The usefulness of medium range weather forecast in improving the quality of output from CROPGRO-Soybean model

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(*Received 23 December 1999, Modified 11 September 2003*)

सार – रायपुर की स्थानीय परिस्थितियों के लिए अंशशोधित किए गए क्रॉपग्रो–सोयाबीन निदर्श का उपयोग सोयाबीन फसल की बढ़ोतरी की अवधि से संबंधित मध्यमावधि मौसम पूर्वानुमान की प्रासंगिकता का मूल्यांकन करने के लिए किया गया है। पूर्वानुमानित पैदावार के संभाव्य वितरण के लिए क्रॉपग्रो–सोयाबीन निदर्श के सहयोग से प्रामाणिक मौसम आँकड़ा, मध्यमावधि मौसम पूर्वानुमान (एम.आर.डब्ल्यूएफ.) और अद्यतन मौसम संबंधी आँकड़ों के उपयोग में लाई जाने वाली पद्धति विकसित की गई। मौसम संबंधी सूचना का पूर्वानुमान देने के लिए फसल प्रबंधन पद्धति की संवेद्यता का निर्धारण करने हेतु 5 दिनों के सटीक एम. आर. डब्ल्यू. एफ. की श्रृंखला तैयार की गई। एक वर्ष के कुछ समय की सापेक्षिक महत्ता को सटीक 5 दिनों के एम. आर. डब्ल्यू एफ. के कारण परिवर्तनशीलता में आई कमी के रूप में लिया गया।

रायपुर में दो संदर्भ वर्षों 1986 (कम उत्पादन वाला वर्ष) और 1993 (अधिक उत्पादन वाला वर्ष) में किए गए अध्ययन से पता चला है कि कम उत्पादन वाले वर्ष (1986) के लिए फसल के पकने से 20 दिन पूर्व ओर अधिक अत्पादन वाले वर्ष (1993) के लिए फसल के पकने से 15 दिन पूर्व उत्पादन का आकलन किया जा सकता है। पुनरूत्पादक चरणों के दौरान दोनों वर्षों के लिए एम. आर. डब्ल्यू. एफ. अधिक महत्वपूर्ण पाए गए हैं। इससे यह भी निष्कर्ष निकलता है कि फसल के बढ़ने की ऋतु में लम्बी अवधियों के पूर्वानुमान उच्चतर मानों के साथ पहले से ही अनुकूल होते हैं।

ABSTRACT. CROPGRO-Soybean model calibrated for local conditions of Raipur has been used to evaluate the relevance of medium range weather forecast relative to the soybean crop growth period. A procedure that makes use of historical weather data, medium range weather forecast (mrwf) and current weather data in conjunction with the CROPGRO-Soybean model was developed to arrive at a probable distribution of predicted yield. A series of perfect mrwf for 5 days were assumed for assessing the sensitivity of the crop management system to forecast information. The relative importance by time of year was taken as a reduction in variance due to a perfect 5-day mrwf.

The results of the study, conducted for two reference years 1986 (low-production year) and 1993 (high-production year) at Raipur, showed that the yield estimation can be done 20 days in advance before the physiological maturity for low-production year (1986) and 15 days in advance before physiological maturity for high-production year (1993). For both the years mrwf during reproductive phases are more valuable. It has also been concluded that the longer forecast periods are responding earlier in the growing season with higher values too.

Key words – CROPGRO Soybean, Yield prediction, Reference year, Medium range weather forecast.

1. Introduction

Many statistical approaches (Stewart and Dwyer, 1990; Gupta and Singh 1988) and crop simulation models (Aggrawal and Kalra 1994; Hundal and Kaur 1997) are being utilised to predict the crop yield. It is of immense importance for government policy-makers in order to assess the relative economic situation well in advance. The export import and storage policies etc. can be prepared in advance with the predicted yield scenarios of the crops.

