Forecasting rain for groundnut farmers—How good is good enough?

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We illustrate how climatological information about adverse weather events and meteorological forecasts (when available) can be used to decide between alternative strategies so as to maximize the long-term average returns for rainfed groundnut in semi-arid parts of Karnataka. We show that until the skill of the forecast, i.e. probability of an adverse event occurring when it is forecast, is above a certain threshold, the forecast has no impact on the optimum strategy. This threshold is determined by the loss in yield due to the adverse weather event and the cost of the mitigatory measures. For the specific case of groundnut, it is found that while for combating some pests/diseases, climatological information is adequate, for others a forecast of sufficient skill would have a significant impact on the productivity.

THAT the agricultural productivity in our country is intimately linked to the vagaries of the monsoon has been known for centuries. In fact, the Indian economy has been said to be a gamble on the monsoon. The most important climatic element for agriculture in the tropics is the rainfall. The agricultural productivity depends on the total quantum of rainfall received in a year/season as well as its distribution within the year. The regions most susceptible to inter-year and intra-year variability are the semi-arid and arid regions. Management practices which take into account the rainfall variability over the region of interest are likely to generate a substantial increase in the sustained productivity[1]. In addition, if it becomes possible to forecast critical events (such as dry or wet spells) and take timely preventive measures, we expect a further increase in yields.

From the century-long meteorological data set available with the India Meteorological Department, the climatological information regarding the probabilities of occurrence of the important features of the rainfall profile (e.g. wet or dry spells) can be derived. Also, with the rapid development of general circulation models over the last two decades, it will soon be possible to generate reasonable forecasts over the medium range (3–10 days) for meteorological subdivisions of India. Establishment of the National Centre for Medium-Range Weather Forecasting at New Delhi has given major thrust to generating such forecasts using the country's first supercomputer. At this stage it is important to consider how the climatological information/meteorological forecasts can be used for developing optimum cropping and management strategies. It is also necessary to spell out how good a forecast should be for it to be useful in a particular context. We address these questions in this paper.

To illustrate how climatological information and meteorological forecasts can be used to decide between alternative strategies, we consider the example of the productivity of groundnut in the red sandy soil of Karnataka and in the adjoining regions of Andhra Pradesh. Agroclimatology of groundnut, an important crop of the semi-arid tropics and a major source of edible oil, has been extensively studied[2]. The adverse weather events which can lead to a substantial loss in the productivity of rainfed groundnut are the dry and wet spells. The impact of prolonged dry spells on the yields in rainfed farming is well known. However, the impact of prolonged wet spells on the pests and diseases and on the productivity of the crops has received less attention. In fact, remedial measures to combat pests and diseases are more readily available to the farmer than those required to overcome the adverse effects of prolonged dry spells. Virmani[2] has suggested that effective use of weather and climatological information could be of great benefit to the groundnut farmers.

The adverse weather events promoting some of the major pests and diseases, leading to loss of productivity in groundnut, the typical losses incurred, as well as costs of possible mitigatory measures are discussed in the next section. Next we consider how climatological information about the adverse weather events, such as wet spells, can be used in deciding between alternative strategies, and discuss whether better results could be obtained with the use of forecasts for the specific season. We show that until the skill of forecasting such an event, i.e. the probability of correctly forecasting the event, is above a certain threshold (which is determined by the loss incurred due to the event and costs of mitigatory measures), the optimum strategy is the same as the one derived from climatological information alone. The agricultural situation thus places limits on the minimum skill of forecasts. It is shown that for groundnuts, the values of the cost–loss ratio involved in measures against different diseases imply different strategies of management. A summary of the results and the general implications of the analysis are presented in the final section.

Impact of adverse weather events on the productivity of rainfed groundnut

We consider here the Chitradurga District of the Karnataka State, which is located in the heart of the rainfed groundnut region. This region is characterized by regular monocropping of groundnut in vast areas with often the same variety, viz. TMV-2 (ref. 3). The crop is generally sown in July and harvested towards the end of about 120 days. This synchronized sowing leads to uniform crop growth stages over large areas and promotes the growth of certain epidemic pests and diseases. This problem is further accentuated by cultivation of groundnut in irrigated lands during summer, which implies the presence of host plants throughout the year[4]. Not surprisingly, the productivity of the rainfed groundnut in this region is critically dependent on the incidence of pests and diseases[5].

As with other epidemic pests and diseases, the organisms are always present at a low level of intensity and can multiply rapidly when the weather conditions are favourable and the plant susceptible to attack. The dry spells promote the incidence of leafminer attacks and wet spells that of crown rot, late Tikka disease and collar rot. Losses in yields of pods and straw of groundnut by pests and diseases are variable, depending on the intensity of the attack and the crop growth stage during such an attack. Estimates of typical losses in yields with incidence of the different pests/diseases discussed here and the costs of plant protection measures are given in Table 1.

