Journal of Agrometeorology 5 (1) : 12-24 (June 2003)

Risk management options using weather forecasts in insect pests and diseases management for some dryland crops

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ABSTRACT

It has been shown that how climatological information about adverse weather events and weather forecasts if available can be used to decide between alternate strategies for dryland sorghum and pearlmillet crops grown in semi-arid areas taking Hyderabad (17° 27' N, 78° 28' E), India as an example. Until the probability of the weather forecast is above a certain threshold, the forecast has no impact on the optimal strategy. This threshold is determined by the loss in yield due to the adverse weather event and costs of protection. In the case of sorghum and pearlmillet crops, it is shown that a significant impact on productivity is possible if reliable weather forecasts are available during critical periods of crop growth.

Key words **:** Economic value, Forecasts, Pests, Diseases, Protection

In dryland agriculture, farmers are required to adopt cropping strategies to cope with rainfall variability both within and between seasons. If rainfall were uniform every year, farmers would choose a single management plan with regard to choice of cultivars, planting dates, seed rates, fertilizer application and use of pesticides. As rainfall variability creates major problems, it never facilitates adoption of uniform strategy all the years. Management practices which take into account this rainfall variability are likely to generate a substantial increase towards the sustained productivity. In additon, if it becomes possible to forecast critical adverse weather events which promote some of the insect, pests and diseases and take timely preventive measures a substantial increase in yields could be expected. At present National Centre for Medium Range Weather Forecasting at New Delhi has been providing forecasts 5 days in advance for NARP zones of India. Gadgil *et al.*, (1994) have shown how the climatological probability information and weather forecasts can be used to decide between alternative strategies for rainfed groundnut in semi-arid parts of Karnataka. With this in view, the present study has been initiated to assess the value of weather forecasts to different weather sensitive decisions in pest management (insect pests and diseases) for some dryland crops which are grown in semi-arid tract of the Hyderabad region.

METERIALS AND METHODS

Hyderabad (17° 27' N, 78° 28' E) situated in the semi-arid tract of southern India receives rainfall mostly during the southwest monsoon season from June to September. Post monsoon rains are not uncommon and contribute to around 18 percent of average annual rainfall. Mean annual rainfall at Hyderabad in the past 84 years has been 767 mm with a low of 374.5 mm in 1980 and a high of 1541.9 mm in 1975. Variation over shorter periods is very much large (Table 1). The crops are generaly sown with the receipt of about 20 mm of rainfall during a week. The mean weekly rainfall is about 20 mm or more for 24^{th} to 40^{th} week with coefficient of variation ranging from 84 to 153 percent which signifies the uncertainty of rainfall occurrence.

The soils of experimental site are red shallow loamy sands. The depth of topsoil varies from 5 to 30 cm and below, there exists a compact heavy layer with 40-60 percent murrum and fine soil. Moisture storage in the profile is only 10 percent by volume. The soils are low in nitrogen and extremely low in phosphorus (Bhaskara Rao and Vijayalakshmi, 1985).

As the adverse weather events like wet and dry spells promote some of the major pests and diseases leading to loss of productivity, these were evaluated for the cropping season. A first order Markov chain probability model was fitted to the weekly rainfall data for the period 1971-99 to calculate initial and conditional probabilities (Robertson, 1976 and Victor and Sastry 1979). The week was classified as wet when the weekly rainfall is greater than or equal to 30 mm as the potential evaporation in the region ranges from 21-28 mm per week during the cropping season. The week was considered as dry when the weekly rainfall is less than 10 mm. These were computed from 3^{rd} week of May to last week of October (21^{st} - 44^{th} standard meteorological weeks) which is the period during which rains are received (Table 2).

Concepts

Simple case of choice between two alternate strategies to adopt a remedial measure such as application of pesticide at a cost C or not adopt it and suffer the loss L in productivity, if the adverse weather event occurs was considered. The decision-maker will have a choice whether to adopt remedial measure or not on the basis of climatological and forecast weather probability information on the occurrence of adverse weather event. Here, the optimal strategy was assumed to be one which maximizes the long term average returns to the farmers by minimizing the effective cost, i.e. the cost of remedial measure or the expected loss, as the case may be (Katz and Murphy, 1997).