TABLE 1

Genetic coefficients for soybean cultivar 'Gaurav' (JS7244) in agroclimatic condition of Madhya Pradesh (after Lal *et al*. 1999)

Growth and development aspects of the soybean crop	Genetic coefficients
Development aspects	
Critical short day length (hour)	11.00
Slope of relative response of development to photoperiod (h^{-1})	0.305
Time between plant emergence and flower appearance (photo thermal days)	15.33
Time between 1st flower and 1st pod (-do-)	06.00
Time between 1st flower and 1st seed (-do-)	10.00
Time between 1st seed and physiological maturity (-do-)	26.00
Time between 1st flower and end of leaf expansion (-do-)	15.00
Seed filling duration (photo thermal days)	23.06
Time required for cultivar to reach final pod load (-do-)	8.84
Growth aspects	
Maximum leaf photosynthesis rate (minimal CO_2/ m^2-sec)	0.90
Specific leaf area of cultivar under standard growth condition (cm^2/g)	370
Maximum size of full leaf (cm^2)	170
Maximum fraction of daily growth partitioned to seed and shell	1.00
Maximum weight per seed (gm)	0.10
Average number of seeds per pod	1.90

Soybean (*Glycine max L. Merr.*) is an important Kharif crop of Madhya Pradesh (M.P.) covering 77 % of cultivated area and contributing 72 % to the total national production. There is need for a reliable estimation of soybean production under varied environmental conditions. In using crop simulation model to real time yield estimation, one of the major constraints is the non-availability of anticipated weather during rest of the season at the time of forecast. In this study an attempt has been made to develop a procedure which makes use of historical weather data, medium range weather forecast (mrwf) and current weather data in conjunction with the CROPGRO-Soybean model to arrive at a probable distribution of predicted yield and assess the sensitivity for crop management.

2.   Materials and method

The different parts of the model, which processed itself to get the results are input, output, genetic coefficients and the validation of the model to use for a specific region.

2.1. *Model description*

The CROPGRO-Soybean model used in this study is a part of the Decision Support System for Agro-technology Transfer (DSSAT) (Tsuji *et al*. 1994) and shares a common input and output data format embedded in DSSAT. Its major components are the vegetative and reproductive development, carbon balance, water balance and nitrogen balance modules. The basic structure of the model, including underlying differential equations, has been explained in several other publications (Boote *et al*. 1985, Jones *et al*. 1991 and Hoogenboom *et al*. 1992).

2.2. *Model input*

Daily weather data, soil albedo, soil water drainage constant, field capacity, wilting point, initial soil moisture in different layers, maximum root depth, crop genetic coefficients and management practices such as plant population, plant row spacing and nitrogen application are required to run the model (Tsuji *et al*. 1994). The long-term observed daily weather data on maximum and minimum temperature, solar radiation (derived from sunshine hour's data using Angstrom's formula) and rainfall at Raipur for the period 1971-97 have been used in this study. Thickness of soil profile, permanent wilting point, field capacity and saturation of the experimental fields are found to be 60 cm, 102 mm, 180 mm and 240 mm respectively.

2.3. *Genetic coefficients*

Crop genetic input data, which explain how the life cycle of a soybean cultivar responds to its environment, has been developed for JS7244 (early maturing *cv*. Gaurav with life cycle of 105 days) which is one of the currently prevailing varieties in the state and presented in Table 1.
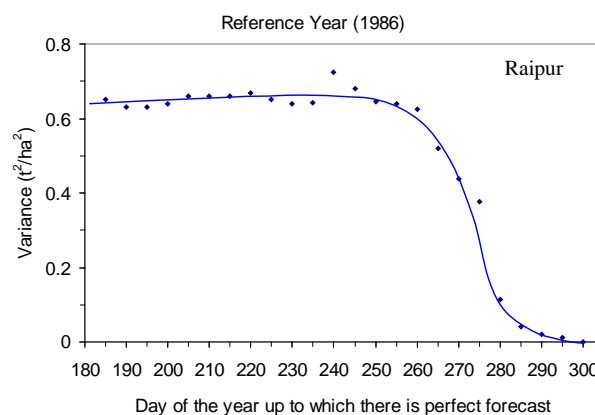
Raipur

Fig. 1. Observed (yields at experimental site) and model simulated soybean yields

Fig. 2. The variance of the distribution of yields at various dates of year 1986 for Raipur up to the time a perfect forecast is made

The coefficients derived can be satisfactorily utilized for evaluation of the growth performances of the crop under certain growth management situations in the state. Coefficients were derived iteratively using Hunt's method (Hunt *et al.*, 1993). Minimum crop data sets used for the calculations of phenology and growth coefficients included dates of emergence, anthesis, maturity, pod initiation and full pod; grain yield, above-ground biomass, grain density and weight.