The main features of the rainfall profile at Chitradurga were derived from the daily rainfall data for 1901–90 supplied by the India Meteorological Department. The average rainfall pattern at Chitradurga on the weekly scale during April–December is depicted in Figure 1. Note the two clear peaks of the weekly rainfall in the pre-monsoon season in May and near the end of summer monsoon from mid-September to mid-October. The normal range of variation of rainfall in any week is also indicated in Figure 1 by solid bars, which extend from the minimum assured rainfall (at 75% probability) to the upper limit of rainfall (again for 75% of the years). Note that this range of variation extends all the way from zero rainfall to about 2–3 cm in May–June and again from mid-October to mid-November. The range is smaller during July–mid-September but is maximum from mid-September to mid-October. The cropping pattern for the region should be tailored for this rainfall profile and its variability.

Given the low average rainfall and high variability over this region, a week with 1 or 2 cm of rainfall can be considered to be a wet week. The probabilities of a wet week with rainfall greater than 1 cm or 2 cm are depicted in Figure 2 *a*. The probabilities of no rain at all (0 cm) and of rainfall less than 0.25 cm in a week are shown in Figure 2 *b*. We find that the probability of wet spells is highest for mid-September to mid-October, but since the variability is very large in October, the probability of dry spells is also not small.

For defining precisely, in terms of rainfall, what constitutes a wet spell that can promote the incidence of a specific pest/disease like late Tikka disease or crown rot, a detailed knowledge of the relationship of the intensity of the attack to the rainfall profile is required. In the absence of detailed quantitative information we base our definition of a wet spell and dry spell on the experience of one of the co-authors (PRS), who is also a farmer from this region. We take an intense wet spell to be one in which there is 2 cm or more of rainfall in two successive weeks. We take a dry spell as one in which there are two successive weeks with less than 0.25 cm of rainfall. The probabilities of successive weeks with wet/dry spells during the growing season July–December are given in Table 2. Groundnut is usually sown in July after the occurrence of sowing rains, i.e. about 1 cm per week. The probability of receiving such rains exceeds 50% in the second week of July (Figure 2) and remains high for the rest of the month. Generally, sowing is done in the second week of July. In Table 2 the different stages of the growth of groundnut are depicted assuming this period for sowing.

If a wet spell occurs at the seedling stage, namely 2–3 weeks after sowing (probability 0.13–0.16 from Table 2), waterlogging of the soil can lead to a high incidence of crown rot, causing rotting of young seedlings[6]. Crown rot in groundnut is caused by *Aspergillus niger*, which is a soil pathogen, and is also transmitted by the seed. The disease is most severe in light sandy soils such as those found in the Chitradurga region. The loss in yield due to crown rot at this stage is reported as being not very high, about 8–10%, because it tends to occur in patches[7]. However, during certain years, such as in 1994, the loss was as high as 30% in several fields of this region. The preventive measure is cheap, costing only about 10% of a typical loss (Table 1).

Leafminer *Aproaerama modicella*, Der. is a major pest in the southern and central parts of India. Leafminer attacks on the crop cause yellowing and webbing of the leaves and leaf drop, resulting in reduction in leaf area and considerable loss (Table 1). A dry spell any time between the 2nd week of August and first week of October can cause rapid multiplication of this pest. We see from Table 2 that the probability of a dry spell

Table 1. Cost-loss estimates for major pests/diseases

Disease/pest incidence	Cost of plant protection measure	Typical loss
Crown rot in seedling stage	Seed treatment by Dithane M-45 5 g/kg of groundnuts (40 kg seeds/acre) at Rs 36/acre	8–10%, i.e. Rs 320–400/acre
Late Tikka disease	Bavistein 1 5 g/l and 250 l/acre at Rs 345/acre	30–45%, i.e. Rs 1200–1800/acre
Leafminer in peg formation stage	Two sprays of Chloropyrephas at an interval of 15 days at 2 ml/l using 250 l/acre at Rs 750/acre	25–92%, i.e. Rs 1000–3600/acre

The estimate costs of the protection are based on the present prices of the chemicals and labour.
Typical yield is assumed to be 4 quintals per acre at Rs 1000 per quintal.