Strategies based on climatological probabilities

Consider first the implication for the strategies on the basis of climatological probabilities alone. The weather variable, a random variable, denoted by θ, has only two possible states.

(i) adverse weather (θ = 1)

(ii) no adverse weather (θ = 0)

Climatological probability of adverse weather derived from historical weather records.

$$p_\theta = P_r\{\theta = 1\} \qquad (1)$$

Table 1 : Minimum, maximum, mean, standard deviation and coefficient of variation of weekly rainfall at Hyderabad

Week	Minimum (mm)	Maximum (mm)	Mean (mm)	Standard deviation (mm)	Coefficient of variation (%)
22	0.0	76.2	8.6	13.3	153
23	0.0	127.8	16.4	23.7	144
24	0.0	137.8	21.8	26.3	120
25	0.0	154.4	30.6	32.1	105
26	0.0	168.4	34.6	31.8	92
27	0.0	198.6	31.2	33.5	108
28	0.0	233.3	29.6	33.6	114
29	0.0	214.5	38.2	39.1	103
30	0.0	153.5	40.5	33.0	81
31	0.0	22.2	39.8	37.7	95
32	0.0	145.9	27.3	29.8	109
33	0.0	192.0	30.9	35.7	116
34	0.0	181.1	33.2	39.7	119
35	0.0	156.0	34.7	35.5	102
36	0.0	212.2	37.6	44.0	117
37	0.0	277.9	41.2	50.4	122
38	0.0	233.0	42.9	46.5	109
39	0.0	340.6	37.6	55.4	147
40	0.0	257.6	22.3	38.2	172
41	0.0	237.7	18.6	34.3	185
42	0.0	133.9	17.6	28.4	162
43	0.0	156.0	16.1	28.9	180
44	0.0	224.3	12.4	30.7	248

From a Bayesian perspective, the parameter p_a can be viewed as the prior probability (climatological probability) of adverse weather. When protective action is taken, the decision maker incurs a cost C. On the other hand, if the decision maker chooses not to take protective action, the expected loss due to the actual occurrence of adverse weather is p_θ1. Thus, the optimal strategy for (i) adoption (ii) non-adoption in this case is

i. protect if $p_0 > C/L$
ii. do not protect if $p_\theta < C/L$

Strategies based on actual weather forecast

Forecast information about θ consists of a random variable F, indicating a forecast of adverse weather (F = 1) or of no adverse weather (F = 0). This simple forecasting system is completely characterized by the two conditional probabilities of adverse weather.

$$p_1 = Pr\{\theta = 1\} \mid F = 1 \mid \quad .. (2)$$
$$p_0 = Pr\{\theta = 1\} \mid F = 0 \mid \quad .. (3)$$

Where p_1 is the probability of adverse weather actually occuring when it is forecast; p_0 in the probability of adverse weather occurring when the forecast is for no adverse weather. In Bayesian terminology, the parmeters, p_0 and p_1, would be termed posterior probabilities of adverse weather. The plausible assumption is made that forecasts of adverse weather issued with the same long run relative frequency as the actual occurrence of adverse weather event (termed overall reliability or unconditionally unbiased) that is

$$Pr\{F = 1\} = p_\theta \quad ... (4)$$

However, the above relation implies that

$$P_0 = \frac{(1-P_1)\ P_0}{(1-P_\theta)} \quad ..... (5)$$

That is p_0 is simply $(1-p_1)$, weighted by the climatological odds of adverse weather, $p_\theta / (1-p_\theta)$, for any worthwhile forecast, these probabilities satisfy the ordering.

$$0 \leq p_0 \leq p_\theta \leq p_1 \leq 1 \quad (6)$$

First, suppose that the decision-maker receives a perfect forecast of F = 1. If protective action is not taken, then the expected loss is p_1 L. If protective action is taken, the cost of spraying the pesticied is C. Hence, the returns will be maximized by choosing a strategy, which minimizes the effective costs, i.e. Min (p_1 L, C). This implies that if $p_1 L > C$, the taking protective action will minimize the effective costs. On the other hand, if $p_1 L < C$, not taking protective action will maximize the returns. The strategy recommended for adoption is thus,

if $p_1 > C/L$; protect,

if $p_1 < C/L$ do not protect

Thus, if the probability of occurrence of a correct forcast is low ($p_1 < C/L$), the strategy recommended is not to take protective action even though adverse weather is forecast.