2.4. *Model validation*

The model was validated with the crop yield data available from experimental site at Raipur under All India Coordinated Research Projects on Soybean for the period 1991 to 1997 (with marginally different sowing dates in different years). 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 have been compared by Lal *et al.* (1999) for location Raipur (Fig. 1). Correlation coefficient of 0.93 between the observed and model simulated yields has been obtained. Although the model realistically simulates the year to year variations in yields, deviations in simulated and observed yields are perhaps due to unaccounted factors such as soil micronutrient status, soil pH, pest or disease incidences etc. Management practices were 28 plants per m^2, row spacing 35 cm, planting depth 5 cm and 20 kg urea applied as basal dose at the time of planting. Emergence was observed 5 days after sowing in all the experiments.

2.5. *Yield prediction procedure*

Yield prediction using crop growth simulation models were carried out by many workers (Aggarwal and

Kalra 1994, Chipanshi *et al.* 1997, Hundal and Kaur 1997, Singh *et al.* 1999). In this study a new procedure is developed to predict soybean yield during the growing season of the prediction year (reference year) using CROPGRO Soybean, medium range weather forecast (mrwf), current and historical weather. The reference year's daily weather data are put into the model upto date on which yield predictions are to be made and then the medium range weather forecast data for next 5 days is added to it followed by sequences of historical data until the end of growing season for 25 years. Using this sequence of weather data, yield estimate is made separately for each of 25 years. The reference year's yield prediction is given on the basis of the mean of distribution of yield estimates during this period.

3.   Results and discussion

On the basis of the marked differences in their yield values, the years 1986 and 1993 were selected as reference years for Raipur. Observed district average of grain yields at Raipur was 613 kg/ha in 1986 and 1159 kg/ha in 1993. While the model estimated yields, for *cv.* "Gaurav" keeping 1st July as sowing date, are 618 kg/ha in 1986 and 1612 kg/ha in 1993. Difference between district average yield and model estimates are due to the fact that the district value is based on the mixed responses of all the varieties of soybean crop with different sowing dates under both rain fed and irrigated conditions including pest and disease effects etc.

The variances associated with the simulated yield distribution are plotted in Fig. 2 and Fig. 3 at various dates throughout the growing season of years 1986 and 1993 respectively. The solid line in the figures is smooth fit to the data. A little change in the variance from sowing
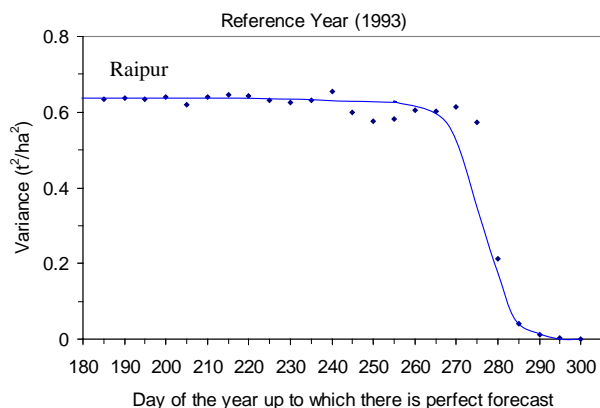
Fig. 3. The variance of the distribution of yields at various dates of year 1993 for Raipur up to the time a perfect forecast is made
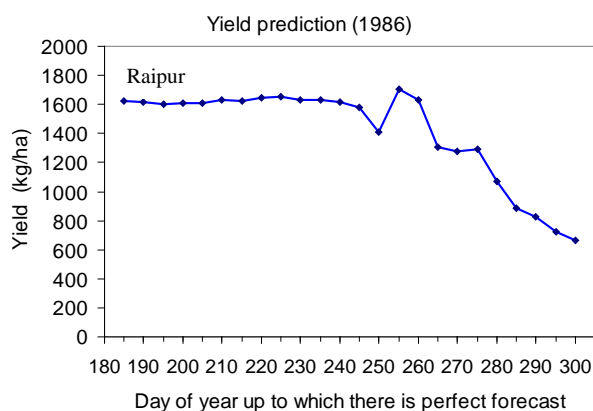

