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Optimum sowing dates for soybean in central India using CROPGRO and ClimProb symbiosis

Rajesh Kumar[1], K K Singh[2], B R D Gupta[1], A K Baxla[2], L S Rathore[2] and S D Attri[3]
[1] *Department of Geophysics, Banaras Hindu University, Varanasi – 221 005, India*
[2] *National Center for Medium Range Weather Forecasting (DST), Mausam Bhavan, Lodi Road, New Delhi – 110 003, India*
[3] *India Meteorological Department, Lodi Road, New Delhi – 110 003, India*

The optimum sowing dates for soybean cv. Gaurav were derived for Jabalpur, Raipur and Gwalior in the state of Madhya Pradesh in central India. Dates were derived based on two strategies: (a) probabilities of rainfall and temperature events using ClimProb, a PC based software package, and (b) the CROPGRO Soybean v3.0 crop growth simulation model. In Madhya Pradesh, the optimum sowing dates for multiple cropping, with the first crop as soybean under rainfed conditions, are between weeks 25 and 27, while the optimum sowing dates for rainfed mono-cropping are between weeks 28 and 29.

1. Introduction

The soybean can be grown under either rainfed or irrigated conditions in India. Under rainfed conditions, the sowing operations are normally timed to coincide with the start of the rainy season. Since the majority of the land is under rainfed cultivation in the state of Madhya Pradesh in central India, the rainfed condition is the focus of this study of the optimum sowing dates for soybean in accordance with the meteorological parameters.

Even though the first cropping season coincides with the south-west monsoon (June to September), the uneven distribution of intra-seasonal rainfall poses certain problems, such as drought in the early stages of crop growth and floods in the middle stages. It is important to time the seed sowing to ensure that the yield will be maximised throughout the crop growth cycle. Farmers producing a second crop invariably suffer from drought in the middle to late stages of growth because a second crop is not usually feasible under rainfed conditions; hence the focus on the first crop only.

In tropical areas, sowing dates are controlled by the moisture status of the soil and, thus, by the onset of the rainy period. Unlike the extratropics where temperature limits crop growth, the key variable in the tropics is the amount of water available in the soil to trigger seed germination. The presence of soil moisture also determines many other agronomic operations at the time of sowing, for example the application of fertiliser, the depth of sowing, etc. Soil loosening as a part of seed-bed preparation affects soil temperature, water movement within the soil, soil water evaporation, biological processes and some chemical processes (Kakade, 1985). In general, then, the growth of the soybean from germination to maturity is dependent on the availability of moisture (i.e. precipitation under rainfed conditions) during the season. In addition to initial soil water, lack of moisture during growth and development can lead to reduced yields (Kung, 1976). Depending on climate, soils, crop variety and management practices, the total water requirement of the soybean crop has been reported to vary between 45 and 70 cm (Doorenboos & Kasam, 1986). The crop coefficient for soybean suggests that the water requirement of the soybean crop varies from 50% of the potential evapotranspiration at the beginning of the growing cycle to more than 105% in mid-season and 45% at the end.

Apart from an upper temperature limit of about 35 °C (Hoogenboom *et al.*, 1993), above which soybean growth is hindered, the final meteorological requirement for high quality soybean production is the presence of dry conditions at harvest time so that the beans can be properly dried and preserved.

In India, most of the studies associated with the application of meteorological information to crop establishment are confined to the determination of sowing dates. For example, the India Meteorological Department has prepared a chart showing the dates of onset of the south-west monsoon over India based on the long-term averages of pentad rainfall for about 180 stations distributed across the country. The pentad that characterises an abrupt rise in the normal rainfall is used to fix the date of the onset of the monsoon. As this chart cannot indicate the pre-existing moisture condition of the soil, it has limited application in agriculture. In a study to determine the optimum precipitation conditions for sowing cotton in the Indian state of Maharastra state, Raman (1974) used two criteria: (a) at least 25 mm rain should be recorded in seven days, with 1 mm or more in any five or more days of the week, and (b) an evaporative loss of 18 mm should be recorded at the end of five days in the spell. These criteria were used in computing the first sowing rains of individual years, and their mean, median and standard deviation were calculated and mapped. More recently, Saseendran *et al.* (1998) have determined the optimum transplanting dates for rice in Kerala state in India using both the climatic probabilities of different events and a crop growth simulation model. They found that under rainfed conditions, the optimum transplanting dates were between weeks 23 and 26 for multiple cropping in a year, and between weeks 26 and 32 for rainfed mono-cropping.