Similarly,

if $p_0 < C/L$ do not protect
if $p_0 > C/L$ protect

i.e., if $p_0 > C/L$, even though the forecast is for no adverse weather, the appropriate strategy is to take protective action.

Table 2 : Probabilities of wet and dry weeks during crop growing season

Standard meteorological week	Dates		Probability of wet week (> 30 mm rain per week)	Probability of dry week (< 10 mm rain per week)
21	May	21-27	0.14	0.79
22		28-3	0.17	0.58
23	June	4-10	0.25	0.38
24		11-17	0.38	0.33
25		18-24	0.21	0.42
26		25-1	0.38	0.33
27	July	2-8	0.42	0.25
28		9-15	0.25	0.29
29		16-22	0.25	0.38
30		23-29	0.38	0.38
31		30-5	0.50	0.29
32	August	6-12	0.46	0.38
33		13-19	0.54	0.25
34		20-26	0.25	0.54
35		27-02	0.21	0.42
36	September	3-9	0.25	0.50
37		10-16	0.33	0.46
38		17-23	0.50	0.26
39		24-30	0.29	0.46
40	October	1-7	0.42	0.38
41		8-14	0.29	0.50
42		15-21	0.17	0.71
43		22-28	0.25	0.63
44		29-4	0.21	0.58

Value of weather forecast

The economic money value (V) of the weather forecast is the reduction in expected expense associated with the forecasts as compared to the expected expense when only the climatological probability of adverse weather is available.

$$V = E_0 - E \quad \text{... (7)}$$

Where E_0 is the minimal expected expense, if only climatological probability is available and E is the minimal expected expense on the basis of actual weather forecast.

If the strategy were chosen on the basis of climatological probability alone, then the minimal expected expense E_0 is

$$E_0 = \min\{C, p_\theta L)\} \quad \text{.... (8)}$$

If the strategy were chosen on the basis of actual weather forecasts, the minimal expected expense E is

$$E = p_\theta C + (1 - p_\theta)\, p_0 L \quad \text{.... (9)}$$
$$= p_\theta [\, C + (1 - p_1)\, L] \quad \text{.... (10)}$$

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

$$E^* = p_\theta C$$

Where E* is the minimal expected expense based on perfect forecast.

Finally, V can be written as;

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

and

$$V = L\,(p_\theta - p_0\,(1-p_\theta) - p_\theta\, C/L) \quad \text{for } C/L > p_\theta \quad \text{... (12)}$$

In the present study, p_θ can be substituted by p_w (probability of occurrence of wet spell).

It can be seen that for any C and L, the value V increases as p_0 decreases (i.e. p_1 increases). For a given p_1, the value V increases with C/L until C/L equals the climatological probability p_θ and decreases with further increases in C/L.

RESULTS AND DISCUSSION

In the Hyderabad region, generally sorghum and pearlmillet crops are sown in June with the onset of monsoon and harvested after 3rd week of September. As is the case with the other epidemic pests and diseases, the organisms are always present at a low level of intensity and can multiply rapidly when weather conditions turn favourable and the crop is susceptible to attack. The wet spell (high relative humidity) promotes the incidence of downy mildew, sugary disease (ergot), grain mould, shootfly and stem borer. Losses in yields by pests and diseases are variable depending upon the intensity of the attack and crop growth stage during such an attack. Estimates of typical losses in yields of sorghum and pearlmillet with incidence of the different pests and diseases and costs of plant protection measures are given in Tables 3 and 4.

Implications for the case of sorghum and pearlmillet

The implications of the climatological probability information for the choice of strategies for combating the pests and diseases of sorghum and pearlmillet crops are discussed below. On the basis of the typical costs, losses for each pest/disease (Tables 3 and 4) and the climatological probabilities of the adverse weather events (wet week) in the critical periods, the strategy to be adopted when only climatological probability information is available as well as when the weather forecast information is also available (Tables 5 and 6).