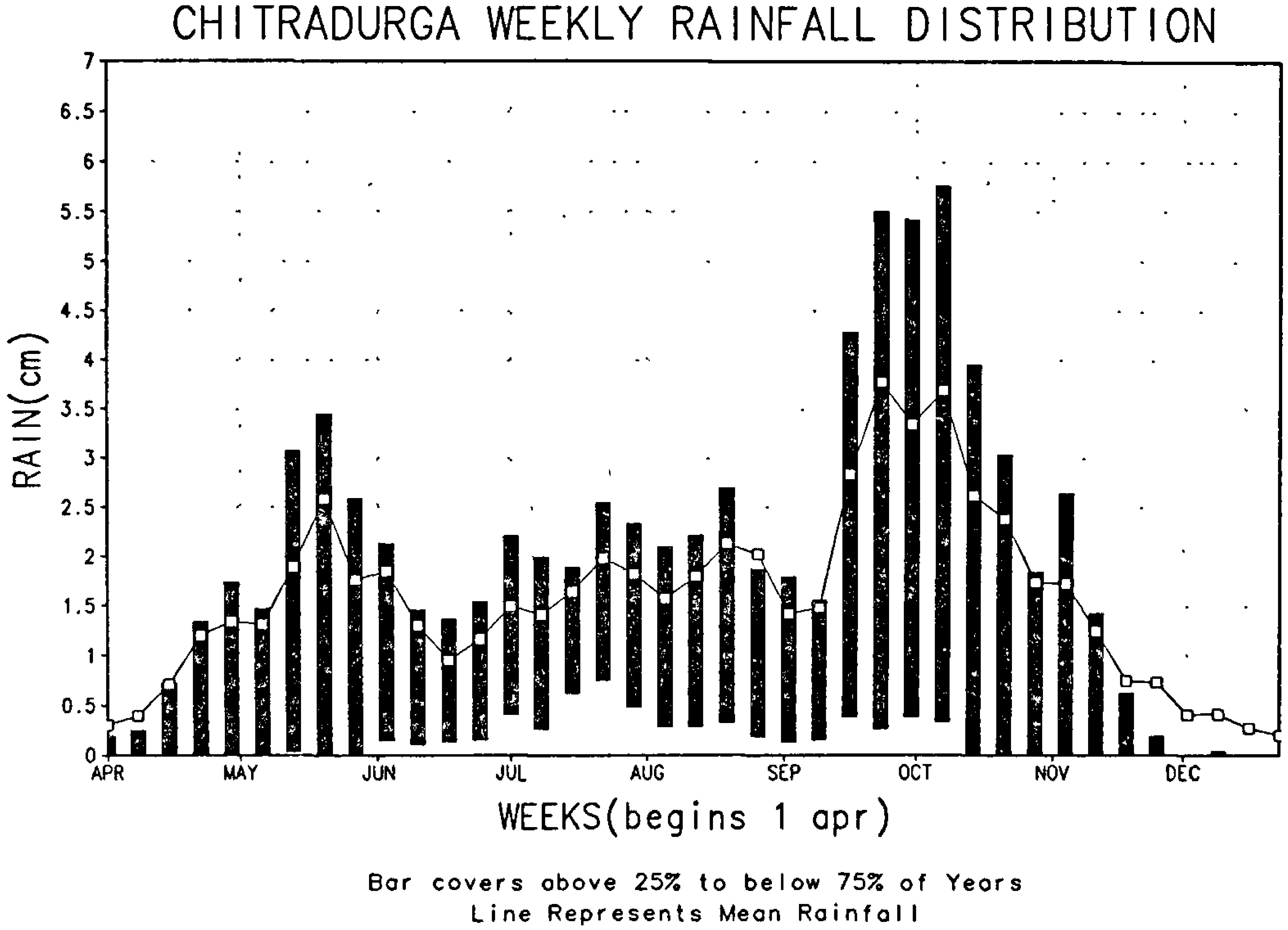
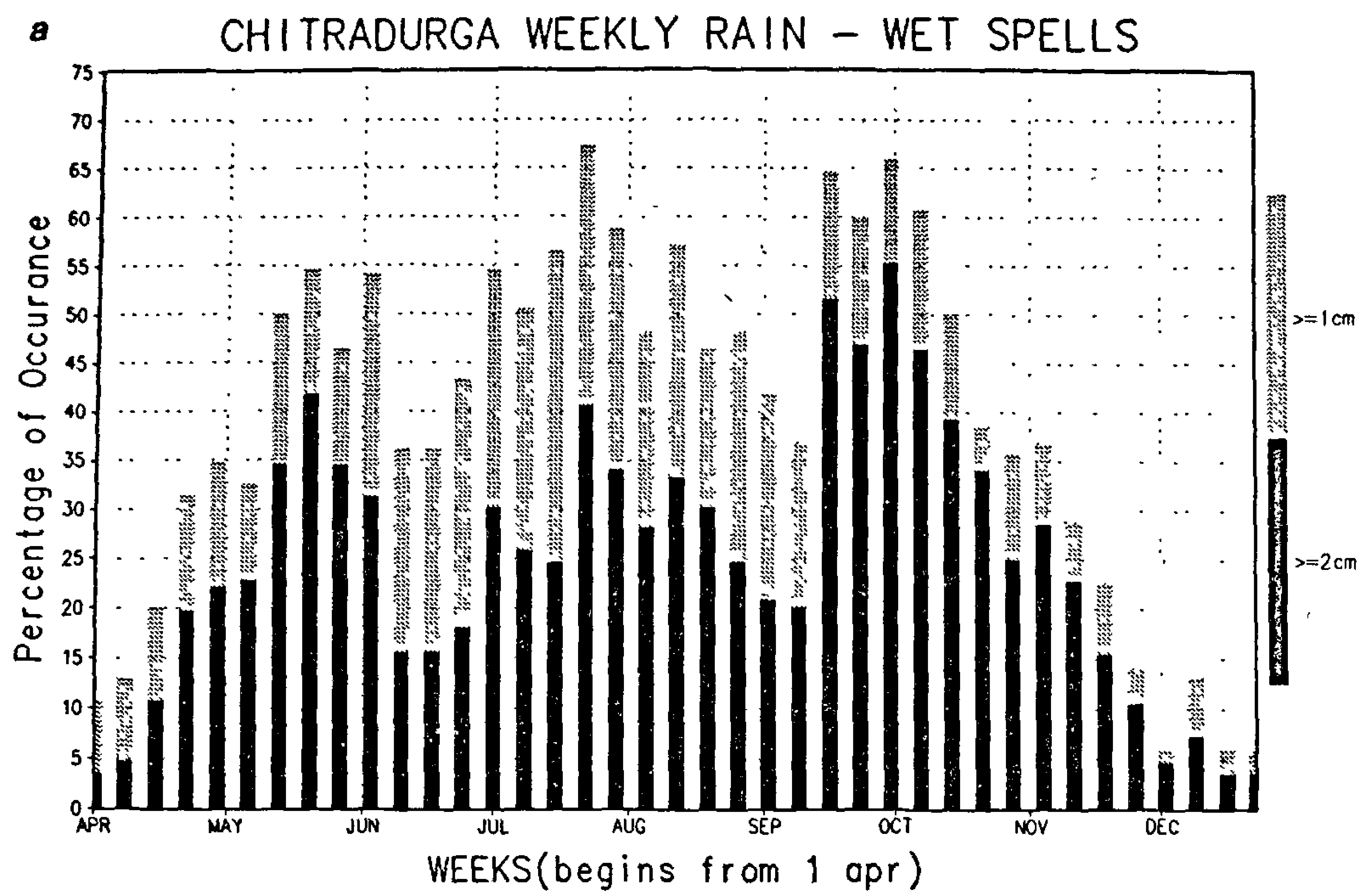


