Therefore, eq. (6) does not suggest constant, zero electric field or electric potential profile, as one may suspect due to the linear nature of the integral operator. The right hand side of eq. (7) will equal – (surface charge density). If the net charge density on the surface is negative in sign, eq. (6) will not be satisfied by the negative ions of a 1–1 electrolyte of the homogeneous region.

7. Though our conclusion that the extent of the inhomogeneous region, d, varies inversely as square root of electrolyte concentrations, C, is similar to the conclusion of Debye–Huckel theory that the ion atmosphere parameter, κ, also varies as square root of electrolyte concentration, C, these two are not the same. Poisson–Boltzmann equation is a nonlinear differential equation, obtained by insertion of the Boltzmann distribution of concentrations in the Poisson's equation, replacing in this manner, the charge density term, by the electric potential term, resulting in a single differential equation involving a single unknown, namely the electric potential Φ and its derivatives. Expansion of the exponential and retention of only the first nonvanishing terms, and neglect of all higher order terms, results in a simple linear differential equation of the kind,

$$\{d^2\Phi/dx^2\} = \kappa^2\Phi(x),$$

where κ^2 is proportional to concentration C. Thus, the conclusion that one obtains from the Deby–Huckel theory is an approximation and bears no relevance to the conclusions obtained in this paper regarding d. Although Debye–Huckel theory of strong electrolytes furnishes a strikingly satisfactory account of many of the properties of electrolyte solutions, it is based upon physical assumptions which, though plausible, are not in exact accord with the formal theory of statistical mechanics.

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Wait and see strategy for leaf miner control in rainfed groundnut

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We propose a methodology for analysis of rainfall data to develop a management strategy for a rainfed crop. As an illustration we discuss control of leaf miner in groundnut. The strategy derived from rainfall analysis saves about 10% and 6.5% of gross yield more than other simple strategies namely (i) never spray or (ii) always spray respectively. The recommended strategy is to wait for rains up to six days after onset of leaf miner attack and then spray if rains fail.

IMPROVEMENT in the productivity of rainfed agriculture is a major challenge for India today. Apart from the possibility of developing crop varieties better suited to rainfed conditions, it is also important to fine-tune management strategies including choice of sowing date, pest control measures, disease prevention, etc. Our contention is that detailed analysis of rainfall data can throw more light on relative profitability of alternative strategies. Daily rainfall data available for about a century can be used to gauge the conditions most likely to occur. They usually determine the consequence of a specific action. This evaluation is necessarily based on a series of assumptions about crop growth, occurrence and development of pests, etc. The assumptions used herein are tentative and can readily be modified. That of course may change the conclusions reached. The attempt, however, is to propose a heuristic methodology which can be applied no matter how the assumptions change.

As an illustration of our methodology, we consider the problem of controlling leaf miner in groundnut. Leaf miner (*Aproaerama modicella* Dev.) is a major pest of groundnut in southern and central India. It is capable of almost totally wiping out the crop which has a potential yield of about 4 quintals per acre. The common measure to control this pest is to spray chloropyrephas at 2 ml/l using 250 l/acre. For the purpose of illustration we use market prices of 1995 given by Gadgil *et al.*[3]. At these rates the gross income per acre is Rs 4000 and cost of pesticide spray is Rs 750 per acre. The pesticide is sprayed on observing the occurrence of attack. If a wet spell occurs, the attack is controlled naturally.

Two simple strategies that can be practised are (i) ignore the occurrence or otherwise of the pest attack and never spray the pesticide and (ii) spray the pesticide as soon as attack is noticed. We introduce a third 'wait and see' strategy according to which a farmer waits for six days after noticing the attack and sprays the pesticide only if rains adequate for controlling the pest fail to occur till then.

Assumptions

Farmers sow groundnut during July to August as soon as the fields receive adequate presowing rains (0.5 cm in 7 days). Starting from sowing date, leaf miner occurs during plant age 35 to 75 days (peg formation phase) if

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there is a dry spell of 2 weeks in this phase. Once the attack occurs and conditions remain favourable, the pest grows exponentially and can completely wipe out the crop in 15 days. Thus the loss due to leaf miner can be expressed as exp(0.33 j)% of gross yield, where j is the number of days for which the pest gets a free hand (neither is any pesticide sprayed nor does a wet spell, i.e. 1 cm rain in 3 days, inhibit its growth). If there is a wet spell, the pest population is fully suppressed. We note that hard scientific data about biology of *A. modicella* is scanty[1,2] and hence assumptions are essentially based on the opinions of informed practitioners.

Rainfall pattern

We have used daily rainfall data for Chitradurg in Karnataka for 84 years to evaluate the proposed strategy. In each year a sowing date was identified as the dry day following a presowing rain, namely, half centimeter in 7 days during July 4 to August 4. Occurrence of a dry spell during the crop age 35 to 75 days was then checked. It turned out that a dry spell suitable for leaf miner attack had occurred in 58 out of 81 years in which sowing rains had occurred in time (i.e. before 4 August). The key question was how frequently and how soon adequate corrective rains occurred. Table 1 gives the frequency of occurrence of corrective rains. A geometric distribution which assigns probability pq^{j-1} for occurrence of corrective rains j days after the attack fits these data well ($\hat{p}$ (estimate of p, the probability of rain on a day, during this period) = 0.14), χ^2 (9 d.f.) = 12.50, (p-value > 0.05).

