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Forecasting for agricultural application

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सार — कृषि मौसम विज्ञान पूर्वानुमानों के लिए निदर्श, मुख्यतः फसल मौसम संबंध और सांख्यिकीय/गणितीय निदर्शों पर आधारित होते हैं । ऐतिहासिक आंकड़ों द्वारा विकसित निदर्श पहले से ही पूर्ण रूप से अपेक्षित मानों को प्राप्त करना संभव बना देते हैं ताकि मौसम के लाभकारी पहलू को प्राप्त करने के लिए समुचित कार्यवाही की जा सके और हानिकारक प्रभाव को कम या अनदेखा किया जा सके । विभिन्न अवस्थाओं के अन्तर्गत इन निदर्शों की वैधता अनिवार्य है जैसा कि सामान्य क्षेत्र की जलवायु की स्थितियां प्रयोगात्मक क्षेत्र की अपेक्षा काफी भिन्न हो सकती है । इस शोधपत्र में उपर्युक्त पहलुओं पर भारत में किए गए कार्य पर विचार विमर्श किया गया है ।

ABSTRACT. Methods for agrometeorological forecasts are mainly based on crop-weather relationship and statistical/mathematical models. Models developed from historic data make it possible to obtain the expected values fairly in advance so that appropriate action may be taken to avail of beneficial aspect of weather and mini- mise or avoid detrimental effect. Validity of these models under different conditions is imperative as the climatic conditions of general field may be quite different from those of experimental one. This paper discusses the work done on the above aspects.

1. Introduction

Crop production in any place is the integrated result of a number of interacting physical and physiological processes that occur during the life span of a crop. These processes are influenced by weather, soil, management practices and crop species. Meteorological information is important for making many operational decisions and agriculturists need weather information for both long range or strategic decisions and for short range or tactical decisions. While most of the physical factors, inputs and agronomic practices can be manipulated, vagaries of weather cannot be controlled. A greater portion of the total annual crop loss is because of aberrant weather. The farm losses due to weather factors though cannot be avoided, it is very much possible to minimise them to a considerable extent by making adjustments with the impending weather through timely and accurate weather forecasts.

Weather forecasts for agriculture can be divided into three categories, *viz.*, (*i*) short range forecast (up to 48 hours), (*ii*) medium range forecast (up to 10 days), and (*iii*) long range forecast (more than 10 days). Each has got a role to play in farm operations and planning of agricultural activities.

It may not be possible, in this paper, to deal with all aspects required in forecasting for agricultural applica- tion. I would like to restrict myself in this paper on some selected topics, *viz.*, (1) hailstorm, (2) frost, (3) pests and diseases, (4) crop yield forecast and (5) preparation and application of agrometeorological advisories to the management of agricultural produce.

2. Hailstorm

A hailstorm is particularly a violent thunderstorm. The local distribution of hailstorms is rather peculiar. The conditions for strong vertical currents, which are pre-requisite for hailstorms, would be best developed in tropical or sub-tropical areas, but the high temperatures in these areas forestall the formation of ice. The largest number of hailstorms take place in latitudes between 30° and 60°. The present method of hail suppression is to add freezing nuclei so as to produce smaller ice particles and thus promote the growth of hailstones of smaller size than nature would produce. Another method of hail suppression involves slowing coalescence and accretion process by introducing great numbers of condensation nuclei into the storm updraft, thus reducing the average drop size and narrowing the drop size spectrum. The material used in hail suppres- sion is mostly silver iodide.

