Farming strategies for a variable climate – A challenge

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Enhancing production of the rainfed belt has become all the more important since the growth rates of production in irrigated regions have decreased in the last decade in association with a fatigue of the green revolution. It is necessary to harness the recent advances in atmospheric and agricultural science to identify farmer-acceptable strategies for maximizing production of rainfed regions in the face of rainfall variability. We present an approach to this problem which involves efforts from an indisciplinary team with scientists and farmers.

THE most striking feature of the all-India food grain production over the last fifty years is the rapid increase associated with the green revolution from the mid-sixties. This rapid increase occurred primarily over irrigated regions with the introduction of new dwarf, fertilizer responsive varieties[1]. This phenomenal growth made it possible for the country to move from a food-deficit state to one which is by and large self-sufficient. Despite the rapid growth in the population in this period, the per capita availability of total food grain has remained stable. However, in the last decade, the growth rates in food grain production on the global as well as national scale, have declined in association with the fatigue of the green revolution[2,3]. Thus, in order to ensure adequate levels of per-capita food grain availability, a significant increase in the production of rainfed areas has to be achieved.

It is important to note that the impact of variation of climate (particularly the monsoon rainfall) on the national food grain production has remained high throughout, with substantial decrease in food grain production during years of deficit monsoon rainfall[4]. Thus the Indian economy has continued to be 'a gamble on the monsoon rains' in spite of the green revolution. While the production increased rapidly over the irrigated regions during the green revolution, the progress has been rather slow in the rainfed belt, which accounts for almost half the total crop production in our country. Hence, there has been a significant decrease in the per capita availability of rainfed crops such as pulses. For increasing the production of rainfed regions, farming strategies which can attain and sustain high growth rates in the rainfed regions in the face of climate variability have to be identified.

Advances in agricultural sciences and particularly in plant genetics, played a crucial role in the green revolution. The 'green revolution package' of adoption of high-yielding varieties, with adequate application of fertilizers and pesticides was developed in the laboratories and field stations of agricultural scientists. Because of the assured high yields, farmers had sufficient resources for the recommended measures, such as high levels of application of fertilizers and pesticides. The substantial increase in yields in the first two decades of the green revolution is a reflection of the success of the transfer of this knowhow in the 'lab to land' programmes.

On the other hand, in the rainfed belt, despite research and development efforts over fifty years, the production has increased rather slowly. The yield gap between the yields at the research stations and farmers' fields continues to be very wide (Figure 1, after Sivakumar *et al.*[5]). The major reasons for this according to Swaminathan[6] are: *'The research farms' programmes have mostly been scientist-oriented and not farmer or user-centered. These were perceived, planned, implemented, supervised and evaluated by scientists. The transfer of results followed a top-down approach. In this "take it or leave it approach", the farmer was at best a passive participant. Scientific findings which became the so-called technologies were born from small plots and short-term research and were invariably not associated with critical cost-benefit studies'*.

It is seen from Figure 1 that for years with low rainfall, the yield gap is small. In other words, the farmers appear to be doing almost as well as possible in years with deficit rainfall. However, for years with high seasonal rainfall, the yields of the farmers' fields are much lower than what could be achieved with the available knowhow, and the yield gap is very large. One of the major differences between the management practices at agricultural stations and that on the farmers' fields is in the degree to which fertilizers and pesticides are applied. It is important to note that over rainfed regions, the benefit of measures such as application of fertilizers, pesticides, etc. in terms of the yield enhancement are not

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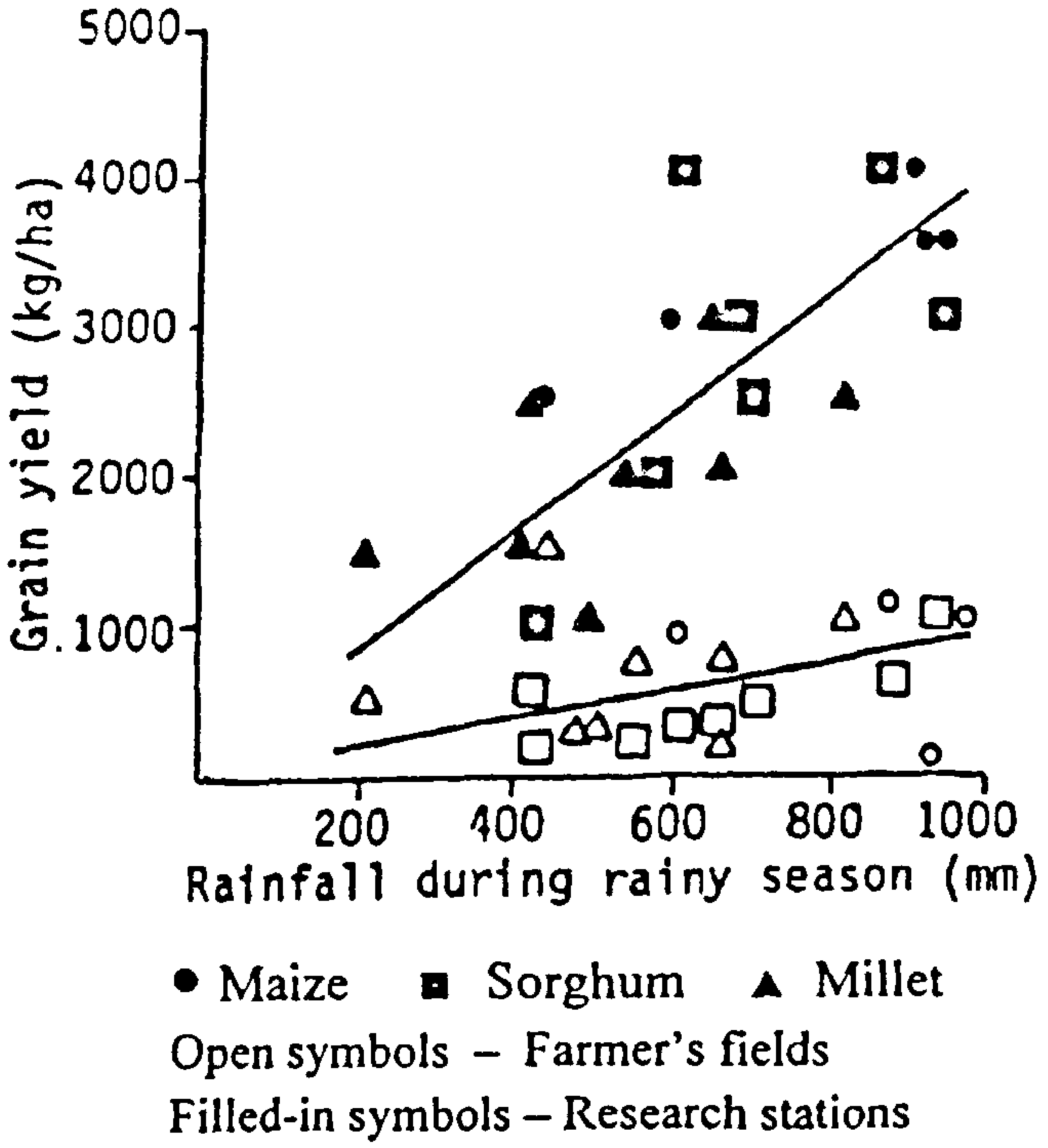

Figure 1. Relationship between rainfall during the rainy season and yield of maize, sorghum and millet at 15 dryland locations in India[5].

the same every year. In years with reasonable rainfall in which good yields are expected, such measures lead to a large enhancement in the yields. In years with poor rainfall, the yields are low irrespective of such applications. Hence in such years the farmers' yield is comparable to that at the field stations.

Since the yields over rainfed regions tend to be low and fluctuate considerably from year to year, the farmers have less resources available than those in the irrigated regions with assured yields. The farm-level decision of whether to invest in the recommended measures, depends upon the ratio of the expected benefit to the additional cost. When the yield (and hence the benefit associated with the recommended measures) fluctuates from year to year, the decision will depend upon the expected benefit over a period of few years, i.e. the number of years in which there is substantial benefit *vis-à-vis* those in which there is hardly any benefit. In the absence of estimates of the expected benefit and its ratio to the cost, the farmers tend to minimize the additional investments, because of the low levels of resource availability over the rainfed regions.

On the other hand, adequate investment at the agricultural stations leads to enhancement of yields in good rainfall years. Hence the yield gap is very large in years of good rainfall. It should be noted that some of these farmers do make such investments over irrigated parts of their lands where the yields are assured[7]. So it is not the lack of knowhow, but rather the lack of estimates of the expected benefit in variable climate, that results in the large yield gap in other years with good rainfall.

Several other recommendations, such as sowing alternative crops if sowing rains are delayed, or undertaking water/soil conservation measures or investing in farm ponds for supplementary irrigation, etc. have been made for different regions in the rainfed belt. For example, in the Pavagada region of Karnataka, where the main crop is groundnut, it is recommended that, if the sowing rains are delayed, soyabean or horsegram be planted instead of groundnut. However, the farmers generally continue to cultivate groundnut even in such years. One of the reasons for this is the lack of market for the suggested alternative crops. Also, the farmers tend not to make additional investments for farm-ponds or water/soil conservation measures because in their estimate the expected benefit is not commensurate with the cost. The relative lack of success in promoting strategies derived at agricultural stations in rainfed areas has led to an increasing realization of the need for identifying farmer-acceptable strategies[3].