In an analysis of the planting date of millet in Niger, Davy *et al.* (1976) found that it always coincided with the first occurrence of 25 mm of rain over a two-day period. In all the studies reported in India, the minimum requirement for sowing is the availability of moisture in the soil and the soil's workability, and the criterion that determines a 'sowing rain' is fixed at the level sufficient to make the soil moist enough to support germination. In India, it is the variation in the onset of the monsoon, its intensity and duration that are largely responsible for the relative performance of the soybean crop.

In this study an attempt is made to determine the optimum soybean sowing dates under rainfed conditions in the three important soybean growing areas of Jabalpur, Raipur and Gwalior in the state of Madhya Pradesh. Climatic data from Jabalpur, Raipur and Gwalior were used to obtain the probability of achieving the target yield of soybean, the probability of rain in the preceding week of sowing date, the probability of a maximum temperature within the optimum limits for crop growth and the probability of producing high quality grain at harvest time. As well as historical weather data, two other tools were used:

(a) *ClimProb to generate the probabilities of different events*. ClimProb is a software package for interactive examination of climate events as defined by the user in terms of conditions placed on daily maximum and minimum temperature and precipitation. ClimProb has been successfully used in other agricultural operations, for example the timing of pest treatment (Peterson & Meyer, 1995) where pest development rates are known to exhibit a temperature response function.
(b) *CROPGRO Soybean model to simulate the grain yield*. CROPGRO Soybean is a process-oriented management level model which has the capability to simulate development, growth and yield under diverse environmental conditions. This model has been used to predict evapotranspiration and irrigation management in the USA (Hoogenboom *et al.*, 1991) and to estimate soybean yields in India (Lal *et al.*, 1999).

By employing these tools it can be shown that the decisions relating to soybean sowing are weather dependent and that the appropriate conditions will increase the probability of successful soybean production in terms of both quality and quantity. It also becomes apparent that optimising quantity does not necessarily optimise quality.

2. Data and methods

2.1. ClimProb

ClimProb (Climatological Probabilities) is a PC-based software package, developed by the Department of Agrometeorology, University of Nebraska, Lincoln, USA to address the need to incorporate climatic information in decision-making. It develops probabilities of climatic events based on past climate data at a given weather station. The factors considered in the development of ClimProb include the need for flexibility in choosing values for thresholds, accumulations and extremes, and a time-window that is specific to a particular application. The software can be considered as a climate related decision-making tool, with particular emphasis on management problems in agriculture, engineering and energy. In addition, ClimProb has been applied in the areas of research, classroom instruction and service/outreach.

ClimProb can be used to find the probability and timing of events associated with daily maximum and minimum air temperatures and precipitation in agricultural decision-making. By examining the historical record for the event in question, ClimProb develops the required probabilities. According to the magnitude, events are ranked and a probability is assigned. Probability plotting positions were assigned as $m/(n+1)$ according to the Weibull plotting position (Weibull, 1939), where m is the rank of the particular events and n is the number of events.

2.2. CROPGRO Soybean model description and its validation

(a) The CROPGRO model

Crop models which share a common input and output data format have been developed and embedded in a software package called the Decision Support System for Agrotechnology Transfer (DSSAT). DSSAT is a shell that allows the users to organise and manipulate crop, soil and weather data, to run crop models in various ways, and to analyse their outputs (Jones, 1993; IBSNAT, 1994; Tsuji *et al.*, 1994). The models running under DSSAT include the CERES model for rice, wheat, maize, sorghum, pearl millet and barley, and the CROPGRO (CROP GROwth) model for drybeans, peanuts and soybean.

CROPGRO is a generic physiological process-oriented legume crop model. Figure 1 illustrates the flows (of mass, information and time) between the major components of the CROPGRO Soybean model. The basic structure of the model, including underlying differential equations, has been explained in several other publications (Wilkerson *et al.*, 1983; Boote *et al.*, 1989; Hoogenboom *et al.*, 1989, 1990). The model accounts for:

- vegetative and reproductive development;
- photosynthesis, respiration, partitioning;
- growth of leaves, stems, roots, shells, and seeds; and
- transpiration, root water uptake, soil evaporation, soil water flow, infiltration and drainage.