3. Frost/low temperature

The greatest agricultural risk associated with low temperature is the threat of occurrence of frost. In the formation of frost, water vapour sublimates passing directly from a gas to a solid. Frost can form at any temperature below freezing. There are two kinds of frosts : (*i*) advection or air mass frost and (*ii*) radiation frost. In addition to advection and radiation frost, there is a special case of frost caused by loss of heat by evaporation. This occurs when cold rain showers wet the leaves and are then followed by dry winds. This may occur while the air temperature is well above freezing. The water drops on the plants evaporate within several minutes causing the decrease in the leave's

temperature under the frost point even though air temperature may be positive. The injury and death of plant caused by frost is due to the formation of ice crystals in and outside the plant cells. Whereas air mass freezings are common in winter in middle and high latitudes, they are an agricultural problem primarily in relation to specific crops which are limited to their winter hardiness. Actual plant damage may be the result of alternate freezing and frost heave in the soil. In the sub-tropics, a freezing is a common phenomenon during most of the time of the year. Because the temperature of air mass cannot be controlled on a large scale, not much can be done to forestall the general hazard due to air mass freezing. For production of most field crops, the only satisfactory solution to the problem of freezing is to avoid it as far as possible by planting after the danger is past and by selecting varieties which will mature before the beginning of the hazard.

Damage due to radiation frost differs from other freeze damage in degree and in its spotty occurrence. The radiation frost hazard is greatest during critical stages of growth, whereas germinating seeds are not often affected by surface frost but young seedlings may be killed unless they are of frost-hardy varieties. Crops like potato, tomato and melon are vulnerable right up to maturity. The flowering stage is a critical period for most crops in field and orchard. Several techniques are available for frost protection.

4. Pests and diseases

The effect of weather on a plant pest/disease is a consequence of its action on the susceptible plant (the host), on the parasitic organism (the pathogen that causes the disease) and the relation between the host and parasite. Some diseases occur widely because the time of an year at which susceptible plants are grown in different regions, favour their developments. Potato late blight, caused by the fungus (*phytophthora infestans*) which requires cool and moist weather, is one such disease. Most races of the fungus cannot survive high summer temperature. But they occur in the regions growing potato in winter and spring and the organism is reintroduced with infected seed tubers each season.

At each of the stages, temperature and moisture must be within a range that permits the process to continue. For infestation of apple scab (*Venturia inaequalis*) disease, the following condition should be fulfilled as per Mills criteria :

"Leaf wetness period (in hours) multiplied by mean temperature (°C) should exceed 140 when infection is probable. This is applicable for temperature below 25°C and leaf wetness hours 9 or more".

After infection and then incubation time up to three to four weeks the fungus grows and breaks the cuticle and is seen as visible scab (dark brown spot). Unfavourable conditions at any of the stages retard development of the disease or may stop it entirely.

Either temperature or moisture can be decisive in the initiation, development and spread of diseases. If one is constantly favourable, the other becomes the limiting factor. If both fluctuate they must be favourable at some critical times. If both are constantly favourable the pest/disease infestation becomes serious. Change in the intensity of one weather element brings about change in the whole disease relationship. The effect of various weather factors on pests/diseases of crops may be worked out in field condition as done by Dubey *et al.* (1987) for sugarcane. The regression model can be developed to estimate the intensity of outbreak of pests/diseases based on meteorological parameters.

A pathogen like virus, fungi and bacteria carried by an insect has an advantage over airborne organisms. The insects take the pathogen more or less straight to the proper host, and in most cases inoculate it directly up to the host tissues. Such pathogens that cause disease are not much dependent on weather.

Weather affects survival, increase in activities of the insects, as well as direction, distance and intensity of migration and flight. Spores of wheat rust are brought from southern part of India by wind according to following Indian stem rust rules formed by ICAR scientists :

(*i*) A storm/depression should be formed either in the Bay of Bengal or in the Arabian Sea between 65°-85°E and 10°-15° N and should end over central India.

(*ii*) A persistent high pressure cell over southern central India (not far from Nilgiris) must be present.

(*iii*) A deep trough extending up to south India and caused by the eastward movement of western disturbances should occur.

If one or a combination of these conditions are satisfied, the disease might appear in central India.