It is clear that for a strategy to become acceptable to farmers, it is necessary to derive estimates of the expected benefit, in the face of rainfall variability of the type experienced over the specific region by the specific crop/variety. For this, the variation of the yield in response to rainfall variability under adoption of different management practices has to be investigated. The last two decades have witnessed major advances in our understanding of the nature of the variation of the rainfall within a season (i.e. wet/dry spells) as well as from year to year (i.e. poor and good monsoon years). With over a hundred years of data on meteorological variables at a dense network in the country, it is possible to derive detailed information on important facets of climate variability. The skill of rainfall predictions on the seasonal and subseasonal scales has also increased and a National Centre for Medium Range Weather Prediction (3–10 days ahead) has been established for generating predictions for agriculture. There have also been major developments in relevant branches of agricultural sciences such as crop modelling in addition to plant genetics. Thus the tools required to evaluate the impact of climate variability on production of a specific crop in a given region have been developed.

For understanding the impact of climate variability on yield, the results of short-term experiments at agricultural stations have to be complemented with analysis of the nature of rainfall variability from the available meteorological data and investigation of the impact of such variability on the yield simulated by crop models. This in turn requires the development of crop models which can realistically simulate the observed variations in yield in response to rainfall variability. With such models, it is possible to estimate the yield associated with different types of rainfall patterns prevalent over the region, for each of the management options. Combining this with the expected frequency of each rainfall pattern obtained by analysis of the historical data, the expected yield over a period of several years can be estimated. From such estimates of expected yield associated with each management option, strategies which are tailored to the rainfall variability of the region can be derived.

If for a specific year, meteorological predictions either on the seasonal scale (i.e. of the seasonal rainfall and its distribution) or on the subseasonal scale (wet/dry spells in the next few days) are available, strategies appropriate for such predictions can also be derived. However, for such a strategy to be adopted, the skill of such predictions, i.e. the probability of correct prediction, needs to be higher than the ratio of the additional cost to the expected benefit of the appropriate strategy[8].

It is important to ensure that the optimum strategies are sought from amongst the options available to the farmers. Furthermore, the constraints of the farmers due to aspects other than production, such as availability of markets, facilities, cost of transportation, etc. have to be taken into account in deriving the appropriate strategies. Hence, the approach for seeking appropriate, farmer-acceptable crops/varieties and management practices for the complex heterogeneous rainfed ecosystems, has to be farmer-centred and radically different from the 'lab to land' approach hitherto adopted by scientists. The optimum strategies will be specific to the farming situation (i.e. nature of the soil in terms of water retention capacity, the level of resources available, etc.), the agroclimatic regime and the expected climate variability. Instead of a package of recommendations derived by scientists, on the basis of theoretical studies and experiments on the field station, a decision support system needs to be developed. Such a system should help the farmer choose rationally between various available options on the basis of the state of the crops, pests, diseases, etc. and the predictions for the seasonal rainfall and intraseasonal variations. For the development of such a decision support system, an interdisciplinary approach with active collaboration of atmospheric and agricultural scientists with farmers is essential.

Here we develop an approach for identifying appropriate strategies for rainfed regions based primarily on information and prediction of climate variability. The methodology developed will be generally applicable. However, we focus on the specific case of production of rainfed groundnut in a semi-arid part of the Indian peninsula – the Anantapur region (Figures 2 and 3). In the next section, the farmers' perspective is elucidated. The essential tools/knowledge for developing a decision support system are then briefly discussed. Next, we illustrate the approach we recommend by considering one specific problem, viz. the identification of optimum sowing window for TMV-2 variety of groundnut in the Anantapur region.

Farmers' perspective and farming strategies

The problem to be addressed is the identification of appropriate farming strategies for attaining specific goals/objectives in a variable climate, particularly rainfall. A distinguishing attribute of agricultural production in rainfed regions is the large variation in yield from year to year (e.g. Figure 4 for Anantapur district) in response to the variation in rainfall. In some years the production is so low (i.e. less than 500 kg/ha) that even the cost of cultivation is not met. Such years of crop failure have a very large impact particularly on small and marginal farmers. The farmers with large landholding and a relatively higher level of resource availability can tolerate a few such years provided that they can make adequate profits in other years. Thus the goal

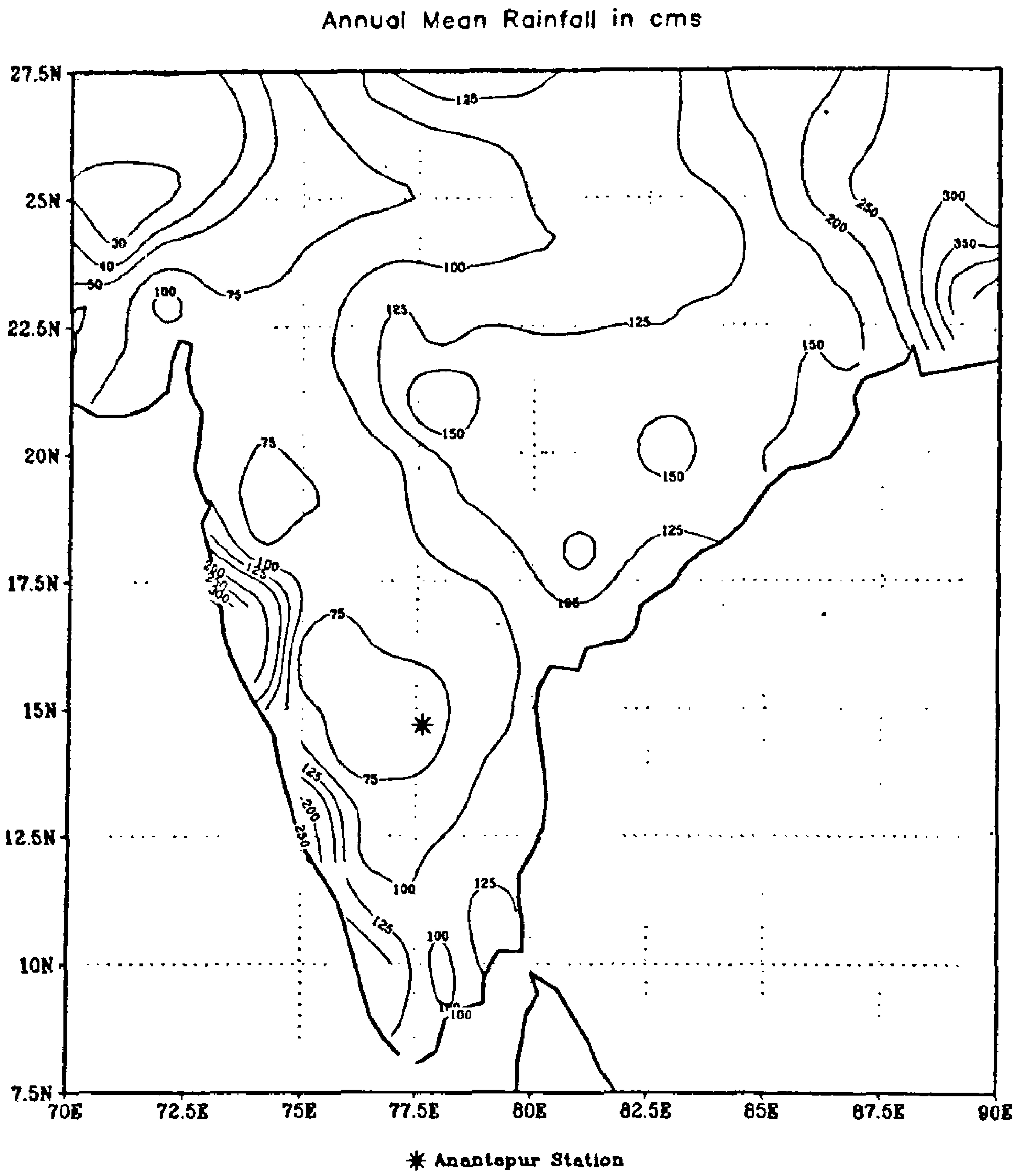

Figure 2. Annual rainfall over the Indian peninsula in cm; location of Anantapur is also shown.