Fig. 4. Yield prediction at various dates during the 1986 growing season at Raipur

Fig. 5. Yield prediction at various dates during the 1993 growing season at Raipur
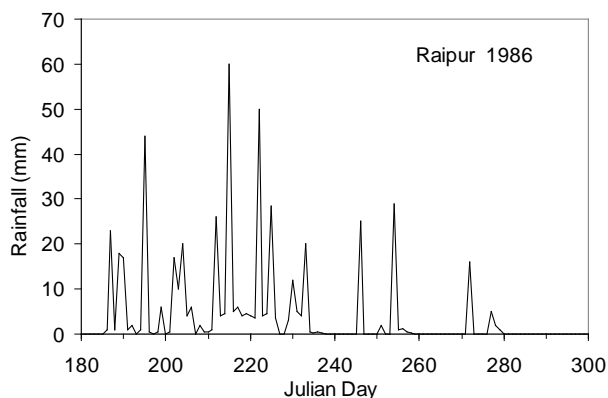
Fig. 6. Distribution of daily rainfall during the 1986 growing season

to first pod (232 Julian day) shows that the variation in yield up to first flower is dominated by the variation in weather after first pod (247 Julian day). Alternately, the variability in weather at Raipur prior to first pod does not have strong impact on yield. It would require a large anomaly in weather early in the growing season to substantially affect the yield. In 1986, after first pod variance begins to decrease slowly upto first seed (258 Julian day) and rapidly between first seed to end of pod stage (285 Julian day) thereafter less rapidly to physiological maturity period and then comes to zero. The variance associated with the simulated yield distribution at different forecast dates during 1993 crop season presented in Fig. 3 shows almost the same pattern as in 1986 (Fig. 2) up to first seed stage. Thereafter the decrease rate of variance becomes a bit slower than that of Fig. 2.

In the process of replacing the 25 sequences of historical weather at Raipur in a forecast period of 25 sequences of the same current weather, the contribution of the former to the variance of the yield is reduced to zero.

The variance increase from the forecast time to the next is a reflection of non-linearity of the plant growth model. After the completion of the replacement process for a given forecast period, the weather sequences follow a different impact on model than before replacement. In short, the effect of weather on the model at a given time depends on antecedent weather. For example, the phenological dates can change, and as they do, the growth processes after the forecast period are altered. The result is that there can be small increase in variances. With many more years of historical sequence, the variances should be much closer to the smooth curves (Fig. 2 and Fig. 3).

It can be seen that though the yields are determined before the end of grain filling stage in both the years 1986 and 1993, the yield prediction in 1986 has marginal improvement by 5 days over the prediction in year 1993, because the fast reduction in variance starts early in 1986 as compared to 1993. In 1986 growing season the rainfall

Fig. 9.   The value of perfect 5, 10 and 15-day weather forecast during the 1993 growing season