4.1. *Role of meteorology in locust outbreak*

All the growth stages and migration of desert locust are considerably affected by meteorological parameters. Locust can migrate long distances, sometimes 5000 km between breeding areas of successive generations (Pedgley 1981). Warnings for both invasion and breeding are necessary to fight the locust for which meteorological forecast and information is very essential.

Locust swarms depend on favourable winds for their movements. The major displacements of locust swarms take place down wind towards areas of convergence. This provides a mechanism for the close and apparently purposeful association observed between distribution and movement of swarms and the rainfall essential for successful breeding. The cartographical analysis of desert locust records from all countries concerned has shown that the large scale quasi-regular seasonal swarm movements, in general, take swarms from areas where seasonal rains are ending to other areas in which the rains are beginning (Haskell 1979). There is also evidence that convergent wind flows might at times have contributed to the process of gregarisation by bringing previously solitary living locusts from long distances into limited areas providing suitable conditions of moisture and vegetation for breeding and, perhaps, also to within range of mutual perception.

There are three main aspects of migratory flights : mass departure, displacement and settling. Locusts rest at night on bushes and trees (Pedgley 1981). In the morning they feed, bask in the sun and take off when

their flight muscles become warm enough (air temperature 17°C). Within one hour of sunrise the thoracic temperature may be 10°C higher than air temperature. During flight their thoracic temperature increases by 6°C due to metabolic heat generated by working flight muscles in steadily flying locusts. Mass departure is delayed in cool weather or when wind speed is greater than 7 mps. Swarm speed is of the order of wind speed at 900 metres in case of no vegetation is available but is slightly reduced due to their settling on vegetation cover. They settle at the mid-day when temperatures are high and also in heavy rain and, at night.

Occurrence of 15-20 mm rainfall within 24-48 hours is most suitable for egg laying. The stony or saline soil is not suitable. Eggs absorb nearly their own weight of water to complete their development. The threshold soil temperature at 10-15 cm depth is 14.6°C for egg development, and for hopper development 17°C.

The importance of meteorological factors in relation to the biology of locust is well understood. The areas and seasons of breeding are, in general, areas and seasons of rainfall. The correct forecast of rainfall in a region and location of areas having rainfall in locust belt may help in the initial control of locust breeding. The major movements of locust swarms take place downwind, towards and with zones of convergent surface wind flow. The day to day and hour to hour movements of swarms can be known in advance by low level wind pattern. Thus a forecast can be made for taking timely protection measures against likely locust invasion.

5. Yield forecasts

Of the agrometeorological forecasts in use, probably the crop yield forecasts are most important economically. The evolution of these methods has made such rapid strides over the past 10 to 15 years that agrometeorologists have now derived them for the main cultivated crops in a number of countries. It gives the national government and planners enough time to make an early assessment of the overall agricultural production in the country, so that policy-makers can take appropriate decisions of price, import, export, storage and internal distribution. The leading countries concerned with yield forecasts include Canada, German Democratic Republic, India, Japan, USA, Israel and USSR (Thomas 1975, Coffing 1973). Most operational yield forecasts were developed for annual grain crops because of their major role in world food supply and their economic significance in international trading.

There are at least three approaches to find out the impact of weather and climate on crop yields :

(a) Crop-growth simulation models describing the detailed impact of meteorological variability on biological/physical processes that occur within a typical plant or plant canopy.

(b) Crop-weather analysis models which are a research tool for the analysis of crop responses to selected agrometeorological variables, and

(c) Empirical-statistical models using a sample of yield data from an area and weather and soil data from the same area to produce estimates of coefficients in the model by some sort of regression techniques. This approach is mostly used in the currently operational crop yield and production forecasts on a national or regional basis.