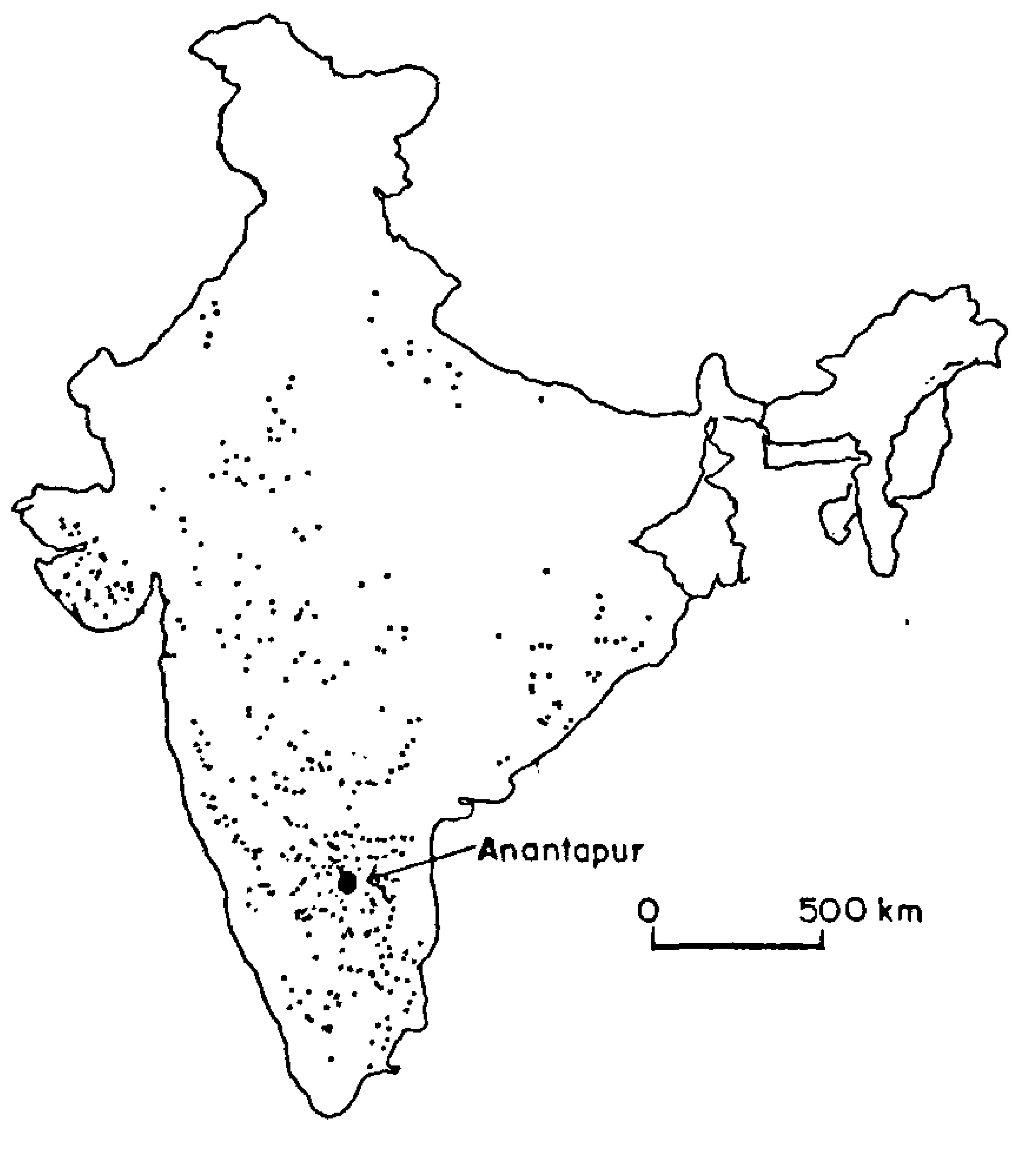

Figure 3. Groundnut growing regions of India.

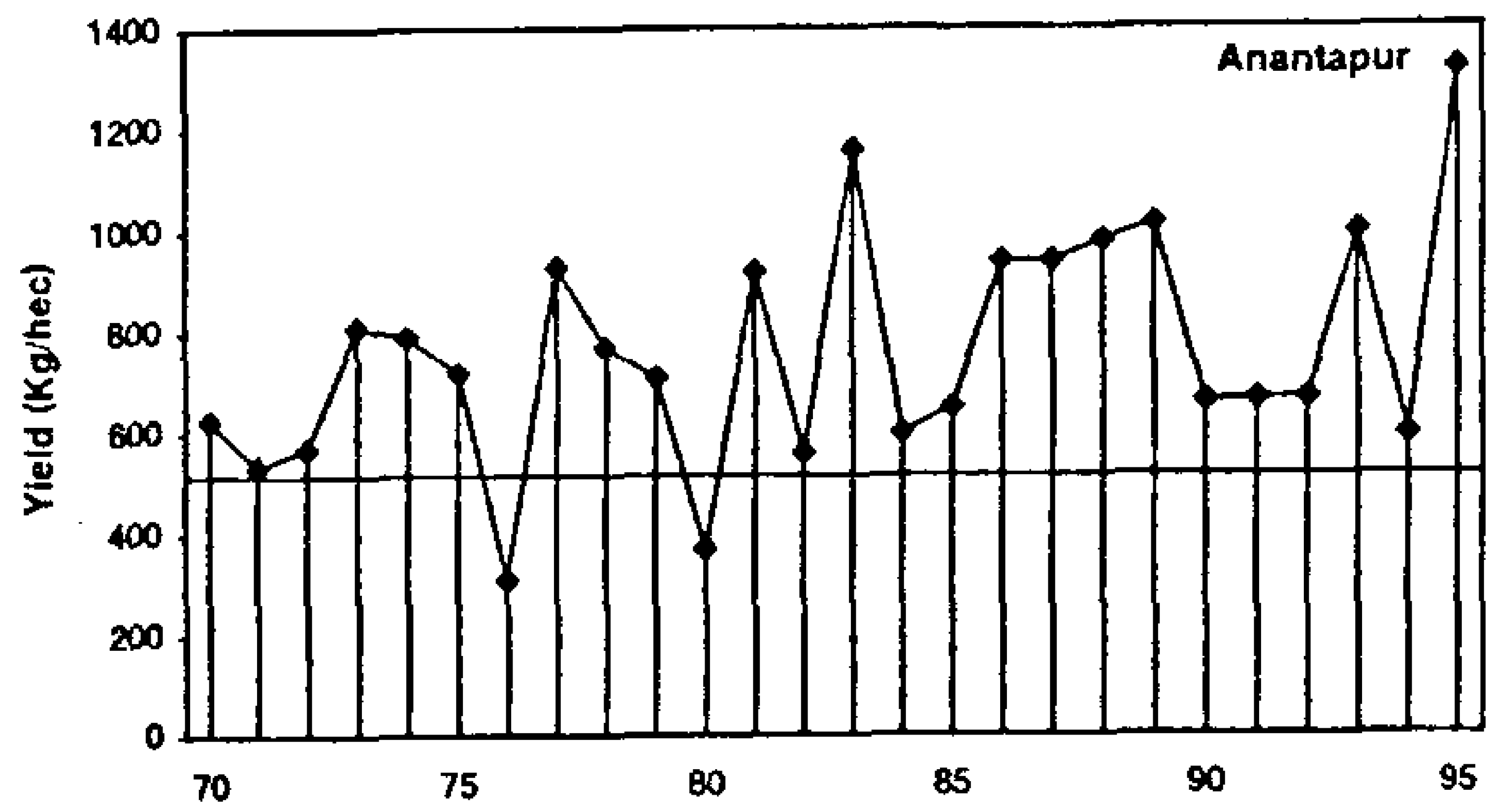

Figure 4. Variation of the average yield of Anantapur district during 1970–95.

for such farmers is generally maximizing the profit over periods of a few years, while for the marginal farmers minimizing the risk of crop failure is as important[7]. The constraints faced by the farmers also differ for the different categories. Hence the available options and the appropriate strategies for attaining the specific goal will necessarily depend on the socio-economic factors. The decision support system must, therefore, encompass all the possible scenarios and goals. The farmers' input and participation is central to the development of such a system.

We set up a network of farmers in the Anantapur area to elucidate the farmers' perspective on important facets of cultivation of rainfed groundnut and in particular the options available to the farmers from which the optimum strategy has to be chosen. The network comprises farmers from twenty-five well-distributed locations in the study area of about 4500 sq km around 77°E, 14°N and a network of twelve marginal farmers from one location[7]. Farmers participating in the network constitute a diverse group in terms of their social status, land holding and farming situation. The network of marginal farmers is from only one location because such farmers from other locations were reluctant to spend time with us. However, in this region, the vast majority of the farmers are marginal and small farmers with land holding of less than 2 ha and between 2 and 12 ha, respectively. For example in Pavgada taluk, 54% are marginal farmers (with about 36% of land holding), 39% are small farmers (with about 49% of land holding) and 7% are large farmers (with about 14% of land holding). Hence we decided that it was important to include marginal farmers at least from one location to get an insight into their perspective.

Data were collected during the kharif season (July–November) of 1998 on the variation of important meteorological variables, soil moisture and growth, development and yield of the plants. Detailed information on the farming situation, farming practices and farm-level decision making was obtained through discussions with the farmers. In particular, information was collected on the basis for decision about the cropping pattern, the management options available to the farmer at each stage, the farmers' assessment of the associated costs, benefit and the nature of meteorological information/prediction required for the decision at each stage. In addition, group discussions involving knowledgeable farmers from each location were conducted to collect information on farmers' perspective of important aspects such as cause for fluctuation in yields, impact of weather events, reliability of different sources of information and prediction of meteorological events. Details are given in Rao and Gadgil[7].

Many of the farm-level decisions depend on the farmers' estimate of the expected profit which in turn depends on the production and the market price. A change in market price and hence expected profit can bring about substantial changes in farming strategies. For example, the farmers in the Anantapur region changed the cropping pattern with groundnut as the major component in the 1970s because of a large increase in the market price of groundnut. For a specific crop, the production, as well as the price and hence the profit vary from year to year. The price depends not only on the production of that region, but also of other regions growing the same crop. It also depends upon the production of other crops meeting the same need (such as another oil seed in the case of groundnut) and the import–export policy of the government. Here, we restrict our attention to the production. The dynamics and impact of price changes are not considered. Hence the goals will be considered in terms of production assuming that there are no changes in market price.