Pests/Diseases in sorghum

Downy mildew

Downy mildew in sorghum is caused by *Peronoscrospora sorgi*, which is a soil

Table 3 : Cost-loss estimates for major pests / diseases of sorghum

Pests / Diseases	Growth stage	Cost of plant protection measures	Typical loss per hectare (unprotected crop)
Downy mildew	Up to 40 days	Seed treatment with metalaxyl @ 4 g kg^{-1} seed (6 kg ha^{-1}) and spray days old crop at a cost of Rs. 1000 ha^{-1}	100% Rs. 10,000/-
Sugary disease (Ergot)	Anthesis stage	Spray mancozeb (Dithane M-45) (0.2%) at anthesis @ 750 l/ha and another at an interval of 10 days at a cost of Rs. 800/ha	50 - 80 % Rs. 5000-8000/-
Grain mould	Grain formation stage	Spray captan (0.1%) + Aureafungin (0.02%) just after Flowering and repeat once after 10 days @ 750 l ha^{-1} at a cost of Rs. 850 ha^{-1}.	50 % Rs. 5,000/-
Shootfly	Within one month after sowing	Apply carbofuran granules @ 12-13 kg ha^{-1} at a cost of Rs. 600 ha^{-1}	90 - 85% Rs. 9000-10,000/-
Stem borer	From 4th week after sowing to harvest	Two sprays of endosulfan @ 12 kg/ha + carbaryl @ 15 kg ha^{-1} at a cost of Rs. 600ha^{-1}	55 - 85% 5500-8500/-

Table 4 : Cost-loss estimates for major diseases of pearlmillet crop

Diseases	Growth stage	Cost of plant protection measures	Typical loss per hectare (unprotected crop) (%)
Downy mildew	Seed to tillering stage	Seed treatment with metalaxyl @ 2 g kg^{-1} seed (5 kg ha^{-1}) and spray metalaxyl (0.1%) @ 400 l ha^{-1} at a cost of Rs. 515 ha^{-1}	10 - 45
Ergot	Grain filling stage	Spray captofol (0.2%) at boot and 50 per cent flowering @ 400-600 l ha^{-1} at a cost of Rs. 260 ha^{-1}	55 - 65

borne pathogen. The disease is transmitted by oospores carried externally on the seed. The high humidity (86%) and continuous rainfall during vegetative phase can lead to high incidence of this disease. The loss in yield due to this disease at this stage is reported to be about 100 percent. This is controlled by treating the seed with metalaxyl (0.1%) and spray on 40[th] old day crop. The probability of getting a wet week during this stage ranges from 0.21 to 0.42. It is seen from the Table 3 that the climatological probability of a wet week (p_w) during the critical period are higher than the cost-loss ratio (C/L). Therefore, optimal strategy would be to adopt the protective measure. The equivalent cost based on the climatological probabilities is 1000 Rs ha^{-1}. The minimum expected expense based on the climatological probabilities is 1000 Rs ha^{-1}. The minimum expected expense based on perfect whather forecast ranges from Rs. 210 to 420 Rs ha^{-1}.

Grain moulds

The occurrence of wet week during grain formation stage (probability ranges from 0.21 to 0.33) promotes the incidence of grain moulds. More than 40 fungi are reported to cause grain moulds. Because of the incidence of the disease, 50% of the grains become soft, powdery and discoloured. The preventive measure involves spraying captan (0.1%) + aureofungin (0.02%) just after flowering and repeating once after 10 days. As the climatological probability of wet week (p_w) during the critical period is higher than the cost-loss ratio, if only the climatological information were available, then the stragegy would be to adopt the protective measure. The minimum expected expense based on climatolgoical information is about 850 Rs ha^{-1}. Whereas the equivalent cost based on perfect forecast ranges from 178 - 280 Rs ha^{-1}.