A few examples of such forecasting schemes are given below :

5.1. Potato

A model for estimating potato yield in German Democratic Republic using the following function has been developed (WMO Tech. Note No. 10) :

$$y = 232\,x_1 + 95\,x_2 + 915\,x_3 + 399\,x_4 + 886\,x_5$$

where,

$x_1 = $ Difference in mean value of air temperature for the second and first halves of the period between planting and sprouting,

$x_2 = $ Average daily precipitation during the period between planting and sprouting,

$x_3 = $ Mean air temperature during the period between sprouting and flowering,

$x_4 = $ Average daily precipitation during the period between sprouting and flowering,

$x_5 = $ Average daily precipitation during the period between flowering and commencement of ripening of the crop.

A value of x between 4300 and 5300 corresponds to the standard yield. If $x < 3500$, the yield will be at least 25% higher than the standard value; if $x > 6100$, at least 25% lower; if $3500 < x < 4300$, 10-25% higher and if $5300 < x < 6100$, 10-25% lower.

5.2. Crop yield forecast in India

India Meteorological Department has developed empirical-statistical regression models for forecasting paddy and wheat yield on meteorological sub-division-wise basis where these crops are grown. Based on these models forecasts are issued during the crop growing season for these crops (Das et al. 1971, Choudhary and Sarwade 1985). Besides weather and crop data a dummy variable called 'Technological Trend' is used in the models. The use of high breed variety, large scale use of fertilizers and insecticides, better irrigation and management etc have contributed for the sharp rise of yield. The increase due to all these factors has been combined and termed as a 'Technological Trend' due to non-availability of separate yield figures for each of these components. In the models a factor has been introduced to account for the technological trend.

For example the following equation has been developed to forecast wheat yield for Punjab :

$$y = 2355.44 - 53.16\,x_1 + 91.2\,x_2 - 33.62\,x_3 + 97.91\,x_4 + 2.08\,x_5$$

where, $y = $ Yield in kg/ha,

$x_1 = $ Mean min. temperature (°C) during 2-11 January,

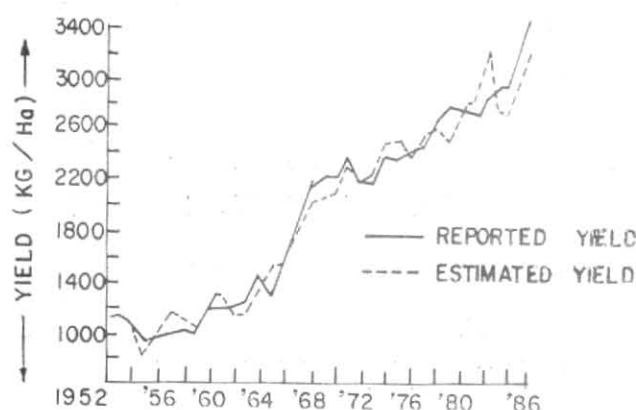$x_2 = $ Total number of rainy days between 9 and 15 February,

Fig. 1.   Actual and forecast yield of wheat of Punjab

Fig. 2.   Probability of rainfall at different risk levels (Indore)

x_3=Mean max. temperature ($^\circ$C) during 24 Feb to 2 March,

x_4=Technological trend,

x_5=Difference between rainfall and PET (mm) during December & January.

Following this equation, yield has been estimated. Fig. 1 gives the actual and forecast yield of wheat for Punjab.

6. Agrometeorological advisory service

The objectives of agrometeorological advisory services are to provide information to the users in real time basis so that one can avail beneficial aspects of climatic information to increase production or to minimise the damage which may be caused directly or indirectly by unfavourable weather. This can be possible if information is provided to the farmers, in advance, on the type of weather situations likely to be encountered and the method to be adopted for efficient management of inputs. Usually national meteorological services provide weather information in general form without any specific indications of the effect of weather on the field crops. Farmers have to take their own decision. Farmers of developing countries may not always be able to make proper operational decisions. They need to be told what to do on each occasion to protect the crops in the field.