Figure 1. The mean weekly rainfall in cm at Chitradurga during April–December. For each week the range of variation from the minimum assured rainfall at 75% probability to the upper limit of rainfall (again for 75% of the years) is shown by a bar.

varies from 0.02 to 0.15 in this period, being maximum in late August and early September. The loss in yield is particularly high when the dry spell causes severe moisture stress[8]. If a wet spell occurs any time during the attack by leafminer, the population of the pest as well as the intensity of the attack decreases[8]. The costs of the remedial measure can be a large fraction, up to 25% of the loss (Table 1).

The occurrence of a wet spell during and after the pod-filling stage, typically in the last two weeks of October (probability 0.21 from Table 2) promotes the incidence of the late Tikka disease[9]. The late Tikka disease is caused by *Cercospora personata*. The disease causes black pustules on leaves and stem, reduces the leaf area, affects pod-filling and decreases the quantity of straw available. The preventive measure involves considerable expenditure (Table 1).

A wet spell at the end of the pod-filling stage – first



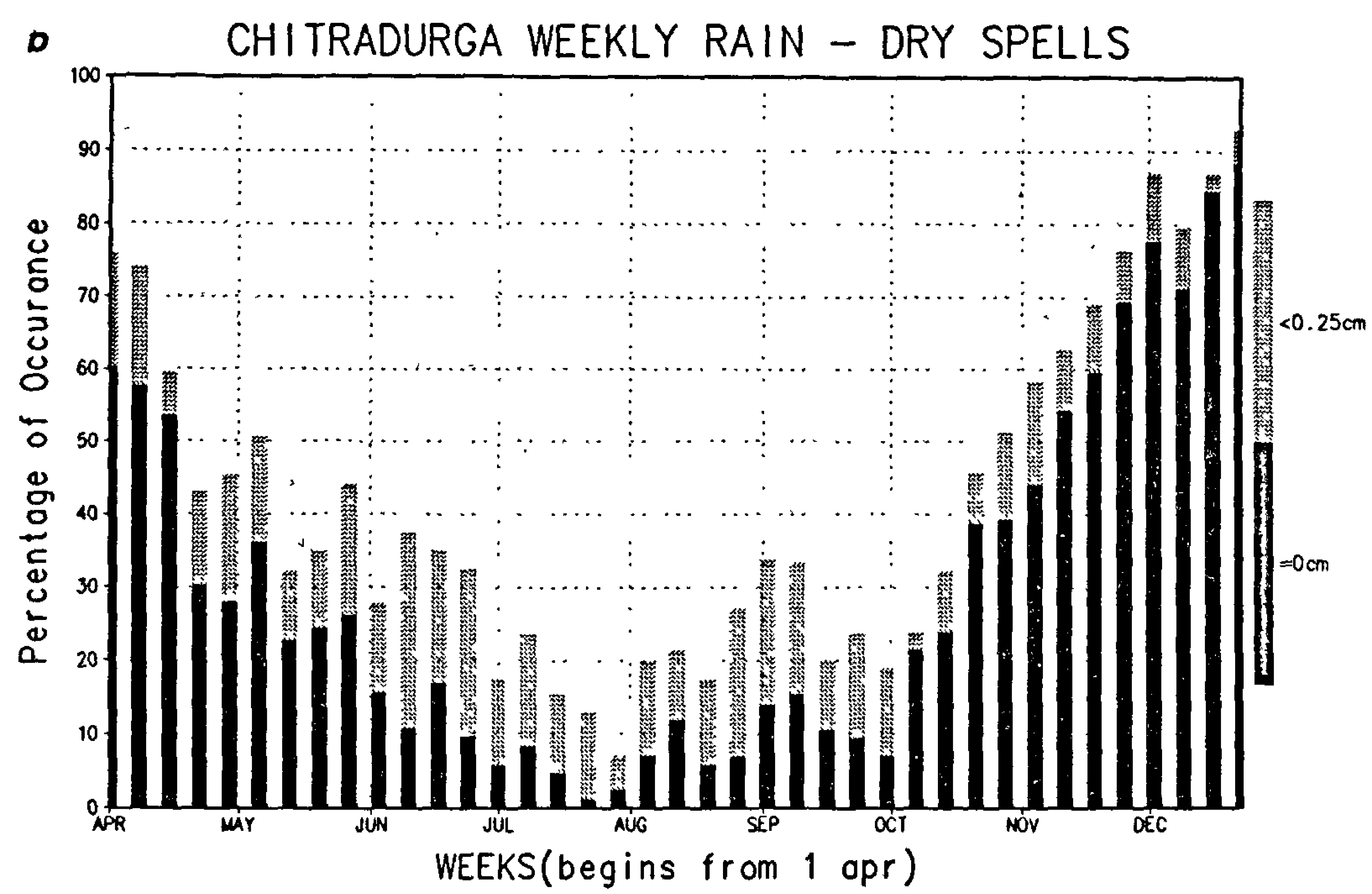


Figure 2. *a*, The probability of a wet week with rainfall greater than 1 cm (dotted) and 2 cm (solid). *b*, Dry week with rainfall less than 0.25 cm (dotted) or zero rainfall (solid) shown as a percentage for all weeks during April–December.

Table 2. Probabilities of wet and dry spells during different crop growth stages

Crop growth stages	Successive weeks	Probability of wet spell, i.e. > 2 cm rain per week for both weeks	Probability of dry spell, i.e. < 0.25 cm rain per week for both weeks
Sowing	Jul 1–7 to Jul 8–14	0.08	0.08
	Jul 8–14 to Jul 15–21	0.04	0.05
Seedling stage	Jul 15–21 to Jul 22–28	0.13	0.02
	Jul 22–28 to Jul 22–Aug 4	0.16	0.00