Sugary disease

Sugary disease (Ergot) is prominently seen soon after the infection by *spharcelea sorgi* take place. Viscous thick honey like ooze is held between the spikelets which flows out under high humidity. Under severe infection the honey like ooze deposits on the leaves and drops on to the soil. It takes only 6-8 days to the formation of honey dew after infection. Humid weather and continuous rains at the heading time are considered favourable for infection. Humid weather and continuous rains at the heading time are considered favourable for infection. The late sown crops are infected to a larger extent than the early sown. The probability of getting a wet week during anthesis varies from 0.46 to 0.54. The loss in yield varies from 50 to 80 percent. This disease can be prevented by spraying mancozeb (0.2%) at anthesis with another application at 10 days after anthesis. As the probability of occurrence of wet week (p_w) is greater than C/L ratio, protective action is recommended. The expected expense if protective action is taken on the basis of climatological information is 800 Rs ha^{-1}. This reduces to 178-280 Rs ha^{-1} if the protective action is taken on the basis of perfect weather forecast.

Shootfly

Shootfly (*Athrigona socate Rond.*) is

Table 5 : Cost-loss ratios, appropriate strategies and minimum forecast skill in sorghum

Pests/ Diseases	Adverse weather event and critical period	Probabilities of wet week (p_w)	Cost (Rs ha^{-1})	Loss (Rs ha^{-1})	C/L	Strategy	Eo (Rs ha^{-1})	E* (Rs ha^{-1})
Downy mildew	Wet spell upto 40 days	0.21 0.42	1000	10,000	0.10	Adopt	1000	210 420
Sugary disease	Wet spell Anthesis Stage	0.46	800	5,000 8,000	0.16 0.10	Adopt	800	368
Grain mold	Wet spell Grain formation stage	0.21 0.33	850	5,000	0.17	Adopt	850	178 280
Shootfly	Wetspell Within one month from sowing	0.21 0.42	600	9,000	0.07	Adopt	600	126 252
Stemborer	Wet spell 4th week to harvest	0.21 0.54	600	5,500 8,500	0.11 0.07	Adopt	600	126 324

p_w Climatological probability of adverse weather event
E_o Equivalent cost, if the strategy is chosen on the basis of climatiological probabilities information alone
E* Equivalent cost for a strategy based on perfect forecast

a widespread and damaging pest in practically all the sorghum growing areas in the semi-arid tropics. As a result of larvae feeding, the central leaf wilts and later dries up giving the typical dead heart symptom. If the attack occurs a little later, plant may produce side tillers that may also be attacked. Late sowing during the rainy season increases the likelihood of attack. The loss in yield was reported to be about 90-100 percent. The occurrence of wet week (p_w = 0.21 - 0.42) during 30 days from sowing promotes the incidence of this pest. This can be controlled by using systemic insecticide like carbofuran (12-13 kg ha^{-1}). The probability of occurrence of wet week in this case also is greater than cost-loss ratio (C/L). Hence protective action would be beneficial. The expected expense if protective action is taken on the basis of

Table 6 : Cost-loss ratios, appropriate strategies and minimum forecast skill in pearlmillet

Pests/ Diseases	Adverse weather event and critical period	Probabilities of wet week (p_w)	Cost (Rs ha^{-1})	Loss (Rs ha^{-1})	C/L	Strategy	Eo (Rs ha^{-1})	E* (Rs ha^{-1})
Downy mildew	Wet spell	0.21	515	600	0.86	Not Adopt	126	108
	Seed to			2,700	0.19	Adopt	515	
	tillering stage	0.38		600	0.86	Not Adopt	228	196
Ergot	Wet spell	0.21	260	3,300	0.08	Adopt	260	55
	Grain filling			3,900	0.07	Adopt		
	stage	0.54		3,300	0.06	Adopt	260	140
				3,900	0.07	Adopt		

Typical yield is assumed to be 20 q/ha @ Rs. 300/quintal
Eo Equivalent cost, if the strategy is choosen on the basis of climatological probabilities alone
E* Equivalent cost for a strategy based on perfect forecast

climatologcial probability of wet week is 600 Rs ha^{-1}. The equivalent cost on the basis of perfect forecast of wet week reduces to 126-252 Rs ha^{-1}.

Stem borer

Stem borer (*Chilo partellus swin*) larvae pupate and adults emerge with the onset of the rainy season. The moth catch in light traps begins to increase during the peak rainy season, i.e. from 4^{th} week to harvest. The probability of getting a wet week during this period varies from 0.21 to 0.54 The smaller larvae feed on leaves producing leaf sacrification and shot holes. Third star larvae bore at base and produce a dead heart and tunnels the stem. This pest can be controlled by jointly using endosulfan (12 kg ha^{-1}) and carbaryl (15 kg ha^{-1}). As the cost loss ratio is less than the probability of occurrence of wet week during the critical period, the strategy is to adopt the protective measure. The expected expense on the basis of climatological probability is Rs. 600 ha^{-1}. The equivalent cost based on perfect forecast reduces to 126-324 Rs ha^{-1}.