The model provides simulations at daily time steps from planting until maturity (harvest). The soil water balance has been adapted from the model of Ritchie

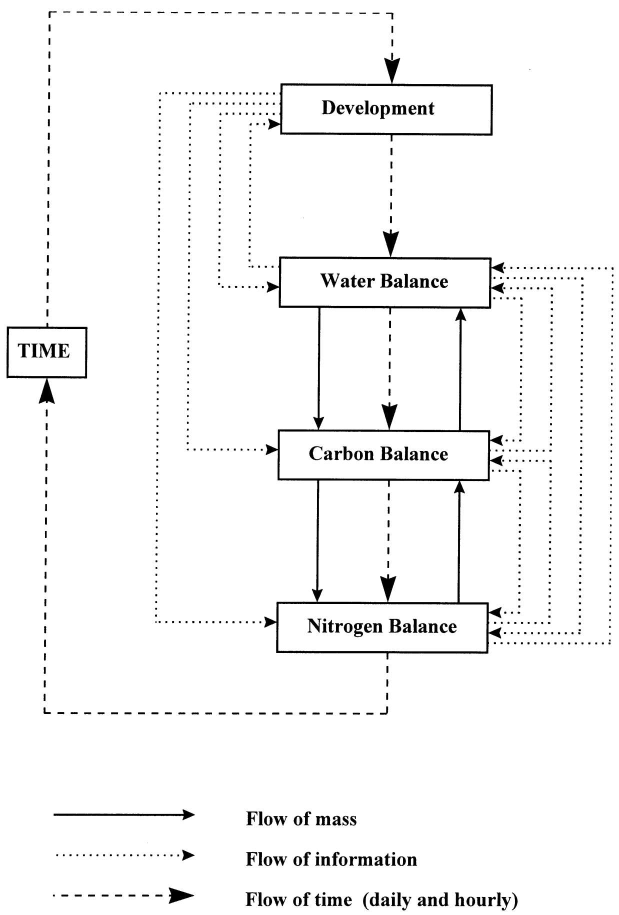

Figure 1. *Relational diagram of the flow of mass and information between the most important modules of the CROPGRO Soybean simulation model.*

(1985), while potential evapotranspiration has been calculated using the Priestley & Taylor (1972) equilibrium evaporation concept. The CROPGRO model includes detailed soil and plant nitrogen balance components which simulate nitrogen uptake, nitrogen fixation and nitrogen mobilisation (Hoogenboom *et al.*, 1990).

(a) Input data

The input files for the crop models which incorporate data on the weather, soil, crop genetics and crop management are depicted in Table 1. In this study, the long-term observed daily weather data from Jabalpur, Raipur and Gwalior have been used: maximum and minimum temperatures, solar radiation (derived from sunshine hours data using Angstrom standard formula) and rainfall. Soil water holding characteristics for selected sites and the period covered by the weather data are given in Table 2. The terms 'lower limit' and 'drained upper limit' correspond to the permanent wilting point and field capacity respectively (Ritchie *et al.*, 1986). Total extractable soil water is a function of soil physical characteristics as well as rooting depth.

Crop genetic input data, which explain how the life cycle of a soybean cultivar responds to its environment, developed for *cv.* Gaurav (JS7244) by Lal *et al.* (1999), were derived iteratively using Hunt's method (Hunt *et al.*, 1993). Minimum crop data sets required for the calculations of phenology and growth coefficients included:

- dates of emergence, anthesis, maturity, pod initiation and full pod;
- grain yield;
- above-ground biomass; and
- grain density and weight.

All calibration data to derive genetic coefficients by Lal *et al.* were obtained from plot experiments at Jabalpur during 1993 and 1994.

(c) Model validation

Validation of the model was carried out by Lal *et al.* (1999) based on the crop yield data available from the experimental site at Jabalpur under the All India Coordinated Research Project on Soybean for the period 1987–96 (with marginally different sowing dates in different years) and at Raipur for the period 1991–7. In order to evaluate the performances of the CROPGRO model in simulating soybean crop yield in response to historical climate variability, a comparison of observed versus model-simulated yields for Jabalpur and Raipur has been made by Lal *et al.* (Figure 2). Both series of data represent the same agro-management and other agricultural practices. Correlation coefficients of 0.90 and 0.93 between the observed and model-simulated yields for Jabalpur and Raipur respectively have been obtained. Although the model realistically