	Jul 29–Aug 4 to Aug 5–11	0.10	0.02
	Aug 5–11 to Aug 12–18	0.13	0.05
Flowering and peg formation stage	Aug 12–18 to Aug 19–25	0.10	0.05
	Aug 19–25 to Aug 26–Sep 1	0.09	0.05
	Aug 26–Sep 1 to Sep 2–8	0.10	0.15
	Sep 2–8 to Sep 9–15	0.08	0.10
	Sep 9–15 to Sep 16–22	0.10	0.05
	Sep 16–22 to Sep 23–29	0.31	0.06
Pod-filling stage	Sep 23–29 to Sep 30–Oct 6	0.23	0.02
	Sep 30–Oct 6 to Oct 7–13	0 30	0.07
	Oct 7–13 to Oct 14–20	0.17	0.10
	Oct 14–20 to Oct 21–27	0.21	0.23
	Oct 21–27 to Oct 28–Nov 3	0.11	0.27
	Oct 28–Nov 3 to Nov 4–10	0.08	0.36
Harvest	Nov 4–10 to Nov 11–17	0.13	0.47
	Nov 11–17 to Nov 18–24	0.06	0.49
	Nov 18–24 to Nov 25–Dec 1	0.04	0.55
	Nov 25–Dec 1 to Dec 2–8	0.00	0.66
	Dec 2–8 to Dec 9–15	0.00	0.69
	Dec 9–15 to Dec 16–22	0.00	0.70
	Dec 16–22	0 00	0.83

or second week of November – can lead to an attack of late collar rot (also known as pre-harvest peg, pod rot), implying a large loss of up to 35% of the yield[10]. The probability of such a wet spell is seen to be between 0.08 and 0.13. The control of the attack at this stage requires soil drenching by Dithane M-45. This involves a large cost of Rs 1300 per acre, which is comparable with the typical loss of about Rs 1400. The protective measures are thus prohibitively expensive. We need other means of avoiding this attack, such as a choice of alternative varieties. In this regard, it is interesting to note that before the introduction of the TMV-2, a longer-duration variety of groundnut was grown in this region. For this variety, the harvesting stage was later in the season when the probability of a wet spell is extremely low. It may be worthwhile to develop a variety for this region (which has a longer rainy season than Coimbatore from where the TMV-2 has been developed) which combines the advantages of the TMV-2 (a bunching variety) with those of a longer-duration variety (reduced susceptibility to collar rot).