Pests / Diseases in pearlmillet

Downy mildew

Downy mildew in pearlmillet is caused by *sclerospora graminicola*. The disease is transmitted by oospores, which lay in the soil and infect young seedlings. High humidity (90 to 100 percent) and temperature range of 20-25° C favours the infection and development of the disease. Once the infection is established, disease can develop at the normal temperature and humidity. The most critical stage of crop growth for infection is tillering stage. The loss in yield due to this disease at this stage is reported to be about 10-45 per cent. This is controlled by treating the seed with metalaxyl (0.1%) and spray on 20 day old crop. The probability of getting a wet week during this stage ranges from 0.21 to 0.38. It is seen from the Table 4 that depending upon the C/L ratio, the strategy based on climatological information changes from one in which the protective measure is not adopted to one in which it is. If the expected yield loss is 10 percent, it is not advisable to adopt a protective measure as the cost of plant protection measure (515 Rs ha^{-1}) and the loss in yield (600 Rs ha^{-1}) are comparable. However, if the loss in yield due to incidence of disease is estimated above 45 percent, the equivalent cost based on perfect forecast ranges from 108 to 196 Rs ha^{-1} compared to expected exposure based on climatological expectancy (515 Rs ha^{-1}).

Ergot

In the case of ergot disease, wet week favours the occurrence of this disease during grain filling stage. The prbability of such a spell occurring during this stage ranges from 0.21 to 0.54. Here, the entire range of cost-loss ratings (C/L) were well below that of the climatological expectancy and the strategy based on climatological probabilities alone is to adopt the protective measure. The equivalent cost based on perfect forecast ranges from 55 to 140 Rs ha^{-1} when compared to the equivalent cost based on climatological expectancy (260 Rs ha^{-1}).

Therefore, a significant impact on productivity of sorghum and pearlmillet crops with cost benefit is possible if reliable forecast (perfect forecast) of adverse weather events during the critical periods are available as the losses due to the incidence of these pests and diseases are high.

Value of weather forecasts in relation to cost-loss ratios

Values of weather forecasts V, which is the difference between the effective cost for climatological probability and unbiased weather forecast were worked out for different cost-loss ratios ranging from 0 to 1 for different probability levels of correct weather forecasts (0.2 to 1.0 at an interval of 0.2) and three probability levels of climatological expectancy of adverse weather (wet spell) (0.21, 0.38 and 0.54). These were evaluated for pearlmillet crop as an illustration. The values of weather forecasts, V, as a function of the cost-loss-ratios (C/L) for selected values of correct weather forecasts p1 and two probability levels of climatological expectancy of adverse weather event (wet spell, pw) for downy mildew and ergot diseases are given in Figs. 1 and 2 respectively. It is noted that for any cost C and loss L, the value V increases as the probability of correct weather forecast p1 increases. For example, in the case of downy mildew and for C/L = 0.1, the value, V, of weather forecast increases from -440 Rs ha^{-1} to 407 Rs ha^{-1}