Since the period of peg formation in which leaf miner attack can come is as wide as 40 days, the event of attack can be classified as early (first fifteen days are a dry spell) or late (any time after that). Table 2 relates this classification of pest attack to occurrence of corrective showers.

Prima facie, an early attack has a lower chance of being washed out by rains (5/18 = 28%) than a late attack (23/40 = 58%). Thus it seems prudent to wait for a shower if pest attack is late while an early attack may need pesticide spray.

Alternative strategies

We propose to compare the four strategies implicit in the discussion so far by reanalysing daily rainfall data. The strategies are:

1. Ignore leaf miner attack, take no pest control measure.
2. Spray pesticide as soon as pest attack is noticed.
3. Spray pesticide if pest attack is 'early' while take no action if attack is 'late'.
4. Wait for 6 days regardless of time of attack. If no corrective shower comes, then spray the pesticide.

Table 1. Distribution of number of days between leaf miner attack and corrective rains

No. of days	No. of years: Observed	Expected
1	15	8.12
2	2	6.98
3	5	6.01
4	4	5.16
5	6	4.44
6	2	3.82
7	2	3.29
8	1	5.25 (8–9)
9	4	
10	1	5.43 (10–12)
11	2	
12	2	
13	1	3.46 (13–15)
14	1	
15	2	
16–40	8	6.04

Table 2. Time of attack and corrective rains

Time of attack	Early shower (within a week)	Late shower (after a week)	Shower after 2 weeks	
≤ 16 days	5	12	1	18
≥ 17 days	23	6	11	40
Total	28	18	12	58

Cost benefit analysis of 4 strategies

As stated earlier, we assume a loss function $L(j) = \exp(0.33\,j)$, where $L(j)$ is the per cent crop lost up to j days after pest attack. This is motivated by the assumption of exponential growth of the pest and nearly total wipe out of the crop in fifteen days. $L(j)$ is about 100% at $j = 15$ and beyond.

Consider strategy 1. If corrective rains occur on jth day (probability $P_j = pq^{j-1}$), the loss suffered is $L(j)$. Hence average loss is

$$\sum_{j=1}^{14} L(j)P_j + \left(1 - \sum_{1}^{14} P_j\right) * 100,$$

where $1 - \sum_1^{14} P_j$ is the probability that pest will get a free hand for 15 days or more. This value turns out to be 22.78% using estimated $p = 0.14$. Thus the expected net crop yield is 77.22%. Alternatively we can scrutinize daily rainfall data directly to calculate the loss for each year. The average loss over 58 years of pest attack is 26.98%. The net yield is 73.02%.

For strategy 2, the pesticide cost is constant (750/4000 = 18.75%) and crop is always saved from pest attack so that the net yield is 100–18.75 = 81.25%.

In case of strategy 3, the expected net gain is (100–18.75) * Probability that attack is early + (100–22.78) * Probability that attack is late. We substitute observed proportions of years of early attack (18/58) and late attack (40/58) to get the net expected yield to be 78.32%.

Strategy 4 combines two aspects of the problem, namely that (i) the probability of corrective shower declines as time elapses, (ii) loss due to pest attack is modest during initial period but explodes afterwards. Hence waiting for rains for sometime is likely to be beneficial as the loss of crop to pest may be small compared to cost of spray. Corrective rains occurred in 34 years out of 58, within 6 days after attack. This prompted us to propose a 'wait and see' period of 6 days. Here the net expected income is

$$\sum_{j=1}^{6}(100-L_j)P_j+(100-(L_6+18.75))\left(1-\sum_{1}^{6}P_j\right),$$

which comes out to be 87.69%. If instead yearly rainfall is scrutinized, the figure we get is 90.21%. Table 3 summarizes these results.

Thus the cost benefit analysis suggests that 'wait and see' is the best strategy of the four. It saves 10.47% over strategy 1 of not spraying at all and 6.44% over the strategy 2 of always spraying. These figures are based on the geometric model. Corresponding figures based on actual yearly rainfall data are 17.19% and 8.96% respectively. Also strategy 4 turns out to be better than strategy 3 which uses information on time of attack.

One point to note here is that strategy 4 is better than strategy 2 in net expected gain. But it also has a variance. It can occasionally lead to lower net gain than strategy 2. Risk of this event is P (net gain under strategy 4 < net gain under strategy 2) = 0.4046.

Thus the strategy has two features, the net expected gain and the probability of gain below strategy 2. One may ask the question as to whether waiting for 6 days is the best choice or an alternative waiting period may be better. Table 4 provides comparison between strategies 2 and 4 with different waiting periods.

It can be seen from Table 4 that if we consider only the net expected gain, waiting for 6 days is the best choice. However, the question of which of the pair of characteristics is the best is not easy to answer. Some farmers may prefer to wait longer because the reduction in net expected gain is marginal while reduction in risk P_K^* is substantial.