Table 1. *Input data required for the CROPGRO Soybean model (figures in parentheses are genetic coefficients values for cultivar JS7244).*

Data type	Parameter
Location data	Latitude (southern latitudes prefixed with a positive sign) Longitude
Weather data	Daily total solar radiation
	Daily maximum air temperature
	Daily minimum air temperature
	Daily total rainfall
Soil data	Soil reflection coefficient
	Stage 1 soil evaporation coefficient
	Soil water drainage constant
	USDA SCS Runoff curve number
	Thickness of soil layer, L
	Lower limit of extract table soil water for soil layer L
	Drained upper limit of extractable soil water for layer L
	Saturated water content for soil layer L
	Root distribution weighing factor for soil layer L
	Initial soil water content for soil layer L
Genetic coefficient data – Development aspects	
	Critical short day length (hour, 11.0)
	Slope of relative response of development to the photo period (H^{-1}, 0.305)
	Time between first flower and first pod (Photo thermal days (PTD), 6.00)
	Time between plant emergence and flower appearance (PTD, 15.53)
	Time between first flower and first seed (PTD, 10.0)
	Time between first seed and physiological maturity (PTD, 26.0)
	Time between first flower and leaf expansion (PTD, 15.0)
	Seed filling duration (PTD, 23.06)
	Time required for cultivar to reach final pod load (PTD, 8.84)
Genetic coefficient data – Growth aspects	
	Maximum leaf photo synthesis rate (minimal $CO_2\ m^{-2}\ s^{-1}$, 0.90)
	specific leaf area ($cm^2\ g\ m^{-1}$, 370)
	Maximum size of full leaf (cm^2, 170)
	Maximum fraction of daily growth partitioned to seed and shell (1.0)
	Maximum weight per seed (g, 0.10)
	Average seed per pod (1.9)
Management data	Sowing date
	Plant density
	Gross irrigation amount
	Row width and seeding depth
	Irrigation date
	Irrigation efficiency
	Irrigation soil depth
	Available soil water
	Triggering irrigation

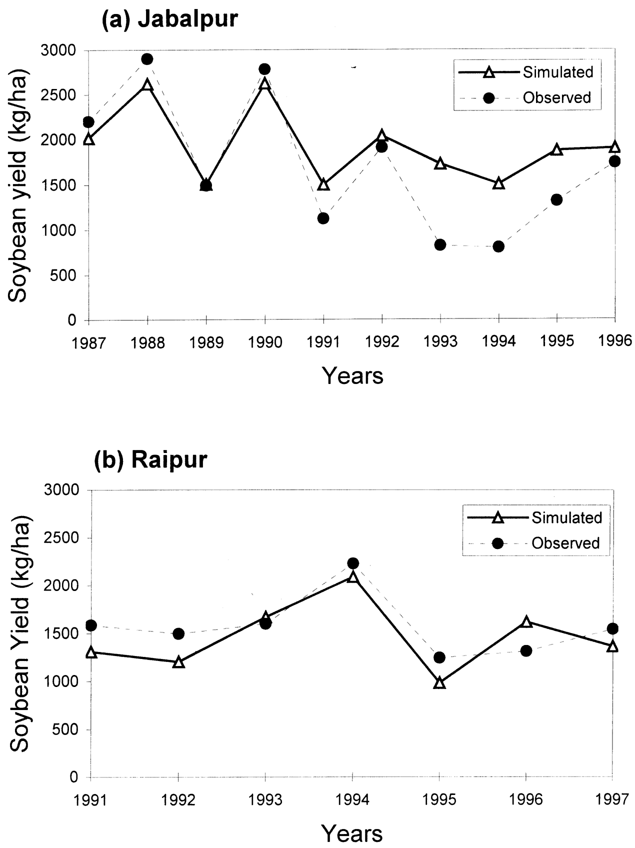

Figure 2. *Observed yields (at experimental sites) and model simulated soybean yields at (a) Jabalpur (1987–96) and (b) Raipur (1991–7).*

simulates the year-to-year variations in yields, deviations in simulated and observed yields can perhaps be explained by unaccounted factors such as soil micronutrient status, soil pH, pest or disease incidences, etc. The large deviations between the observed and simulated yields at Jabalpur in the years 1993 and 1994 are due to rust which was reported at the experimental sites. Thus, the CROPGRO Soybean model simulates interannual variability in crop yields depending upon the daily weather variables for each of the selected years.