The major goals are then, maximizing the overall production and minimizing the risk of crop failure. The farmer has to make decisions at different stages beginning with land preparation, choice of the crops/varieties, application of fertilizers, choice of the sowing opportunity, application of pesticides, choice of the harvest date, etc. On many of these aspects, some recommendations have been made by agricultural scientists for enhancement of production. Most of these measures (such as water and soil conservation measures, application of soil amendments, fertilizers, pesticides, etc.)

Table 1. Farm-level decision making

Decision about investment	Timing of the decision	Factors that benefit depends on	Benefit* range (%)	Cost* per year (%)
Soil and water management				
Apply soil amendments e.g. farm yard manure 12 t/ha once in 4 years	Before land preparation	Expected yield in next four years; benefit increases with yield	10–45	20
Increase of fertilizer application to recommended dosage N.P.K 25:50:25	Two days prior to sowing	Expected yield; benefit increases with yield	10–40	17
Plant protection measures				
Seed treatment fungicide at 5 g/kg	Before sowing	Seed rot incidence; benefit increases with severity of incidence	10–20	2
Late leaf spot Spray fungicide	7 days after incidence	i) severity of incidence; ii) expected yield; benefit increases with both	10–50	10–19

*As % of basic cost of cultivation (cm).

involve additional expenditure. Some of the farm-level decisions along with the farmers' estimates of the additional cost, what the benefit depends on and the range of benefit (as a percentage of the basic cost of cultivation) are given in Table 1. It is seen that the additional cost is higher than the minimum benefit, except for the decision about seed treatment. Note that the benefit of application of soil amendments depends upon the yield levels in four successive years. Hence the input required for making these decisions is the expected yield in one or a series of few years. In fact, the benefit (in terms of yield enhancement) associated with many of the farm-level decisions depends upon the yield. Analysis of the probability of different levels of yield for the rainfall variability of the region is necessary for generating estimates of the expected benefit.

We also collected information on the kind of meteorological prediction required for different decisions. For example, prediction of dry/wet spells during the harvest period can help in the decision regarding timing of the harvest. If prediction of seasonal rainfall and its distribution can be used for predicting the yield in a specific year, benefits of various measures such as fertilizers can be estimated. A rational decision on whether to undertake the measures can then be made.

Some decisions such as choice of the sowing opportunity do not involve additional costs. However, a wrong decision can lead to a loss, as when sowing is postponed to be nearer to the recommended time-slot and a sowing opportunity does not occur later in that season. Some of the recommendations are conditional. For example, it is suggested that for groundnut, sowing should be done at the earliest opportunity in May, June or July; if an opportunity does not arise till August, some other crop should be planted[9]. Generally the farmers do not follow these recommendations and go ahead and sow groundnut even in August. One of the reasons is that in their experience the yields are high even for late sown crop during some years. It is clear that to determine the optimum strategy in this case, what is needed is an assessment of the impact of the sowing date on the yield in the face of the variability of rainfall of the kind experienced. For decisions about other measures such as application of fertilizers for which the associated benefit depends on the expected yield, it is necessary to estimate the variations of the yield in response to variation in rainfall. The available knowledge and the tools available from recent scientific developments for deriving such estimates are considered next.

Enhancement of rainfed production – The available knowledge and tools

It must be noted that farmers have considerable knowledge of the complex rainfed ecosystems because rainfed agriculture has been carried out over much of the semi-arid regions for a very long time. During this period, the farmers have been making decisions regarding the choice of cropping patterns and various management options such as timing of sowing, application of fertilizers, etc. In fact some of the crops grown today such as jowar (sorghum) and tur/redgram (pigeonpea) have been cultivated for over two thousand years in our country[10]. Even the relatively recently introduced crops like groundnut have been cultivated for over hundred years[10]. Hence we expect the farmers of the rainfed regions to have considerable knowledge of the rainfall variability of their region as well as the impact of the rainfall variability on the different stages of the different traditional crops. The traditional cropping patterns and farming practices probably evolved by trial and error to be appropriate to the climate variability of the region. For example, in the traditional cropping system of the Anantapur region (Figure 5), the choice of the crops to be planted in a specific year depended upon when the sowing rains occurred[7].

However, the present cropping pattern over a large part of the rainfed belt is markedly different from the traditional pattern. Thus, in large areas of the Anantapur region, the complex traditional system is replaced by groundnut variety TMV-2 (which is not the traditional one) intercropped with one of the traditional crops like tur/redgram. Now Anantapur is at the centre of the groundnut growing area of the peninsula (Figure 3). Even when the same crops continue to be grown (as in the case of jowar over certain parts of Maharashtra and

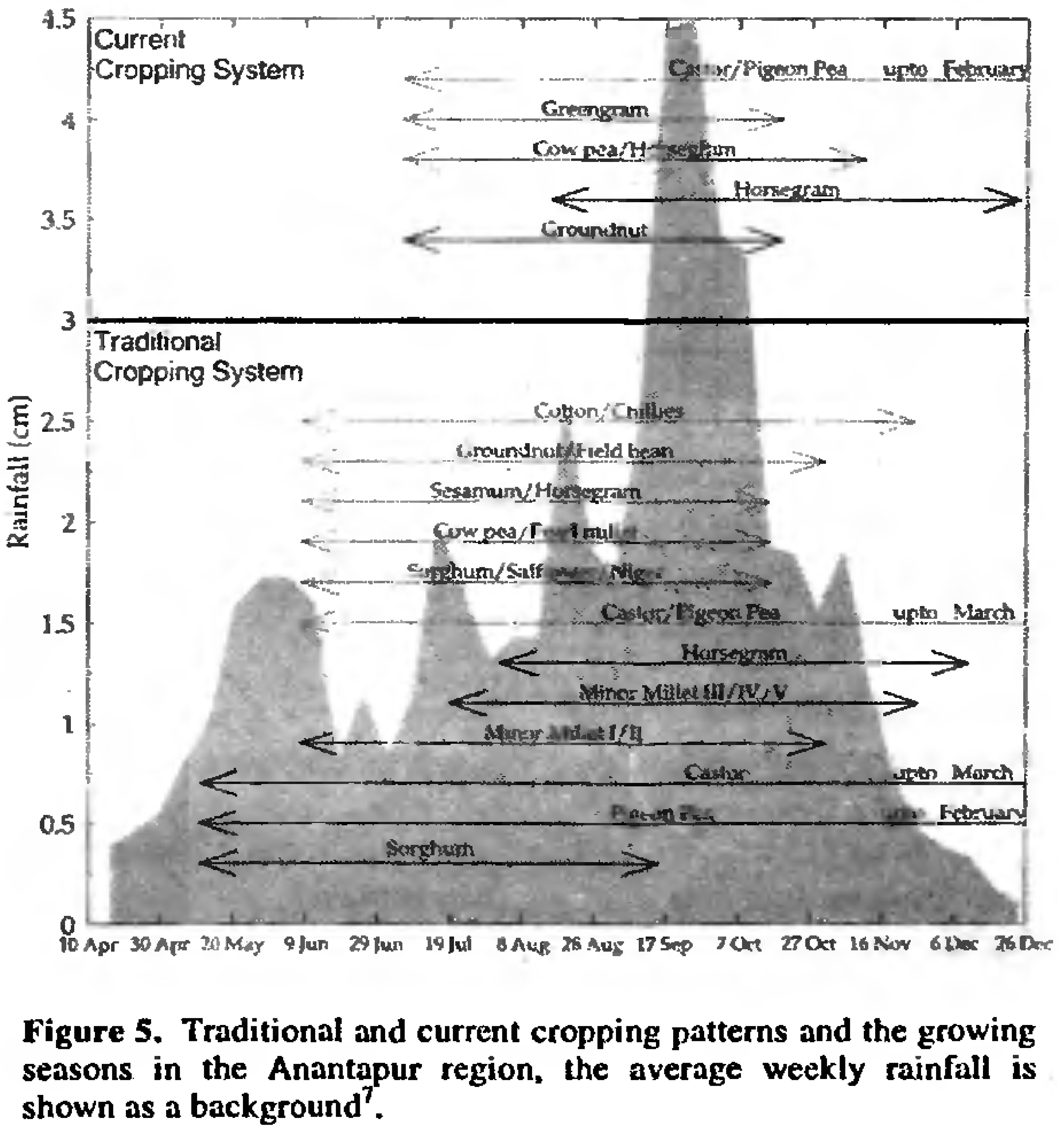

Figure 5. Traditional and current cropping patterns and the growing seasons in the Anantapur region, the average weekly rainfall is shown as a background[7].

Karnataka), the varieties grown are often not the same as the traditional ones, but those introduced in the 70s or later. Hence, while there is considerable traditional knowledge of rainfall variability (such as the likelihood of dry/wet spells in the different parts of the rainy season), the detailed impact on the specific crop variety is not known since the experience of two decades is not adequate. It is therefore necessary to combine traditional knowledge with modern scientific tools to gain an insight into the links between rainfall variability and production of crops/varieties cultivated at present.

Rainfall variability and prediction for groundnut farmers

The nature of rainfall variability at Anantapur station has been elucidated by analysis of the daily data during 1911–98. There is a large variation in the annual rainfall from about 20 to about 100 cm and in rainfall during the groundnut growing season (July–December) from about 10 to about 80 cm. More importantly, the pattern of distribution within the season varies considerably from year to year (e.g. Figure 6 for 1973 and 1975 with similar seasonal totals).