Typically as income and land holding declines, the farmer becomes more and more a risk averter. At what level of land holding will the risk (and hence strategy 4) become unacceptable is an important question and deserves investigation.

Table 3. Comparison of four strategies (Chitradurga)

Strategy	Net expected income using: Geometric model for corrective rains (%)	Average from yearly data (%)
No spray	77.22	73.02
Immediate spray	81.25	81.25
Decide on time of attack	78.47	78.47
Spray after waiting for 6 days	87.69	90.21

Table 4. Comparison of alternative waiting periods

Waiting time K days	Chitradurga P_K^*	Chitradurga G_K	Ananthpur P_K^*	Ananthpur G_K
1	0.8600	82.49	0.9100	81.55
2	0.7396	82.29	0.8681	82.60
3	0.6361	85.69	0.7536	83.39
4	0.5470	86.71	0.6857	83.89
5	0.4704	87.37	0.6240	84.08
6	0.4046	87.69	0.5679	83.92
7	0.3479	87.65	0.5168	83.33
8	0.2992	87.26	0.4703	82.27
9	0.2573	86.50	0.4279	80.63
10	0.2213	85.32	0.3894	78.28
11	0.1903	83.71	0.3544	75.06
12	0.1637	81.59	0.3225	70.78
13	0.1408	78.90	0.2935	65.18
14	0.1211	75.55	0.2670	57.94

P_K^*: Probability that gain under strategy of waiting for K days less than gain under strategy 2.
G_K: Net expected gain of strategy 'wait for K days'.

How general is this strategy?

A question that immediately comes to mind is whether the wait and see strategy that seems to be quite good will work at other locations as well. To probe this aspect we have examined the rainfall data at another site namely Ananthpur in Andhra Pradesh.

Daily rainfall data were available for 80 years namely 1911 to 1990. Out of these 80 years, for three years the data were inadequate while for five other years, sowing rains were too late and no crop was possible. Of the remaining 72 years, 52 years were suitable for occurrence of leaf miner attack. Washing rains occurred in the first six days in 16 years. The attack was early in 25 years and late in the remaning 27 years. The number of days after which washing rains came followed a geometric distribution, as in case of Chitradurga. The main difference was that the probability of precipitation on a given day after the pest attack was $p = 0.09$ as opposed to $p = 0.14$ for Chitradurga. Thus for the period of interest, Ananthpur seems drier than Chitradurga. A natural consequence is that the number of years in which washing rains obviated the need for pesticide spray is 16 as opposed to 34 in case of Chitradurga. Therefore the net

Table 5. Comparison of four strategies (Ananthpur)

Strategy	Net expected income using Geometric model for corrective rains (%)	Average from yearly data (%)
No spray	60.07	52.96
Immediate spray	81.25	81.25
Decide on time of attack	70.00	70.00
Spray after waiting for 6 days	83.91	80.75

saving due to the wait and see strategy is also smaller. The summary of results is given in Table 5.

It can be seen that the wait and see strategy continues to be the best. However, the margin over the 'always spray' strategy is reduced to about 2.7%. Of course the advantage that for 16 years pesticide spray is avoided is still there. Another difference is that the expected net gain is slightly higher for waiting period of 5 days. This suggests that while waiting itself may be useful in many localities, the optimal period may have to be calculated separately for each locality.

Discussion

The calculations above are based on an assumed exponential loss function. This expert opinion may need validation. Further, all assumptions about the crop growth made for Chitradurga are assumed to be applicable to Ananthpur, without any modifications. This also can be changed if warranted. Most importantly, the wait and see strategy reduces use of pesticides harmful to environment. Gadgil *et al.*[3] have shown how climatological information and meteorological forecasts can be used in management of rainfed groundnut. They have argued that optimum strategy to combat pests and diseases can depend upon the reliability of forecast. The strategy presented here does not depend upon rain forecast for the period following pest attack and in this sense the question of reliability of forecast does not apply here. The strategy which performs well at both the localities studied, is based on climatological information that in many years corrective rains do come following pest attack and the loss due to pest in this period is affordable. Such a strategy will not be available when preventive measure in anticipation is necessary as in case of the fungal disease *tikka*.

We note that optimality claim here is based on expected net gain (as in case of Gadgil *et al.*[3]) and variance of this net gain is not used explicitly. Further work on this aspect is necessary.

The possibility of developing pest and disease management strategies such as the 'wait and see' proposed here deserves to be explored for other crops, varieties and localities.

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MEETINGS/SYMPOSIA/SEMINARS

National Seminar on History of Indian Sciences

Date: 6–8 May 1998
Place: Ernakulum

The scope of this seminar encompasses history and development of Indian sciences from ancient to modern. The programme consists of invited talks and contributed papers.

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International Conference on Environment and Agriculture

Date: 1–3 November 1998
Place: Kathmandu, Nepal

Topics include ecology & environment, agriculture, biodiversity and environmental affairs. The programme includes a keynote address, invited lectures, contributory papers, poster presentations, exhibition, etc.

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