An effective disease and pest management strategy implements appropriate plant protection measures before any significant damage is caused to the crop. However, decisions regarding taking up (or not taking up) such measures are taken by individual farmers. These decisions are based on the consideration of cost of the plant protection measure to the farmer (which may vary from one farmer to another) and the loss likely to be incurred if mitigatory measures are not taken. We consider next how climatological information and forecasts of adverse weather events can be used by the farmer in taking the decisions. A practical prescription covering the entire season can be obtained only after more elaborate analysis. We intend to illustrate here only the theoretical framework for making an appropriate decision. For simplicity, we discuss in detail the procedure to be adopted for a single specific fortnight.

Choice of strategies on the basis of climatological information and meteorological forecasts

We consider a simple case of choice between two alternative strategies – to adopt a remedial measure such as application of pesticides (at a cost C) or not adopt it and suffer the loss L in productivity, if the adverse weather event (for example, a wet spell) occurs. The farmer has to decide whether to spray a pesticide or not on the basis of climatological information on the probability of a wet spell in the period of interest (e.g. probability of p_w of 0.16 for July 22 to August 4 from

Table 2), and a forecast of whether a wet spell will occur (if available). If he chooses to spray the pesticide, the cost incurred is C. If he chooses not to, and if a wet spell does occur, a loss L, in yield is incurred. *We take the optimum strategy to be one which maximizes the long-term average returns to the farmer by minimizing the effective cost, i.e. the cost of remedial measure or the expected loss, as the case may be*[11, 12].

Strategies based on climatological information

Consider first the implications for the strategies on the basis of climatological information alone, i.e. on the basis of the probability of p_w of a wet spell during the critical period. If the farmer decides to spray the pesticide, the cost incurred is C. On the other hand, if the farmer chooses not to spray, since the probability of the wet spell is p_w, the expected loss due to the occurrence of the wet spell is p_wL. Thus, the optimal strategy in this case is

spray the pesticide if $C < p_wL$,

i.e. if $p_w > C/L$,

do not spray if $p_w < C/L$.

Strategies based on forecast

While the methods of forecasting may be diverse (based on models of atmospheric circulation or statistical models), the skill of the forecast can be assessed using three summary statistics, viz.

p_1 – the probability of a wet spell occurring when it is forecast,

p_0 – the probability of a wet spell occurring when the forecast is for no wet spell,

p_f – the frequency with which a wet spell is forecast.

However, these three measures are not independent. The probability p_f is related to the climatological probability p_w, the probability p_1 of correct forecast and the probability p_0 of incorrect forecast by

$$p_w = p_f p_1 + (1 - p_f)p_0. \quad (1)$$

For models generating an unbiased forecast, we expect a wet spell to be forecast on an average as often as it occurs, i.e. p_f should be equal to the climatological probability p_w.

For any worthwhile forecast, we expect that the probability of occurrence of a wet spell when a wet spell is forecast to be larger than that of the occurrence of the wet spell when no wet spell is forecast. Hence,

$$p_1 > p_0. \quad (2)$$

Combining (1) and (2) it can be shown that

$$p_1 > p_w > p_0. \quad (3)$$

This implies that a worthwhile forecast must be better than climatology, which is the traditional wisdom of meteorologists. How stringent the conditions on successful and unsuccessful forecasts are depends on the period. Thus, for a forecast of rainfall > 2 cm during the first week of October, the probability p_1 of such a wet week occurring when it is forecast must be greater than 0.55 (Figure 2 *a*); the probability of a wet week occurring when no wet week is forecast, p_0, must be less than 0.55. The condition on p_1 is less stringent for the first and second weeks of September, with only about 20% probability of rain of 2 cm or more. However, in that case the limit on p_0 is more stringent, with an upper limit of 0.2.

Consider first the case when the forecast is for no wet spell. Then the wet spell occurs with the probability p_0, and if the pesticide is not sprayed, the expected deficit due to the incidence of pest is p_0L. If the pesticide is sprayed, the expenditure is C. Hence, the returns will be maximized by choosing a strategy which minimizes the effective costs, i.e. $\min(p_0L, C)$. If $p_0L > C$, then spraying the pesticide will minimize the effective costs. On the other hand, if $p_0L < C$, not spraying the pesticide will maximize the returns. The strategy recommended is thus

if $p_0 < C/L$: do not apply the pesticide,

if $p_0 > C/L$: apply the pesticide. (4)

Hence, if $p_0 > C/L$, even though the forecast is for no wet spell, the appropriate strategy is to spray the pesticide.

When a wet spell is forecast, analogously the expected loss is p_1L and the cost of spraying the pesticide is C; hence, the returns can be maximized by a strategy which implies $\min(p_1L, C)$. The appropriate strategy is

if $p_1 < C/L$: do not apply the pesticide,

if $p_1 > C/L$: apply the pesticide. (5)

Thus, if the probability of a correct forecast is small ($p_1 < C/L$), the strategy recommended is not to spray pesticide even though a wet spell is forecast.