Fig. 7. Distribution of daily rainfall during the 1993 growing season

Fig. 8.   The value of perfect 5, 10 and 15-day weather forecast during the 1986 growing season
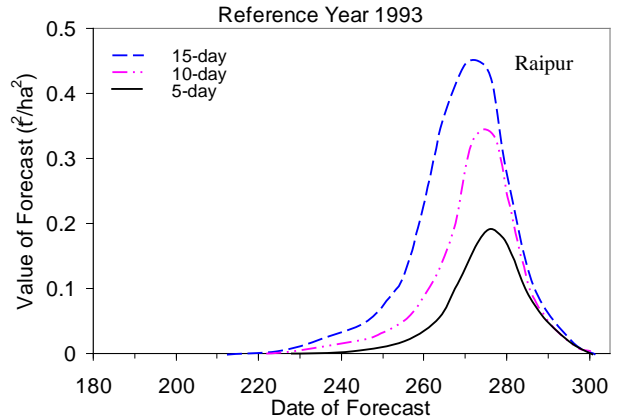
(Fig. 4) was unevenly distributed during the reproductive stage while there was good distribution of rainfall (Fig. 5) in the year 1993. Crop growth suffers from water stress of 0.60 in 1986 against 0.30 in 1993 during first seed to physiological maturity. During the deficient rainfall conditions at seed filling stage in year 1986, the sugar and protein in the stem and leaves of the plant were utilised in grain filling processes, thus enables prediction of yield at an early stage.

The following discussion represents the predicted yield on the basis of simple average of the yield distributions show the predicted yield as a function of the forecast time in year 1986 and 1993 respectively. It is evident from Fig. 4 that after two months from sowing date the yield shows a significant dependence on 1986 weather. A good growing weather in year 1986 around 257 Julian day reflects increase in average yield as

predicted by the model. After Julian day 257, there is negligible precipitation (Fig. 6) except around 272 Julian days upto end of growing season. Hence there is a decline in the model predicted yield. The model yield in 1986 is 768 kg/ha, which is nearly comparable with the district average of 613 kg/ha. Again the trend of predicted yield in 1993 is nearly same upto Julian day 240 as in the case of year 1986. Then there is increase in predicted yield due to good rainfall (Fig. 7) during first pod to first seed stage. Thereafter decrease in rainfall caused decline in predicted yield value. Again significant rainfall around the later half of the grain filling period gave an upward swing in the predicted yield value. The final yield value carried by the reference year 1993 is 1716 kg/ha, which is also nearly comparable with the reported district average yield of 1159 kg/ha.

4.   Value of medium range weather forecast

In general, it is difficult to assess the value of weather forecast because it has different implication to different users. An alternative value and meaning used here is on the basis of the resulting reduction in variance of distribution of yield. With the above meaning, it is relatively easy to obtain the value of a perfect daily forecast. This is done by taking the difference between the variance at the beginning and end of each forecast period for all possible dates. Thus for a 5-day perfect weather forecast at day 182, the variance at day 187 along the smooth curve would be subtracted from that at day 182, for forecast date 183 the variance at day 188 from that at day 183 and so on. The result of carrying out this is shown in Fig. 8 (year 1986) and Fig. 9 (year 1993) for 5, 10 and 15 days. These curves are comparable to the variation of sensitivity of a crop, say growing season water stress proposed by Hubbard and Hanks (1983). These

curves indicate the relative importance of weather forecast made during different stages of crop.

In the year 1993 peak value of 5-day forecast observed is around 4th October and in 1986 this is around 29th September. These forecast periods fall in the reproductive stage of the crop hence of immense importance. Thus, the weather predictions made on the scale of 5-day during the reproductive stage of the crop should be as much accurate and reliable as possible, reaching near a perfect forecast. Figures also depict that the longer the forecast period (10 days and 15 days), the greater its value and the peak value reach earlier in the growing season. Also its relative importance starts early in the growing season.

5. Conclusions

The yield in 1986 has been determined before the end of the grain fill stage (three weeks in advance before physiological maturity) and in the year 1993 the yield is determined two weeks in advance before physiological maturity, *i.e.*, at the end of grain filling stage. A 5-day weather forecast is relatively more valuable during reproductive stage in both the years, *i.e.*, during low-production (1986) and high-production years (1993). The peak values obtained for years 1986 and 1993 are about 29th September and 4th October respectively which indicate that the soybean yield predictions in the years with deficient rainfall, specially during reproductive stage, is possible one to two weeks earlier compared to prediction timings of yield in the years with good and evenly distributed rainfall. It is also concluded that the longer the forecast period, higher the value of forecast and earlier in the growing season its relative importance starts.

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