2.3. Procedures adopted

An empirical approach to optimising the sowing date was taken by setting out specific water requirements of the soybean *cv.* Gaurav at different stages of growth. A specific temperature requirement during the growth period of soybean was also taken into account. In the tropical environment of Madhya Pradesh, the water requirement is about 65 to 80 cm for normal growth and development of the soybean (Mavi, 1986). In Madhya Pradesh, the whole crop period for the Gaurav variety of soybean is about 115 days.

For successful production, certain requirements must be met. It is assumed that the crop requires 100 days of the 115-day crop period to reach physical maturity,

Table 2. *Soil water holding characteristics at three selected sites in Madhya Pradesh, India.*

Location of site	Period for which weather records are available	Soil depth (cm)	Lower/drained upper limit (mm)	Saturated water content (mm)	Extractable water content (mm)
Jabalpur 23.15° N, 79.97 ° E	1969–96	70	133/226	294	93
Raipur 21.27 ° N, 81.60 ° E	1971–97	60	102/180	240	78
Gwalior 26.15 ° N, 78.148 ° E	1965–88*	90	126/234	333	108

* Not available after 1988.

during which time it requires 80 cm of water. This assumption is in agreement with the experimental results from the All India Coordinated Research Project on Soybean. In addition, to achieve a successful harvest, the soya grains must remain relatively dry during the last 15 days of the crop period following maturity to avoid deterioration. It is therefore assumed that the quality of the soybean grain will be maintained if no more than 3 cm of rain falls during this 15-day period. For the preparation of the field before sowing it is assumed that 5 cm of precipitation falling in the week preceding the sowing date will lead to successful germination. It is also assumed that a temperature of not more than 36 °C is suitable for the growth and development of the soybean crop.

If the crop is to be sown on a specific date of the year, the probability of meeting these events (requirements) can be calculated using ClimProb. To keep the experiment manageable, seeds were planted at the beginning of each of the 52 standard meteorological weeks of the year, and weather variation within a week was ignored. The different probabilities used in the study are described below:

- P_5 probability of 5 cm or more precipitation received during the week preceding the sowing;
- P_w probability of precipitation ≥ 80 cm received during the crop growth period (wet period);
- P_d probability of precipitation ≤ 3 cm received during the last 15 days of the crop period, i.e. following physical maturity when a dry harvest will ensure crop quality;
- P_t probability of the temperature being less than 36 °C during crop growth; and
- P_y probability of the target yield of 1000 kg/ha being achieved in the farmer's field.

The probability of all these events occurring together in the same year is taken as the product of the individual probabilities:

$$Q = P_5 \, P_w \, P_t \, P_d$$

This latter probability is referred to as the Q-probability because it takes into account, albeit empirically, the quality of the harvested crop.