There is considerable traditional knowledge about variability of rainfall patterns, since rainfed cultivation has been carried out for several centuries in this region. The periods used by the farmer are however, not weeks

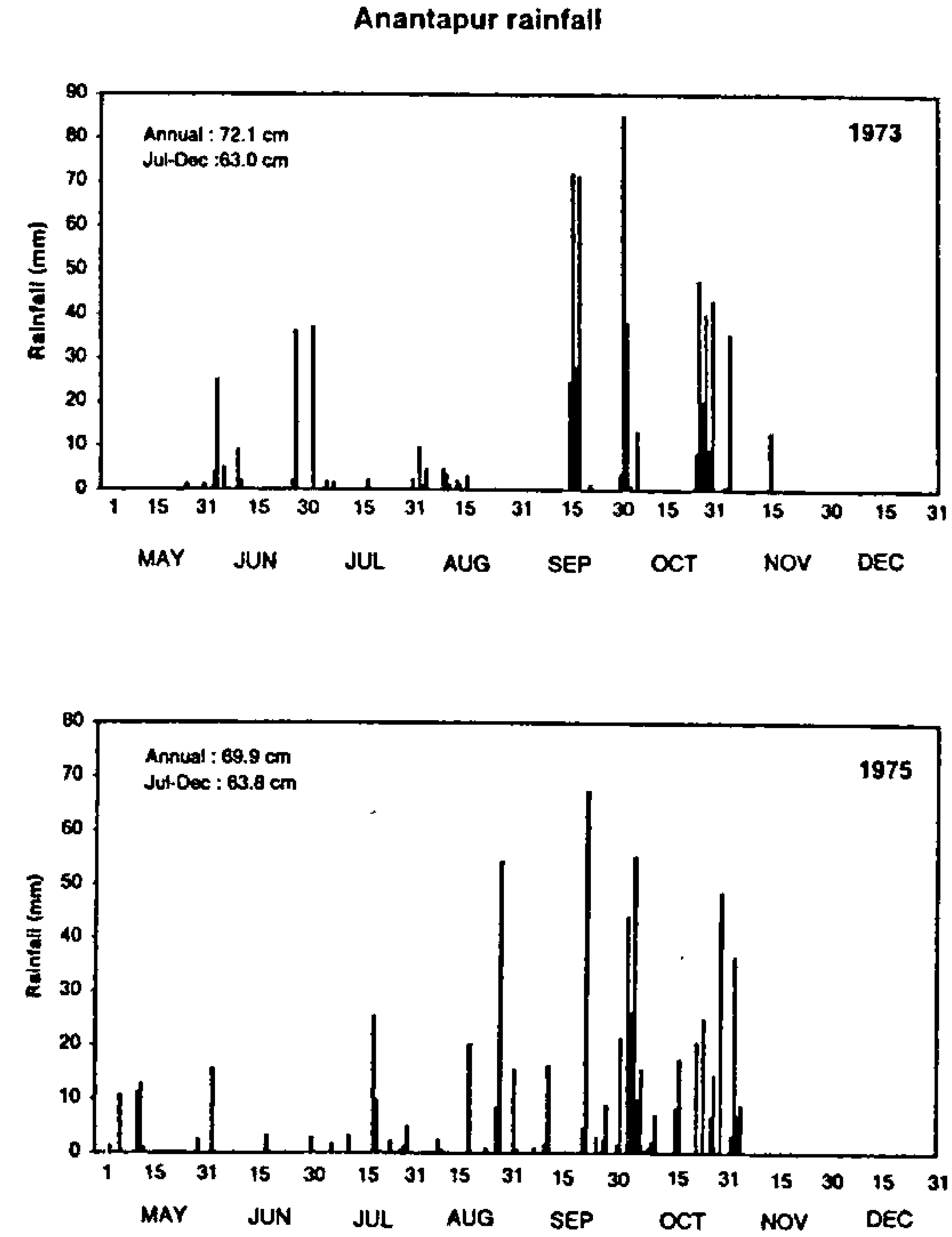

Figure 6. Daily rainfall at Anantapur during 1973 and 1975. The tota annual rainfall and rainfall during July–December are also indicated.

Table 2. Anantapur rainfall (cm)

Nakshatra	Duration*	Mean	SD
Ashwini	13 April – 26 April	0.85	1.55
Bharani	27 April –10 May	1.23	2.05
Kritika	11 May – 24 May	2.84	3.28
Rohini	25 May – 7 June	3.41	3.53
Mrigashira	8 June – 21 June	2.31	2.60
Aridhra	22 June – 5 July	1.88	2.33
Punarvasu	6 July – 19 July	2.86	5.13
Pushya	20 July – 2 August	2.78	3.42
Aslesha	3 August – 16 August	2.58	3.64
Makha	17 August – 30 August	4.23	6.47
Pubbha	31 August – 12 September	3.50	4.29
Uttara	13 September – 26 September	9.03	7.40
Hasta	27 September – 9 October	6.71	5.65
Chitta	10 October – 23 October	3.80	4.05
Swathi	24 October – 5 November	3.29	4.46
Vishaka	6 November – 18 November	0.42	1.13
Anuradha	19 November – 2 December	0.98	1.81
Jyeshta	3 December – 15 December	0.60	1.51
Moola	16 December – 28 December	0.12	0.52
Purvashada	29 December – 10 January	0.24	1.48
Uttarashada	11 January – 23 January	0.02	0.09
Sravana	24 January – 5 February	0.24	1.50
Dhanishta	6 February – 18 February	0.03	0.20
Shatabhista	19 February – 3 March	0.13	0.45
Poorva Bhadra	4 March – 17 March	0.15	0.61
Uttara Bhadra	18 March – 30 March	0.24	0.76
Revati	31 March – 12 April	0.52	0.97

*After IMD (ref. 11).

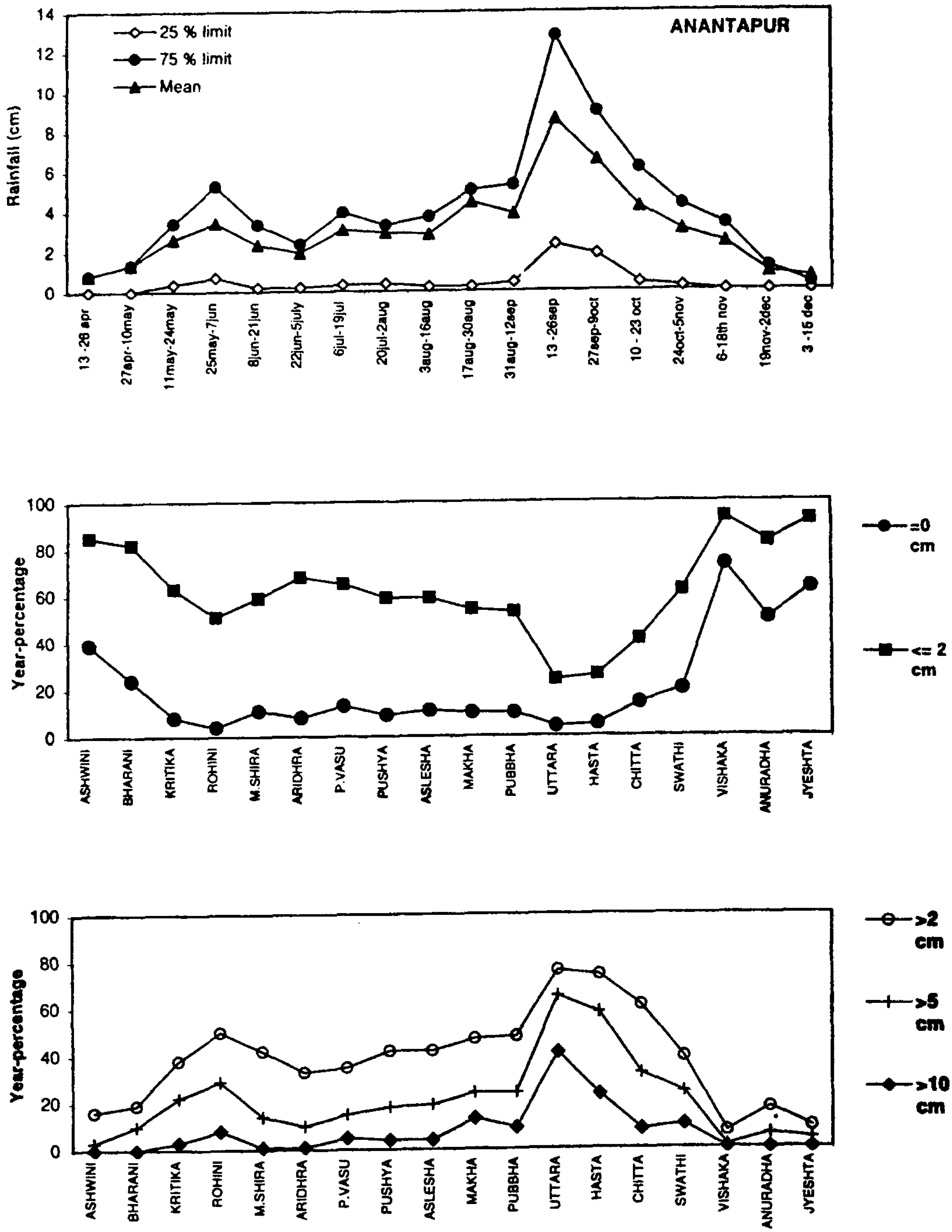

Figure 7. The rainfall according to nakshatras. *Above*, the average, lower and upper limits of 75% of the years; *Middle*, the probability of zero rainfall and rainfall less than 2 cm; *Below*, the probability of rainfall greater than 2, 5 and 10 cm.

or months but so-called 'nakshatras' which are 13 or 14 day periods which are also based on the solar calendar (Table 2 after IMD 1998, ref. 11). The nakshatras stand for the twenty-seven constellations through which the sun passes in a year. Hence the period of each nakshatra is about 14 days. The nakshatra commences when the sun enters the specific constellation. The knowledge of the variability is thus in these time-units rather than weeks or months. The appropriate time for farming operations is also worked out in terms of these time periods. Hence the knowledge of rainfall variability derived from analysis of quantitative data collected over a century can be discussed with the farmers most effectively if worked out for each nakshatra rather than months or weeks (e.g. Figure 7). We found that using this 'language that connects' made a major difference in our interaction with the farmers.