The services rendered will be effective only if there is close collaboration between agricultural and meteorological interests. Meteorologists provide weather information of past, present and future of an area and agricultural scientists give the state and stage of various crops. They jointly identify the effect of impending weather on the field crops and appropriate advisories are formulated to combat the effect of adverse weather.
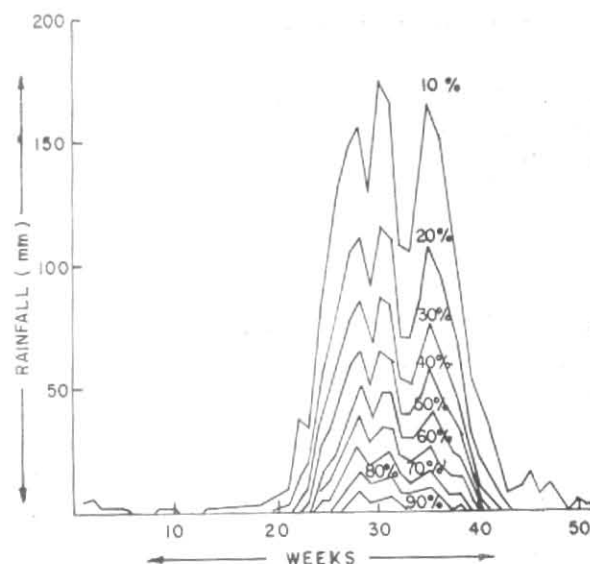
To prepare agrometeorological advisories need various information which is difficult to provide by one single agency. Of these the most important is weather information which immediately affects farm planning and operations. This includes (i) cloud cover and duration of sunshine, (ii) rainfall, (iii) temperature, (iv) winds, (v) humidity, (vi) dew, (vii) drying conditions and (viii) soil water status. As the rainfall is the dominant factor in the tropics especially those countries which are under the influence of monsoon, great care is needed to be taken to collect rainfall information up to the 'Tehsil' level and on the behaviour of monsoon. In countries, like India, this single factor of rainfall outweighs the effects of other meteorological elements and hence prominence is given to rainfall, its distribution and intensity.

Normally, monthly or weekly average rainfall is used for agricultural planning. Average rainfall for many stations, especially in low rainfall areas, is not adequate for crop growing. But crops are grown in those areas at least for a few years when the rainfall of these years is adequate and more than average value. A detailed probability analysis can bring out the amount of rainfall expected at different probability levels which in turn can give the number of years of adequate, deficient and excess of rainfall. India Meteorological Department has computed probability of rainfall of about 1500 stations and this information has been used to delineate states into different homogeneous rainfall zones (Biswas and Khambete 1979, Biswas and Basarkar 1982 and Sarker et al. 1982). Fig. 2 gives probability of rainfall at different risk levels which is very much useful for preparing advisories.

Impact of same amount of rainfall may be quite different on two locations of different atmospheric demand and soil. This could be demarcated with the help of agroclimatic classification. India Meteorological Department delineated India into different zones and subzones using data of one station of each district and some

WX. WARNINGS TO BE ISSUED FOR	RAIN	ONSET OF MONSOON > ANY RAIN 50mm PER DAY	ANY RAIN
	DURATION		
	CLOUDY WX	CLOUDY WEATHER	CLOUDY WEATHER
	DROUGHT		
	HIGH WIND	35 km ph.	35 km ph
	TEMP	MIN < 12°C MAX > 38°C	
	HAIL STORM		

NORMAL WATER REQUIREMENT	MONTHLY R.F.	213	140	156	72	33	6	4	1	3	12	25	235	213·8	140	2156	72	33	6	4	1	3
	RAINY DAYS	10	8	8	4	1	0	0	0	0	1	1	7	10	8	8	4	1	0	0	0	0

LIFE HISTORY AND MEAN DATES OF IMPORTANT EPOCHS OF CROP GROWTH: PLANTING — GERMINATION — TILLERING — EARLY GROWTH — ELONGATION — FLOWERING & MATURITY — HARVEST

STANDARD WEEKS	29	33	37	41	45	49	1	5	9	13	17	21	25	29	33	37	41	45	49	1	5	9	13	17
MONTHS	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	

Fig. 3. Crop-weather calendar

of the States using micro-level data. Weekly probabilistic rainfall, potential evapotranspiration and soil characteristics have been used for the agroclimatic classification (Biswas 1982, Sarker & Biswas 1988). This information is very much useful for selecting appropriate crops for the regions as per moisture and/or thermal regimes.