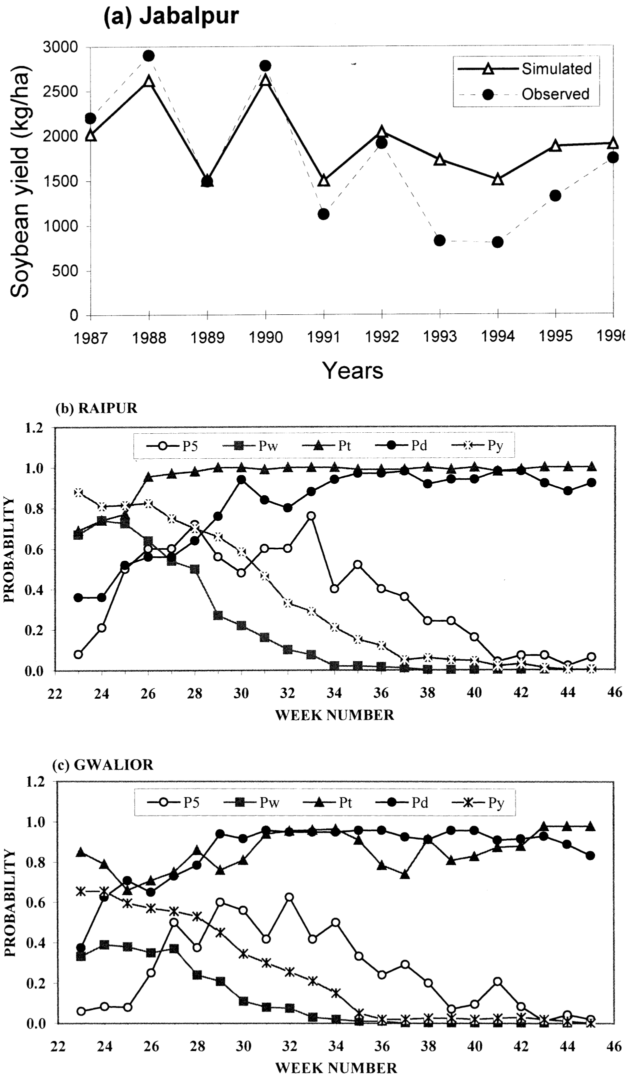

Figure 3. *The probabilities of growth period rainfall exceeding 80 cm (P_w), harvest period rainfall not exceeding 3 cm (P_d), target yield of 1000 kg/ha (P_y), the planting period rainfall exceeding 5 cm (P_5), and the growth period temperature not exceeding 36 ° C (P_t), for each possible sowing week of the cropping season at (a) Jabalpur, (b) Raipur and (c) Gwalior.*

A physiological approach to simulate the probability of a target yield was taken by using the CROPGRO Soybean simulation model (Hoogenboom *et al*., 1993) to obtain cumulative yield probabilities associated with weekly sowing dates throughout the crop growth period. Note, however, that the soybean yield is significantly higher in the experimental fields (up to

2500 kg/ha) than in the farmers' fields (approximately 1000 kg/ha). The probability of achieving a yield of 1000 kg/ha (P_y) was then multiplied by the probability of a dry harvest (P_d) to give the new probability:

$$Y = P_y P_d.$$

This probability involving the yield estimation from the CROPGRO Soybean model is referred to as the Y-probability because of its association with the target yield. For different sowing dates these probabilities were then plotted on a weekly basis.

The advantage of using Q-probability is its empirical nature. It also takes into account the progress of the crop and the resulting harvest quality. A deficit rainfall situation during the wet season can be taken into account, but flooding, which may result in poor crop performance, is not accounted for by this method. Furthermore, the method does not respond to any excess rainfall received during the dry harvest period. Unlike precipitation, temperature remains within fixed limits during the monsoon season in central India. The inherent limitations of the CROPGRO model – for example, the inability to factor in the impact of pest and diseases, micro-nutrients and weather hazards on crop growth – weakens the Y-probability because it depends upon the cumulative probability of yield simulated by the model. However, by comparing the probabilities from the two methods, the optimum sowing date can be predicted. The optimum time of sowing is taken as the date or dates on which the highest calculated values of these two probabilities, Q and Y, occurs; and the matching of these probabilities predicts the optimum sowing date/dates.

3. Results and discussion

Figure 3 shows the probabilities of experiencing optimum rainfall and temperature and achieving the target yield at each of the three locations (Jabalpur, Raipur and Gwalior). It is clear from the figures that P_5 remains less than 0.2 until week 23 of the year for Jabalpur and Raipur, and until week 25 for Gwalior. But this probability reaches 0.4 in week 25 for Jabalpur and Raipur and in week 27 for Gwalior. This variation may be due to the progress of the monsoon from south to north across central India – reaching Raipur first (normal onset: 10 June), then Jabalpur (12 June) and then Gwalior (19 June). Again, P_5 for Jabalpur and Raipur shoots up to 0.75 in weeks 27 and 28 respectively, but reaches a maximum of 0.6 for Gwalior in week 29.

The probability of adequate moisture (P_w) during the growth period exceeds 0.4 at weeks 19, 20 and 24 for Jabalpur, Raipur and Gwalior respectively. The value of P_w increases to 0.9 for Jabalpur and 0.74 for Raipur in weeks 22 and 25 respectively (i.e. the start of the monsoon period), and the probability remains at 0.9 till week 27 for Jabalpur and more than 0.45 till week 28 for Raipur. Then it gradually decreases and reaches zero in week 36 and 37 respectively at the end of the monsoon period. The value of P_w at Gwalior never exceeds 0.4. It reaches 0.4 in week 24 and remains above 0.3 between weeks 22 and 27, decreasing sharply thereafter. P_w remains at more than 0.6 between weeks 21 and 30 for Jabalpur and between weeks 22 and 26 for Raipur, whereas P_w is slightly more than 0.3 between weeks 22 and 27 for Gwalior. This P_w is in the accordance with the number of rainy days, and the amounts ensure adequate moisture.