It is seen that although the rainy season extends from May to November, rainfall of 1 cm or more occurs with over 75% probability only during Uttara (13–26 September) and Hasta (27 September – 9 October). In fact there is a local proverb which says that if Uttara rains fail, the time has come to move off from the region. The probability of no rain at all in a nakshatra decreases from over 50% in the first part of the rainy season to be the minimum at 20% in Uttara and picks up to above 50% from the last week of October. The farming strategies have to be tailored to this kind of variability.

Modelling impact of climate variability

One of the most important tools is a model which can simulate the impact of climate variability on yield realistically. Such a model has to perform reasonably well in simulating the yield under different farming situations (e.g. different soils), for the different management options available (such as to spray or not to spray pesticides) and for the different varieties that are available. Here we discuss a model for the impact of climate variability, which incorporates the direct impact on growth and development as well as the indirect impact via triggering of pests/diseases for a specific soil type and a specific variety.

Modelling growth and development of the plant

The PNUTGRO model for the growth, development and yield of groundnut developed by Boote *et al.*[12] has been validated for the prevalent variety TMV-2 at the Anantapur agricultural station by Singh *et al.*[13]. They showed that the year to year variation of the observed yield (in response to the variation in rainfall) is well captured in the simulation (Figure 8). Thus under pest and disease-free conditions, akin to those at the agricultural station, the PNUTGRO model can be used to simulate the yield and its interannual variation in response to that of the rainfall.

However, generally there is a large gap between the PNUTGRO yield and the district-average yield (Figure 9, after Singh[14]). On the whole, the PNUTGRO model over-estimates the yield. One of the reasons is that it does not incorporate losses due to pests and diseases which can be quite large on the farmers' fields. The problem of modelling the impact of these biotic yield-reducing factors is addressed next.

Modelling the indirect impact of climate variability

Crop models such as PNUTGRO simulate the direct impact of the variability of the important climate elements such as radiation, rainfall, etc. on growth and development and hence the productivity of the crop. In

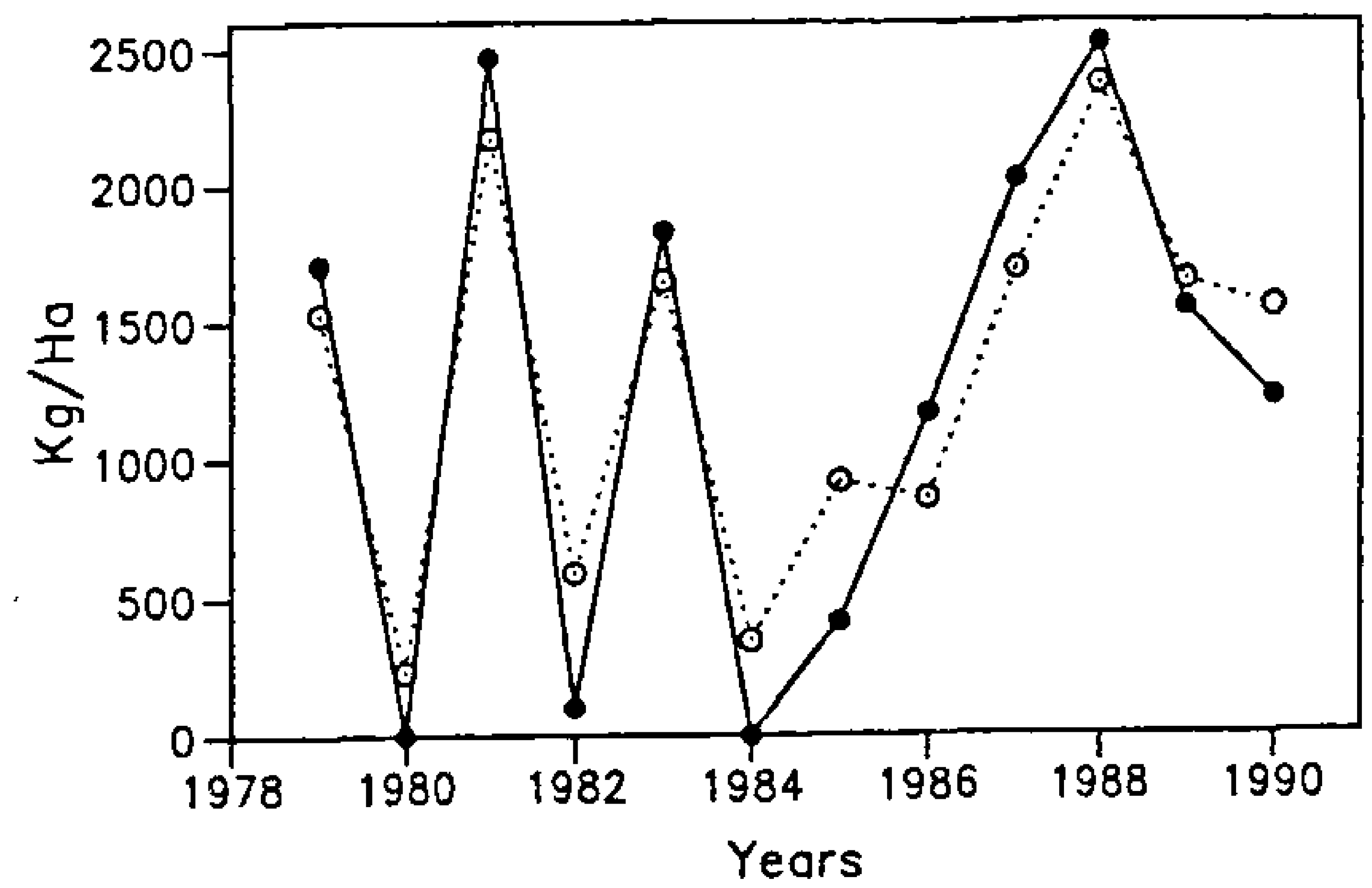

Figure 8. Variation of the observed (open circles) and PNUTGRO yield (filled circles) at Anantapur agricultural research station during 1979–90 (ref. 13).