Another important information is the crop weather calendar which helps in preparing agromet advisory. This gives detailed pictorial information regarding the major crops grown in the different districts, their dates of sowing, the dates of commencement and duration of major epochs in the life history of the crops during each season and their probable weather requirement. It also includes the average conditions of rainfall, temperature, wind, sunshine etc encountered at the various phases of plant life. It becomes a useful tool to issue warning for any considerable deviation of weather elements from their normal value. Fig. 3 gives a pictorial form of crop-weather calendar.

The factual information on the species and varieties of crops, their stage and state, ongoing agricultural operations and insects, pests and diseases are equally important. This information is collected by the national agricultural departments through their extension services.

The final part of the advisories consists of the agrometeorological advices jointly framed by the agricultural meteorologists and the agricultural specialists. These are based on the studies conducted and knowledge available on crop-weather relationship, probability analysis of rainfall, weather, insects & pests and their inter-relationship and knowledge of available agricultural resources.

6.1. Interpretation of advisories

The interpretation of weather for crop takes into account the impact of weather on germination, growth rates, freeze protection and irrigation demands. The cumulative effect of weather, encountered and that anticipated, is used to determine the necessity of chemical sprays, dates of harvest, duration of harvest, quality and storage capabilities of grains, fruits and vegetables.

The interpretation of weather for livestock is generally based on an index based on temperature & humidity effect on livestock. This index provides an indication regarding heat stress, cold stress and shelter requirements, and the effects of weather on the productivity of milk, meat and eggs.

The incidence of plant diseases can be forecast in the light of accumulated and anticipated weather as there exists a very close relationship between many plant diseases and the weather. Both synoptic and statistical approaches are used for these forecasts, which are concerned with probable development, extent and time of spread or suppression of the diseases. Advice on control measures to be taken is also included.

6.2. Dissemination of agrometeorological advisories

The agrometeorological advisories are meant to be utilized by the farmer in the field in his day to day operations. As such, the primary objective in the dissemination of these advisories should be that :

(i) The format should be fixed which will enable the farmer to get acquainted with a given flow of information.

(ii) These should be made available to the farmer at the time of his convenience. The broadcast or telecast should be done at the leisure time of the tiller.

(iii) The advisories should be worded in a simple language preferably in the local language of the farmer.

(iv) There should be separate advisories covering subdivisions of the country or state so that only the relevant information is available to the farmer in each district.

In India these advisories are broadcast by a network of national radio stations covering small villages. Generally the broadcast is done in the early morning (when the farmer is getting ready to go to his field), in the afternoon (when the farmer can find some leisure in his lunch time) and again in the evening (when the farmer is back home after the day's work). These are broadcast in the local languages. The national television network also telecasts these advisories in the regional languages. The national ministry of agriculture has developed a very good infra-structure both at the state and district levels for efficient rapport with the farmers in the fields. This is carried out under the government community development projects and the national extension services.

The important role of education and extension in agriculture is to help the farmer to :

(i) accept new agricultural technology for obtaining better yields,

(ii) assess his resources and take rational decisions for the best use of them. The agrometeorological advisories become a great aid in this respect and

(iii) find out the necessary technical know-how as well as inputs to be applied according to his needs.

The important extension methods by which these advisories are disseminated to the user level are :

(i) Individual contacts — Farm and home visits, office calls, telephone and personal letters.

(ii) Group contacts — Conferences, meetings, workshops and field trips.

(iii) Mass contact — Bulletins, leaflets, circulars, letters, radio and television, exhibition and posters.

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