The probability of dry conditions during harvest (P_d) is more than 0.75 if sowing is undertaken before week 7 and after week 29 at Jabalpur, before week 7 and after week 28 at Raipur, and after week 27 at Gwalior. These periods are therefore suggested for harvesting in order to ensure a crop of good quality grain.

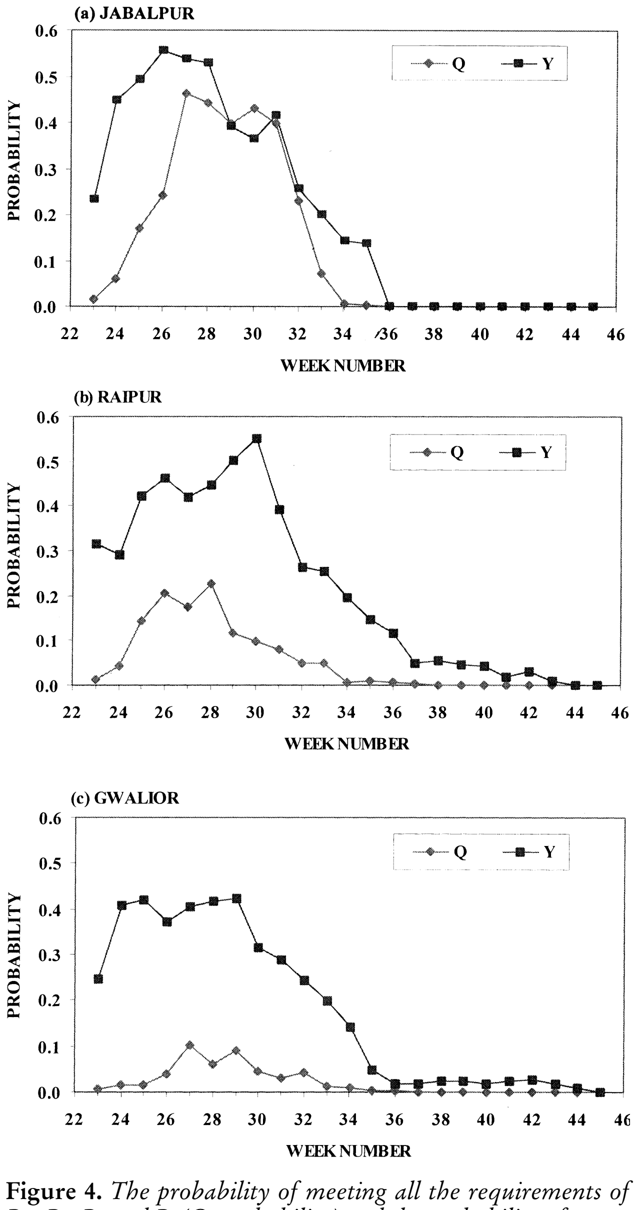

Figure 4. *The probability of meeting all the requirements of P_w, P_d, P_5 and P_t (Q-probability) and the probability of meeting both the target yield and harvest-period rainfall criteria (Y-probability) at (a) Jabalpur, (b) Raipur and (c) Gwalior.*

The probability of maximum temperature being less than 36 °C during crop growth (P_t) is more than 0.75 for seed sown in weeks 1 to 12 and 27 to 52 at Jabalpur, weeks 1 to 10 and 17 to 52 (except week 23) at Raipur, and weeks 1 to 12, 18 to 24 and 27 to 52 at Gwalior.

The probability of achieving the target yield of 1000 kg/ha (P_y) is more than 0.8 if seed is sown in weeks 12 to 24 at Jabalpur and weeks 14 to 26 at Raipur; the probability at Gwalior is 0.6 to 0.7 between weeks 11 and 25. Thereafter P_y sharply decreases at all the stations.

The combined probability Q – the product of wet growth period (P_w), dry harvest period (P_d), rainfall of 5 cm in the preceding week of the sowing (P_5), and temperature of less than 36°C (P_t) during crop growth – is shown in Figure 4 for Jabalpur, Raipur and Gwalior. These figures indicate the probability of achieving successful crop growth *and* a successful harvest. At Jabalpur the Q-probability is optimised by sowing the crop between weeks 26 and 32, at Raipur between weeks 26 and 30, and at Gwalior between weeks 27 and 30 (though the Q value at Gwalior remains less than 0.1). The probabilities peak at week 28 for all three locations.