Using (3) it is clear that $p_1 < C/L$ implies $p_w < C/L$, and the strategy recommended by (5) for this case is the same as (1), which was obtained using climatological information alone. Similarly, from (2) $p_0 > C/L$ implies $p_w > C/L$. The strategy recommended by (4) for this case is also identical to (1), which was obtained from climatological information alone. Thus, the use of forecast will yield a different strategy, only if

Table 3. Cost-loss ratios, appropriate strategies and minimum forecast skill

Pest/ disease	Adverse weather event and critical period	p_w (or p_d)	C (Rs/acre)	L (Rs/acre)	C/L	Strategy: regarding protective measure	E_c (Rs/acre)	E^* (Rs/acre)	p_0	p_1
Crown rot	Wet spell July 22–Aug 4	0.16	36	320	0.11	Adopt	36	6	0.11	0.16
				400	0.09				0.09	
Leaf miner	Dry spell (1) in a specific fortnight between mid Aug	0.02	750	1000	0.75	Not adopt	20–72	15	0.005	0.75
				3600	0.21				0.015	0.21
	to early Oct	0.15					300	112	0.044	0.75
							540		0.14	0.21
	(2) In any fortnight in the above period	0.4	750	1000	0.75	Not adopt	400	300	0.17	0.75
				3600	0.21	Adopt	750	300	0.21	0.4
Late Tikka	Wet spell last half of October	0.21	345	1200	0.29	Not adopt	252	72	0.17	0.29
				1800	0.19	Adopt	345		0.19	0.21

p_w (or p_d) Climatological probability of adverse weather event. (w = wet spell; d = dry spell).
E_c Equivalent cost.
E^* Equivalent cost for a strategy based on perfect forecast.
p_0 Upper limit on probability of wrong forecast.
p_1 Lower limit on probability of successful forecast.

$$p_0 < C/L < p_1 . \quad (6)$$

For the forecast to have any impact at all on the decision between alternative strategies, the probability of a wet spell when no wet spell is forecast must be less than the cost–loss ratio, which in turn must be less than the probability of a wet spell when it is forecast.

For an unbiased forecast, the proportion of time a wet spell is forecast, p_f, must equal the climatological probability p_w. Note that the upper limit of p_0 is determined by (3) and (6). When p_f equals p_w, it can be shown that (1), (3) and (6) imply

$$p_0 < \frac{p_w}{1-p_w}\left(1-\frac{C}{L}\right) \quad \text{for } p_w < C/L,$$

$$p_0 < C/L, \quad \text{for } p_w > C/L . \quad (7)$$

The corresponding lower limits on the probability of successful forecasts p_1 are simply that p_1 be larger than the largest of p_w and C/L . As pointed out earlier, the limits on p_0 and p_1 are not independent. However, we have specified both so that it is easy to assess which of them is more stringent in a given case.

Value of forecast

For p_0 and p_1 obeying (6), equations (4) and (5) imply that pesticide should only be applied when a wet spell is forecast and not when a wet spell is not forecast. The expected effective cost in that case will be

$$E = (1-p_f)\,p_0 L + p_f C .$$

Note that the loss in yield occurs only with probability p_0 of the wet spell occurring when no wet spell is forecast. Consequently, the effective cost increases with increasing p_0, or decreasing p_1. The effective cost for an unbiased forecast ($p_f = p_w$) is given by

$$E = (1-p_w)\,p_0 L + p_w C . \quad (8)$$

For a perfect forecast ($p_1 = 1, p_0 = 0$) the above equation reduces to

$$E^* = p_w C . \quad (9)$$

If the strategy were chosen on the basis of climatological information alone, the expected effective cost, E_c, is

$$E_c = p_w L \quad \text{for } p_w < C/L,$$
$$= C \quad \text{for } p_w > C/L . \quad (10)$$

The value of the forecast, V, can be defined as the difference between the effective cost E and the effective cost E_c, viz.

$$V = E_c - E .$$

Using (7) and (10) we get

$$V = L\,(1-p_w)\,(C/L - p_0) \quad \text{for } C/L < p_w ,$$
$$= L\,(p_w - p_0(1-p_w) - p_w C/L) \quad \text{for } C/L > p_w . \quad (11)$$

It can be seen that for any C and L, the value V

increases as p_0 decreases (i.e. p_t increases). For a given p_1, the value increases with C/L until C/L equals the climatological probability p_w and decreases for further increases in C/L.

Implications for the case of groundnut

We consider here the implications of the above analysis for the choice of strategies for combating the three pests/diseases discussed earlier in rainfed groundnut. On the basis of the typical costs, losses for each pest/disease (Table 1) and the climatological probabilities of the adverse weather event in the critical periods, the strategy to be adopted when only climatological information is available as well as the limits on the skill of the forecast are given in Table 3.

Note that when a forecast of skill high enough to have an impact on strategy (i.e. when (3) and (6) are satisfied) is available, the strategy is to adopt the protective measure when an adverse event is forecast and not adopt it when it is not forecast. The critical periods mentioned in Table 2 are based on the assumption that sowing is done in the second week of July. Depending on the actual time of sowing in a given season, these periods may shift a little. In that event the value of the climatological probabilities of the adverse weather events have to be revised using Table 1.