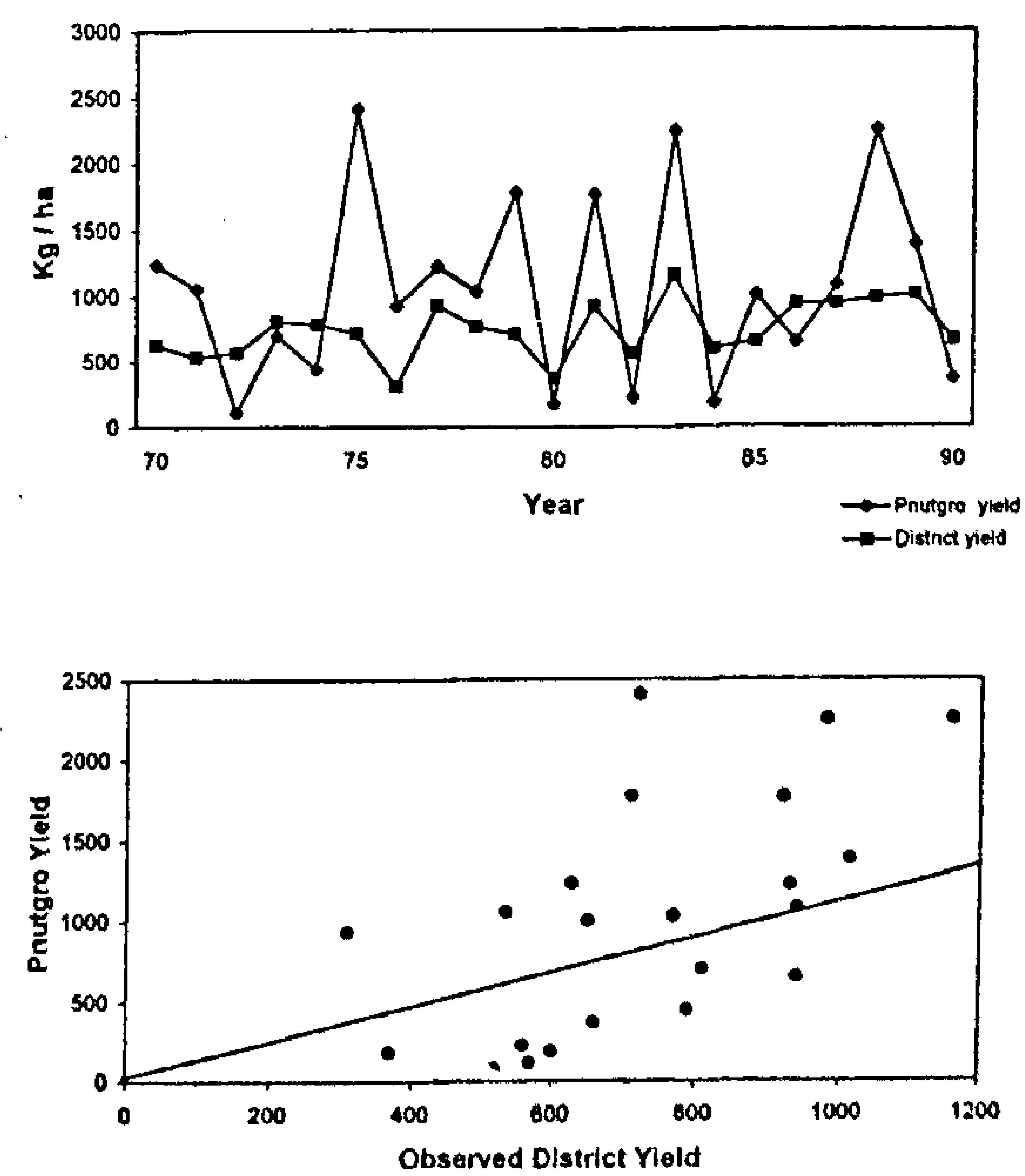

Figure 9. Variation of the PNUTGRO yield and district average yield for Anantapur during 1970–90 (ref. 14) (*above*). PNUTGRO yield versus observed district yield (*below*).

addition, climate variability can have an impact on the productivity via triggering of pests and diseases. We discuss briefly a heuristic model, which simulates the timing of the farming operations such as ploughing, sowing, etc. as well as triggering pests/diseases here. The details are given in Gadgil, Rao and Sridhar[15].

The timing of the land preparation operations such as ploughing and sowing depends upon the soil moisture in the top 20 cm of the soil. In the model, the criteria for these operations are specified in terms of the soil moisture on the basis of the farming practices of the region. We have assumed (as in current practice) that farmers sow at the first opportunity in the broad sowing window. The growth in population of pests such as leaf miner is promoted by dry spells, whereas the incidence of diseases such as late leaf spot, seed rot, etc. is promoted by wet spells. On the basis of the existing knowledge, the criteria triggering such pests/diseases are specified in terms of soil moisture and/or rainfall at different phenological stages of the plant. The extent of loss in yield due to incidence of such pests/diseases is also assumed on the basis of existing knowledge. Thus given the variation of soil moisture in any season, the sowing date as well as the occurrence of different pests/diseases and their impact on yield can be derived from this model. Whereas data on rainfall and other meteorological parameters are available at a large number of stations and over long periods, soil moisture data are relatively sparse. Hence, to derive soil moisture from rainfall variations on the daily scale a simple water-balance model is used[15].

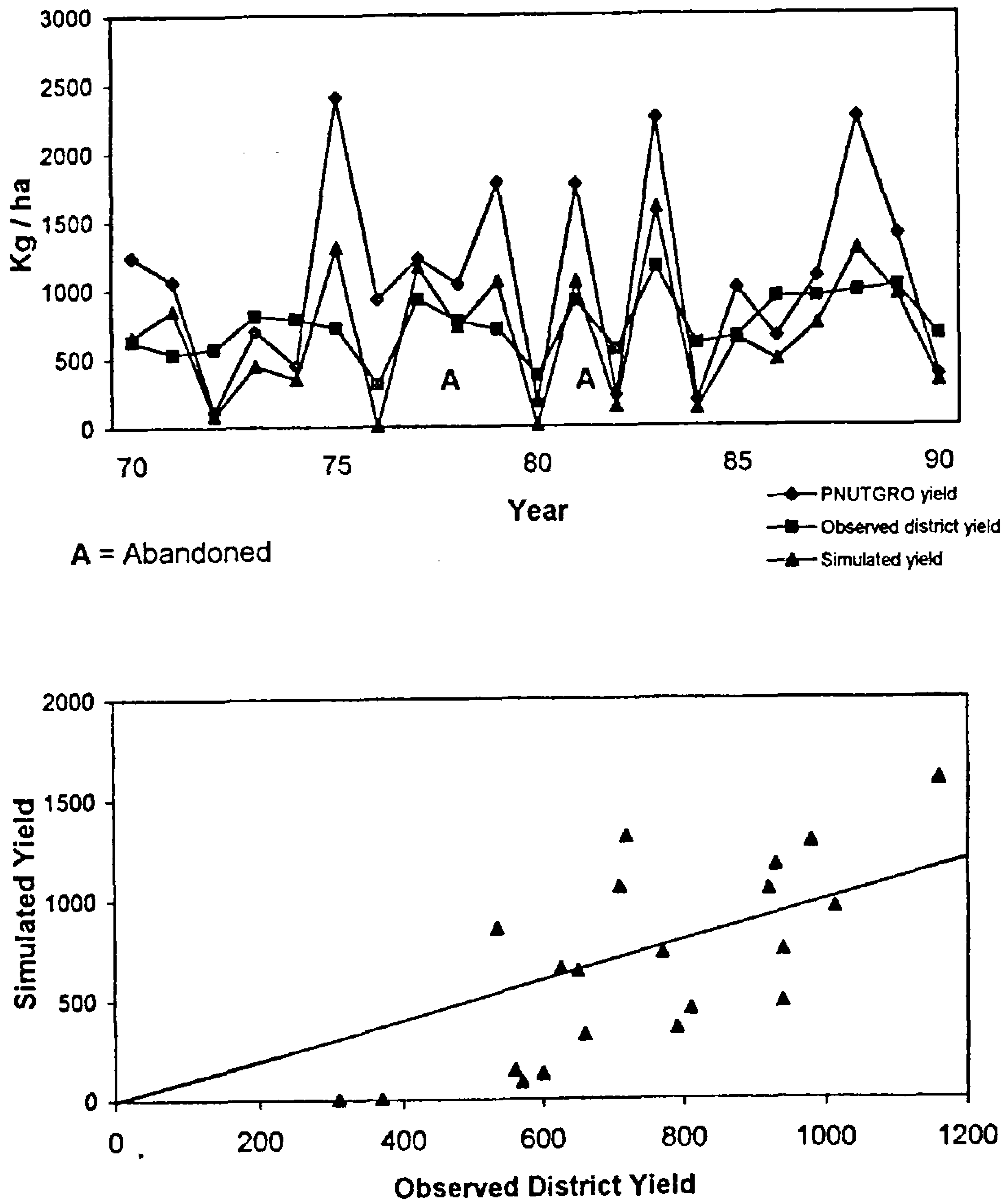

Figure 10. Variation during 1970–90 of the yield (i) simulated by PNUTGRO model; (ii) simulated by using the heuristic model in conjuction with PNUTGRO model; and (iii) observed district average yield for Anantapur[15] (*above*); Simulated yield (ii) versus observed district yield (*below*).

The results of the simulation by the heuristic model for 1970–90 using the rainfall data for the Anantapur agricultural station were found to be close to the available results on sowing date and incidence of leaf miner and late leaf spot[15]. This heuristic model has been run for each of the eighty years for which rainfall data are available for the Anantapur meteorological station, and probabilities of the occurrence of the different pests/diseases derived[15]. Such assessments are useful in deriving expected benefit of use of plant protection measures.

It is important to note that input from farmers regarding conditions for ploughing, sowing and impact of wet/dry spells has been critical to the development of this model. This model as well as PNUTGRO have been validated with the data collected from the farmers' network[7].

Assessing the total impact of climate variability

The heuristic model for indirect impact is used in conjunction with the PNUTGRO model for the available data at the Anantapur agricultural station to simulate the variation in yield during 1970–1990. Figure 10 compares the yield thus simulated with the PNUTGRO yield and observed district yield. It is seen that the simulation by the heuristic model used in conjunction with the PNUTGRO model is close to the observations. This suggests that a large fraction of the yield gap between the PNUTGRO yield and the district yield can be attributed to the pests/diseases incorporated in the heuristic model. There seems to be a slight tendency to underestimate the yield which may be due to an overestimate of losses due to pests/diseases in the heuristic model.

Models which incorporate the direct and/or the indirect impact of climate variability and which can simulate reasonably well the dates of the farming operations such as sowing and the observed variability in yield, will be major tools in investigations of the variation of yield under different management options. Hence, such models will play an important role in our endeavour to identify strategies which are tailored to the climate variability of the region or to its prediction for a specific season. Next we illustrate the approach to identifying optimum strategies by addressing one of the problems the farmers wanted us to investigate, viz. the optimum sowing window for this region.