The Y-probability, associated with achieving the target yield of 1000 kg/ha *and* a good quality crop at harvest time (i.e. the product of (P_y) and (P_d)), is also plotted in Figure 4. It can be seen that the optimal time of sowing with respect to the Y-probability at Jabalpur is between weeks 24 and 3, with a peak at week 26; at Raipur it is between weeks 25 and 31, with a peak week 30; and at Gwalior between weeks 24 and 30 with two peaks at weeks 25 and 29. The figures also reveal that the Y-probability tends to have a broader distribution than the Q-probability. This may be attributed to the fact that the target yield of 1000 kg/ha was used in calibrating the model though the yield potential of this cultivar is of the order of 2500 kg/ha. Given this, the model tends to simulate higher yields even under existing management conditions which leads to higher Y-probability values.

4. Limitations of the study

The primary thrust behind the development of crop simulation models was the need to predict how weather and genetic characteristics may affect the potential crop yields under a specified management scheme. But the crop simulation models currently available are still incomplete in many respects. One of the greatest drawbacks is their failure to account for pest effects, which severely limits their use as farm management tools. For example, the IBSNAT crop growth models (Tsuji *et al.*, 1994) are limited to validation and testing only on fields with good pest control; and Boote *et al.* (1989) have established that the collection of data on crops which experience pest damage is not very useful for model validation. Although plant water and nitrogen supply have been given attention in some crop simulation models, the availability of nutrients (phosphorus, potassium and other essential plant nutrients) are assumed to be in abundant supply in the soil and hence are currently excluded. Other factors not included in the model are weeds, diseases and toxicities of the soil, as well as soil salinity and soil erosion problems. Because of this, the yields predicted by the simulation models are higher than the actual yields achieved in the field. It is unlikely that complex models will predict yields with any more accuracy on account of our lack of knowledge and/or uncertainties in biomass partitioning and because much of the input information that is needed is not available and/or is costly to obtain. However, less complex models suffer from the lack of any capability to predict unusually low yields caused by plant stress.

5. Conclusions

Based on empirical analysis, the probabilities of meeting crop water requirements, of staying below the maximum temperature during crop growth and of achieving dry harvest conditions were used to calculate the Q-probability. The probability of achieving both target yield and dry harvest, i.e. the Y-probability, was obtained and compared with the Q-probability. Optimum sowing dates for soybean were derived for Jabalpur, Raipur and Gwalior in the state of Madhya Pradesh under rainfed conditions. The results of the calculations are summarised in Table 3.

It is apparent from Table 3 that the optimum sowing dates (based on the Y-probability) for all three stations ranged between weeks 24 and 31, with peaks at week 26 for Jabalpur, week 30 for Raipur, and weeks 25 and 29 for Gwalior. However, when based on Q-probability, the optimum sowing dates at all the three stations varied between weeks 26 and 32, with a peak at week 28. On the basis of these probabilities, farmers undertaking multiple cropping (supported by a rising value of Q) should sow their soybean crop in week 25 at Raipur, in week 26 at Jabalpur, and in week 27 at

Table 3. *Optimum sowing season based on the Q-probability and Y-probability for Jabalpur, Raipur and Gwalior.*

Station	Growing season			
	Q-probability		Y-probability	
	Period (weeks)	Peak (week)	Period (weeks)	Peak (week)
Jabalpur	26–32	28	24–31	26
Raipur	26–30	28	25–31	30
Gwalior	27–30	28	24–30	25, 29

Gwalior. This will allow enough leeway at the end of the first crop for a good early establishment of the second crop. Where mono-cropping under rainfed conditions is concerned, sowing should be done in week 28 at both Jabalpur and Raipur, and in week 29 at Gwalior.

Although the two approaches (Q and Y) gave similar recommendations for optimum sowing times, it is clear that the differences in absolute magnitude between the two probabilities can be quite large. It is not clear which value is superior but presumably the physiological approach model would account for more variability than the simple empirical assumption of 80 cm of rainfall in a 115-day period. The yield-based probabilities for successful growth and harvest were higher than the empirically-based probabilities at all three locations.

The methodology in this study can be adopted for optimising sowing/planting dates where a given quality and quantity of production is required and is suitable for areas where climatic information is available. This study suggests that soybean-growers in Madhya Pradesh should be encouraged to use climatic and agrometeorological advisory services to ensure successful production.

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