi-location and multi-year (3-5 years) approach.

Strategic Research Plan

Objective 1: Identify representative benchmark sites in the various groundnut-growing agroclimatic subregions as target R&D agroclimatic zones and simultaneously, identify collaborating partners willing to participate and share their resources in the proposed research.

India has been divided into 15 agroclimatic zones and each zone has further been divided into subregions depending upon homogeneous physical characteristics such as topography, rainfall, soils, and cropping patterns. A few benchmark sites will be selected from each major groundnut-growing agroclimatic subregion (i.e., area >100,000 ha under groundnut in a year). The sample size so selected will be statistically analyzed so that the results drawn from selected samples represent the whole population. Since the proposed research is multidisciplinary in nature, collaborating partners willing to participate and share their resources will be identified from agricultural universities, national agricultural research systems (NARS), and non-govrnmental organizations (NGOs) that operate within the jurisdiction of the targeted agroclimatic subregion. This will facilitate scientists from various disciplines working together to address the key research issues in a partnership mode.

Objective 2: Characterize natural resource bases and perform a physical and socioeconomic constraint analysis for groundnut production in the target regions.

For characterizing the groundnut production environment in various regions, all available databases for soils, cropping systems, climate, and input use will be collected. These data will be used in conjunction with the districtwise data on district average groundnut crop yield, area, meteorological and soil parameters, and input use from 1966 to 1994. The data will be assembled and analyzed using new tools such as geographical information system (GIS). A detailed socioeconomic survey at the benchmark sites by a team of agrobiologists and socioeconomic scientists using participatory rural appraisal (PRA) techniques will be used to identify regionwise constraints for groundnut production. Further analyses on spatial distribution of constraints, and yield gap will be carried out and opportunities for crop intensification will be identified. GIS maps with a report on the various analyses will be compiled with a view to get a broader picture of the groundnut production environment in the various subregions.

Objective 3: Apply and refine integrated, cost-effective NRM practices based on the natural resources of the groundnut-growing farmers.

There is considerable expertise in the country in the various disciplines relevant to groundnut production. Coordinated research efforts in the past 25 years have since resulted in evolving a number of simple technologies that can enhance the groundnut productivity. A package with the best available technology will be prepared in consultation with the multidisciplinary team of participating scientists. The package of practices so prepared will be custom made for each representative subregion taking into consideration the farmers' perspectives, their natural resource endowments, current practices followed in the region, and crop intensification practices recommended but not implemented in the region. These practices will be tried on the participating farmers' fields providing necessary education to the farmers on the merits of following such practices.

Objective 4: Evaluate the technical and economic feasibility of applying promising NRM practices for crop intensification.

Multilocational trials with promising NRM practices for crop intensification will be conducted on farmers' fields for about 3-5 years. Practices followed in these trials will be evaluated annually. Those practices that are found to be less efficient will be refined or substituted by more efficient ones. The participating socioeconomic scientists will evaluate economic feasibility of employing such practices in terms of cost-benefit ratio. Steps will be taken to ensure sustainability of a package of practices, once found technically and economically feasible.

Objective 5: Assess the impact of this research project on the participating farming community in terms of its ability to adopt new technology.

The last objective will aid in evaluating the overall success of the project. In achieving this objective, the proposed research aims to find answers to the following questions:

- Have the participating farmers successfully adopted the new technology?
- Has this research effort made any impact outside of targeted regions?
- If yes, what is the extent of adoption?
- If not, what are the reasons for resistance to change in technology?
- What lessons can we learn to achieve better results in transfer of technology?
- Has the project been successful in meeting its broad objective of improving the livelihood of the farming community?

It is proposed to conduct a detailed survey of not only the participating farmers but also of the farmers in the neighboring areas.

Appendix I

The Standard Meteorological Weeks

Week no.	Month	Date	Week no.	Month	Date
1	January	1-7	27	July	2-8
2		8-14	28		9-15
3		15-21	29		16-22
4		22-28	30		23-29
5		29-4[1]	31		30-5
6	February	5-11	32	August	6-12
7		12-18	33		13-19
8		19-25	34		20-26
9		26-4	35		27-2
10	March	5-11	36	September	3-9
11		12-18	37		10-16
12		19-25	38		17-23
13		26-1	39		24-30
14	April	2-8	40	October	1-7
15		9-15	41		8-14
16		16-22	42		15-21
17		23-29	43		22-28
18		30-6	44		29-4
19	May	7-13	45	November	5-11
20		14-20	46		12-18
21		21-27	47		19-25
22		28-3	48		26-2
23	June	4-10	49	December	3-9
24		11-17	50		10-16
25		18-24	51		17-23
26		25-1	52		24-31

1. In a leap year, Week 9 will be from 26 February to 4 March, i.e., 8 days instead of 7 to include 29 February.

About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the SAT ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Program (UNEP), and the World Bank.

ICRISAT

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