Tailoring strategies to rainfall variability – The choice of the sowing window

The detailed investigation is presented in the companion paper by Rao *et al.*[16]. The sowing window used at present is 22 June to 17 August. Farmers generally sow at the first opportunity, i.e. when the top layer of the soil becomes sufficiently moist in this sowing window. We have noted that in the traditional cropping system the farmers used to sow at the first opportunity in May or June. In fact in the package of recommendations developed by agricultural scientists[9], it is suggested that even for the TMV-2 variety of groundnut, sowing should be done at the first opportunity in May, June or July. It is further suggested that if no opportunity occurs till the end of July, groundnut should not be sown. Apparently farmers tried this when TMV-2 was first introduced in the region, but found that sowing earlier than 22 June often led to failure and arrived at the present sowing window. Even if no opportunity arises till the end of July, the farmers do sow in August, despite the recommendation to the contrary. This is because in their experience there have been years with good yield even when sowing is done in August. Hence they sought our advice on the optimum sowing window for this agroclimatic regime.

We investigated this problem using the PNUTGRO model to study the variation of yield with sowing date and the heuristic model to analyse the sowing opportunities in each year, using the rainfall data for Anantapur during 1911–1998. We found that the probability of crop failure is very high for sowing dates before mid-June (Figure 11). This is consistent with the experience reported by the farmers. An unexpected result is that the yield is enhanced considerably if the sowing is postponed to after mid-July (Figure 11). An analysis of the moisture stress in the model showed that the most critical period is 60–75 days after sowing which is the pod filling stage. A wet spell has a high probability of occurrence at this stage if the stage coincides with Uttara (13–26 September) and Hasta (27 September – 9 October), i.e. only when sowing is done after mid-July. Thus such a sowing window is optimal for the rainfall variability of this region. Using the heuristic model, we showed that giving up a sowing opportunity before this date does not involve much risk. This is because for every year during 1911–98 for which such an opportunity occurred before mid-July, another occurred after mid-July. The response of the farmers to these results was very positive. In the kharif season of 1999 several farmers have conducted field trials with late sowing to test this finding.

Challenges ahead

We believe that any endeavour to identify optimum farming strategies for the rainfed belt needs concerted efforts from an interdisciplinary group which includes practising farmers. An understanding of the impact of the variability of rainfall (of the type experienced over the specific region) on the yield of the crops/varieties of interest, under the different available management options is a prerequisite to identification of such strategies.

For gaining insight into the links between rainfall variability and yield, experimental studies at agricultural stations have to be complemented with investigations of (i) the nature of climate variability of the region by analysis of the available meteorological data for several decades, and (ii) the impact of such variability on the yield simulated by realistic crop models.

We find that input from farmers is critical, not only in identifying the different management options, but also in developing realistic crop models for the total impact of climate variability. Farmers also provide valuable input on the problems that need to be addressed. In our experience, when we succeed in providing answers to such problems, as in the case of choice of sowing window, they are more than willing to test the findings with experiments on their own land. Thus, the farmers can contribute to the on-field testing of the results as well. When farmers participate in the endeavour to identify appropriate strategies and test them in field trials, the chance of their adopting the successful strategies is naturally very high. In our discussions with the farmers, several other problems of concern with respect to the prevalent groundnut variety TMV-2, such as the determination of the optimum seed rate were identified.

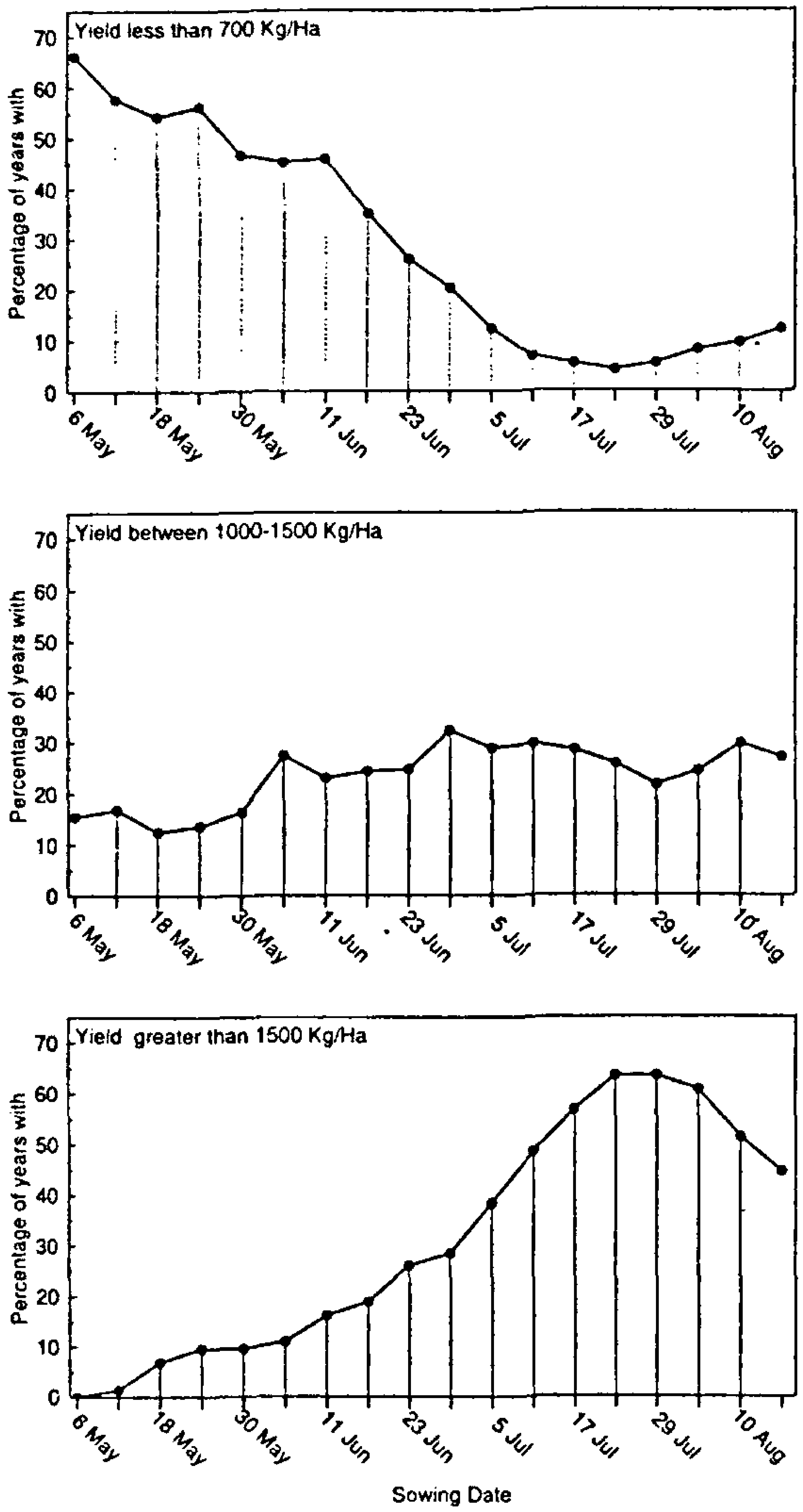

Figure 11. Variation of the probability of PNUTGRO yield with sowing date yield < 700 kg/ha (*above*); between 1000 and 1500 kg/ha (*middle*); and > 1500 kg/ha (*below*).

In addition to tailoring strategies to the nature of the climate variability of the region, the approach developed here can also be used for identifying the strategies appropriate for a specific season when predictions of seasonal or intraseasonal scales are available. For example, over the Anantapur region the probability of high seasonal rainfall decreases substantially during the El Nino[17]. This suggests that expected benefits of fertilizers, etc. will be lower during such years.

Although TMV-2 is the most popular variety of groundnut, farmers are on the look-out for other varieties which may perform better. Other varieties are grown on some farms. However, farmers are aware that the time required for such field trials in variable climate is several years. Hence they would like information on the performance of such varieties in the face of rainfall variability of the region. This needs to be addressed with crop models for the different available varieties.

So far we have focused only on the production of groundnut. This crop is grown extensively because the farmers believe that groundnut is the crop that can give maximum income in these rainfed areas. It would be worthwhile to explore whether the production of other important crops such as tur/red gram (which is one of the main sources of protein in a vegetarian diet) can be enhanced to the level that it becomes remunerative. The appropriate cropping pattern for this region with sustainable high yields needs to be identified. The variety of groundnut now cultivated does not utilize the rainfall in May and June which, though variable, is not negligible (totalling to about 10 cm). Whether this can be utilized by growing alternative crops or fodder needs to be explored. Such problems of alternative cropping systems have been addressed earlier and recommendations have been generated. Farmers do not consider these recommendations appropriate partly because they are often not consistent with their experience and there are other problems with the suggested alternative crops such as lack of market. Hence farmers generally do not accept the recommendations. For example, last year when rainfall was very low in July and early August, it was recommended that horsegram be sown. Nevertheless, farmers have sown groundnut in August. It appears that for deriving alternative cropping strategies, it is important to incorporate variability into assessing the performance of the possible crops and take into account the existing constraints (such as availability of markets, etc.).

An exercise in assessing alternative cropping strategies for the region will be useful in case the price of groundnut crashes (as is likely with globalization, import relaxation, etc.). From the viewpoint of meeting the needs of our nation, it would also be good if some important food grains such as pulses are grown over large areas in such regions. For assessing the possible yields of several such crops, a pre-requisite is a crop model which can simulate realistically the impact of climate variability. Such models do not exist for all the important crops and those that exist have to be validated for this region.

We believe that the approach developed here, involving an interdisciplinary group with practising farmers, addressing problems posed by the farmers, will be successful for identifying appropriate farming strategies for the rainfed belt which are acceptable to the farmers. This approach could be also readily applied to identify strategies for enhancement of other important rainfed crops.

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