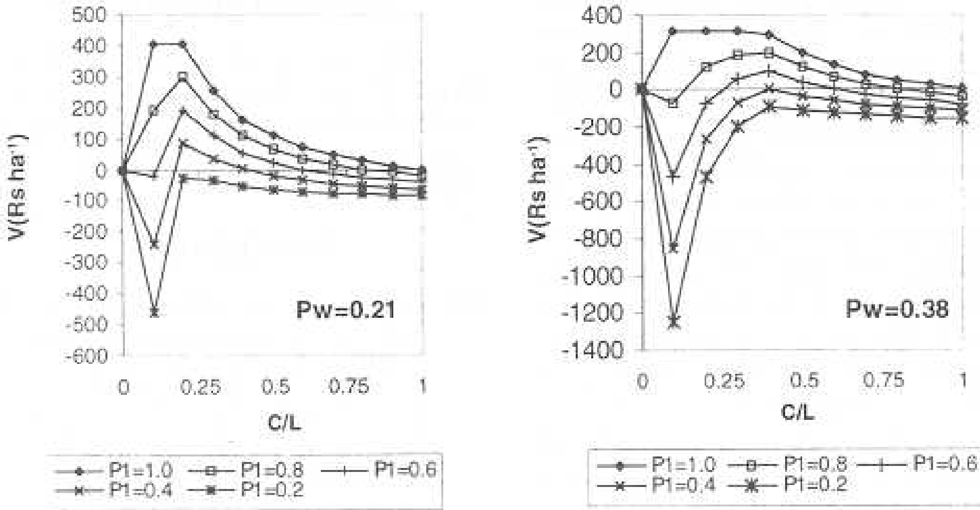

Fig.1 : The value of unbiassed forecasts V as a function of C/L for selected values of P1 for downy mildew disease of pearlmillet crop

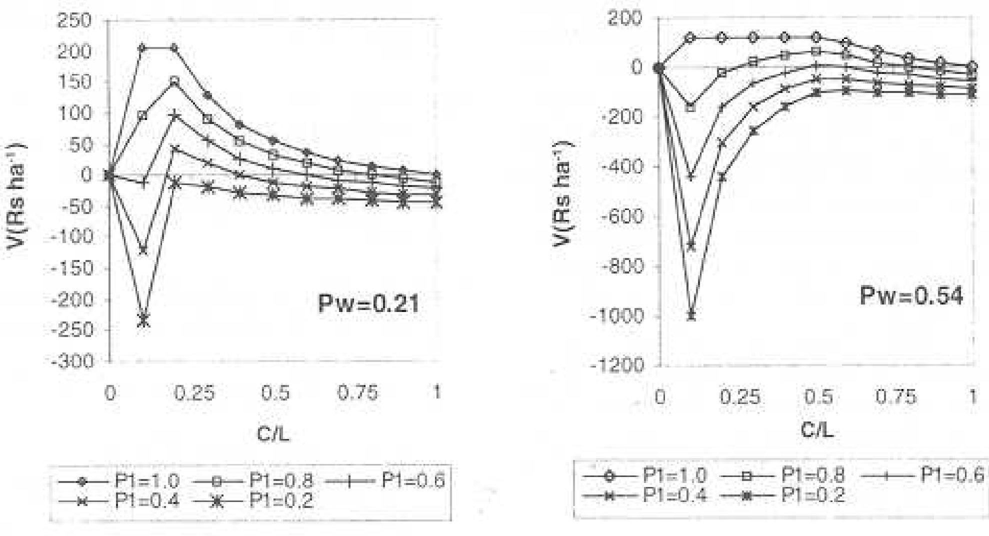

Fig.2 : The value of unbiassed forecasts V as a function of C/L for selected values of P1 for ergot disease of pearlmillet crop

as the probality of perfect weather forecast increase from 0.2 to 1.0. For a given p1, the value V increases with C/L until C/L equals climatological probability and decreases for further increases in C/L. Hence, the utility of these forecasts would be limited to the operations whose relative economic risks would range between (a) zero and (b) where C/L equals the climatological expectancy. These figures can be used on an operational basis in the choice of strategies for combating the diseases on the basis of typical C/L ratios and probability levels of climatological expectancy and unbiased forecast of adverse weather events and values of forecast.

CONCLUSIONS

It has been clearly demonstrated how climatological information about the adverse weather events can be used in deciding between alternate strategies and also whether better results could be obtained with the use of actual weather forecasts for the specific season using the examples of dryland sorghum and pearlmillet grown in seasonally semi-arid regions like Hyderabad. It was also shown that until the probability of the actual weather forecast is above certain threshold (C/L), it has no impact on the optimal strategy; the optimal strategy would be the same as the one derived from climatological information. This threshold is determined by the expected loss in yield due to the adverse weather event and the cost of the mitigatory measures.

ACKNOWLEDGEMENTS

The authors are grateful to Dr.H.P. Singh, Director, Central Research Institute for Dryland Agriculture, Hyderabad for his valuable encouragement in conducting the above study.

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