The first case considered is of crown rot due to a wet spell occurring 2–3 weeks after sowing. As the climatological probability of the wet spell, p_w, during the critical period is higher than the cost–loss ratio, if only climatological information were available then the strategy should be to adopt the protective measure. The protective measure is cheap, being less than 1% of the returns. Although the equivalent cost may be reduced considerably by using a forecast, this gain is not much in terms of the money saved. Also, the condition on the probability of wrong forecast is so stringent that when the forecast is for no wet spell, the probability of a wet spell occurring, p_0, should be less than 9%. This is a case when the strategy based on climatological information is adequate; the condition on the allowable error in forecast is too stringent and returns too low to make the forecasting worthwhile.

Consider next the case of the leafminer attack, which is favoured by the occurrence of a dry spell any time between August and October. The probabilities of such a spell occurring in a specific fortnight in this period range from 0.02 to 0.15 (Table 2). We consider the strategies for the two limits of this range of p_w in Table 3. Here the entire range of cost–loss ratios is above that of the climatological probabilities p_w and the strategy based on climatological information alone is not to adopt the protective measure. Again, while the returns are greater if forecasts are used, the allowable limit for wrong forecasts, i.e. for p_0, is perhaps far too stringent to make skillful forecasts which can have a significant impact. We note, however, that in these cases, although on an average the farmer's returns are maximized by adopting the optimum strategy, when an intense attack occurs the losses suffered are high. In such situations, a strategy which minimizes the maximum losses (minimax) may be more appropriate. However, in this paper we restrict our attention to determining strategies that maximize the average returns and leave alternative optimization to future studies.

There is another important point about a leafminer attack. Although the probabilities for a dry spell within a specific fortnight during August–October range from 0.02 to 0.15, we find the probability of at least one such dry spell during this period to be 0.40, which is high. Thus, the average loss expected if no protective measure is adopted is high; the impact of a skillful forecast of a dry spell – perhaps based on conditional statistics, i.e. using the rainfall profile in the season up to that point, would be more than that assessed in Table 2.

In the case of late Tikka, depending upon the cost–loss ratio, the strategy based on climatological information changes from one in which the protective measure is not adopted to one in which it is. Since C/L varies from values less than p_w to values in excess of p_w, the value of the forecast is very high in this case. If a forecast of sufficient skill can be generated, the returns to the farmer can increase substantially as the losses are high.

We find, therefore, that a significant impact on productivity of groundnut is possible by forecasts of the wet spell during the critical period for the late Tikka disease. If reliable forecasts for a dry spell in the fortnight ahead, during August–October, are available, then considerable loss due to a leafminer attack could be avoided. On the other hand, forecasts are not likely to have any impact for prevention of crown rot.

Summary and conclusions

We have attempted to show how the nature of the forecast required, and the minimum skill of the forecast, depends upon the agricultural system, using the example of rainfed groundnut in semi-arid parts of Karnataka. We find that for certain purposes (e.g. combating crown rot at seedling stage), climatological information on the variability of the adverse weather events may be adequate; forecast is unlikely to have a significant impact. But for others (such as late Tikka) substantial loss can be prevented if forecasts of adequate skill are available. An analysis of cost–loss ratio and the minimum skill of forecast can also point out cases (such as avoidance of collar rot at pod-filling stage) where neither climatological information nor forecasting is likely to be useful. For such cases, alternative varieties or cropping patterns, better suited to the climatic pattern, may have to be adopted or developed.

A detailed analysis of every cropping system which is sensitive to fluctuations in climate is required for identification of the nature of those weather/climate events which have a large impact on productivity. To assess the impact of dry spells more realistically, the studies will need to incorporate realistic hydrological models which yield soil moisture as a function of the climate variables and detailed crop physiological models. This will require concerted efforts by genuinely inter-disciplinary groups.

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Landscape ecological analysis of a disturbance gradient using geographic information system in the Madhav National Park, Madhya Pradesh

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The Madhav National Park, due to its unique location (nearest to any township), is under tremendous pressure. The present study is aimed at analysing the impact of a disturbance on landscape structure using satellite remote sensing and geographic information system (GIS). The Landsat TM data have been used to identify vegetation types. The patch characteristics of the vegetation types, viz. size, shape, porosity and patch density, have been studied. Physical and manmade features have divided the national park into three zones, viz. north, central and south. These zones are also utilized as management zones by the Forest Department. The study indicates that the central zone is distinctly different from the south and north zones. Patch size and porosity have been found to be the most important parameters determining differences in the ecological states of the three zones of the park. The patchiness and shape also provide supportive information and characterize the patches of the zones.

LANDSCAPE ecology has emerged as an important discipline to study the landscape structure, function and changes. Ecology, over decades, has focused on 'vertical' study, i.e. relationships between plants, animals, air, water and soil within a relatively homogeneous spatial unit. Landscape ecology, however, focuses on the 'horizontal' study, i.e. relationship between the various spatial units[1]. Landscape analysis takes into account recognizable landscape elements at different spatial scales to study homogeneity/heterogeneity and causative mechanisms[2,3]. Each landscape is formed by several landscape elements which appear as patches and vary markedly in size, shape, type, heterogeneity and boundary characteristics. Each of the above characteristics has its