Vol. 18, No. 1, pp. 58-67 (2018)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Application of CERES- and GRO- Models as a Research and Agronomic Tool in Irrigated Plains of Punjab, India

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ABSTRACT

A well calibrated and validated crop simulation model can serve as a research and agronomic tool to study uncertainties in crop production due to weather variability. This paper aims to evaluate the applicability of CERES- and GRO- models as a research and agronomic tool in irrigated plains of Indian Punjab for wheat, rice, soybean and groundnut crops. The simulations with CERES-Wheat model revealed that the period between mid-February to mid-March was most critical for optimum growth and yield of wheat in Punjab. A temperature increase in 2nd fortnight of February decreased wheat grain yield by 2.40, 3.30, 2.15, 1.26 and 0.69% per °C for crop sown in 4th week of October, 1st week, 2nd week, 4th week of November, and 1st week of December, respectively. The enhanced concentrations of CO_2 were able to offset the adverse effects of temperature increase on growth and yield of crops to some extent. The optimum sowing time for direct seeded rice extended from mid May to mid June and that of transplanted rice from mid June to July. Soybean crop yields maximum when sown on 5th June with a row to row spacing of 35 cm and plant to plant spacing of 3.5 cm. The groundnut crop sown in 1st fortnight of May with a row to row spacing of 30 cm but plant to plant spacing of 22.5 cm or 30 cm gave comparable yield. However, with later sowing in June and July, the optimum row to row spacing and plant to plant spacing was 30 cm and 22.5 cm, respectively. In view of such simulations, the overall benefit of these models reveals that these can be used to save time and money to find agronomic answer to "What if ?" scenarios.

Key words: DSSAT, CERES-Wheat, CERES-Rice, PNUTGRO, SOYGRO, Simulation, Agronomic tool

Introduction

Information needs for agricultural decision making at various levels are increasing rapidly due to increased demands for agricultural products and increased pressure on land, water and other natural resources (Jones *et al.*, 2003). Field experiments to evaluate agronomic practices are laborious, time consuming and expensive; especially when a number of variables are to be tested and require multi-year data for verification. In present agricultural scenario, crop simulation models can play a pivotal role. Use of crop simulation model provides a suitable tool to evaluate crop growth as affected by various management and environmental factors and their interaction. A well-validated and calibrated simulation model of crop growth can help to evaluate various treatments for their response on crop growth and yields. Crop model provide a means to quantify the effects of climate, seasonal weather conditions, soil, management and genotype and their interactions on crop growth, yield, resource use efficiency and environmental

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inputs Boote *et al.*, 1996 and Lopez-Cedron *et al.*, 2005). They can be used to quantify the gaps between potential and actual yields, to determine likely environmental impacts and to evaluate management options. Thus models can potentially provide a unique means of quantifying the potential impacts of climate change on crop production and in the evaluation of adaptation strategies.

The DSSAT-family of crop models have been used widely by researchers most extensively in predicting the growth and yield of crops, as a crop management tool and in climate change studies (Chippanshi *et al.*, 1997; Bannayan *et al.*, 2003; Hundal and Prabhjyot-Kaur, 2007, Pathak and Wassmann, 2009). These are physiologically based simulation models which take into consideration phenologic development, growth, senescence, photosynthesis, respiration, infiltration, drainage and evaporation on a daily basis and respond dynamically to weather inputs. Further, these show considerable potential to evaluate crops, crop varieties, cropping practices and genetic potential patterns for yield. An important aspect of most of these studies is a consideration that weather influences the performance of crops, interacting in complex way with soil and management (Jones *et al.*, 2003). The DSSAT models software helps decision-makers by reducing the time and human resources required for analyzing complex alternative decisions (Tsuji *et al.*, 1998; Bhusal and Timsina, 2010) (Fig. 1). It also provides a framework for

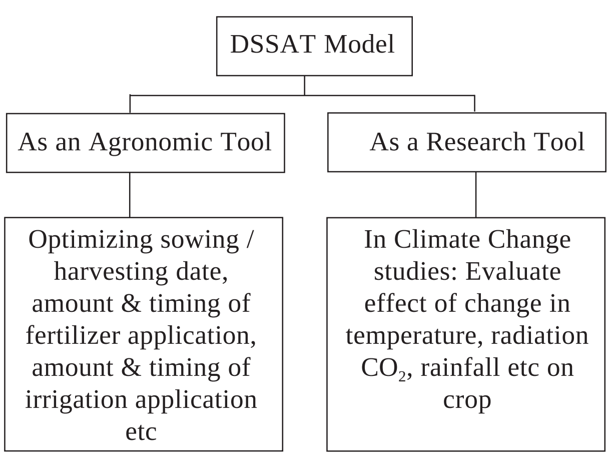

Fig. 1. Application of DSSAT models

scientific cooperation through research to integrate new knowledge and apply it to research questions. Prior to the development of the DSSAT, crop models were available, but these were used mostly in laboratories where they were created. For example, the original crop models implemented in DSSAT, the CERES models for maize (Jones and Kiniry, 1986; Sharma *et al.*, 2013; Mourice *et al.*, 2014; Chisanga *et al.*, 2015) and wheat (Ritchie and Otter, 1985) and the SOYGRO soybean (Wilkerson *et al.*, 1983; Singh *et al.*, 2010) and PNUTGRO peanut (Boote *et al.*, 1986; Gilbert *et al.*, 2002) models, were already enjoying early successes. Those models required different file and data structures and had different modes of operation. The decision to make these models compatible led to the design of the DSSAT and the ultimate development of compatible models for additional crops, such as potato, rice, dry beans, sunflower, and sugarcane (Hoogenboom *et al.*, 1994; Jones *et al.*, 1998; Hoogenboom *et al.*, 1999). The DSSAT is a collection of independent programs that operate together; crop simulation models are at its center. In addition, programs contained in DSSAT allow users to simulate options for crop management over a number of years to assess the risks associated with each option. Earlier studies on the calibration and validation of DSSAT simulation models and their application in yield prediction and climate change studies have been conducted in India (Singh *et al.*, 2004; Hundal and Prabhjyot-Kaur, 2007; Patel *et al.*, 2008; Pathak and Wassmann, 2009). In the present study an attempt was made to illustrate the application of the CERES- and GRO-models as an agronomic and user friendly research tool to evaluate the various agronomic practices for optimum crop production.

Materials and Methods

The DSSAT models

The DSSAT is designed to enter, store, and manipulate weather, soil and crop data; run crop simulation models; and analyze crop model outputs (Hoogenboom *et al.*, 1999). There are a number of crop models in DSSAT software, and one of key aspect of DSSAT is that the crop models share identical input and output formats. The models are based on biophysical processes, using daily time steps for integration (Tsuji *et al.*, 1994). These models simulate the impact of the main environmental factors such as weather, soil type, and crop management on growth, development and yield of crops. Input requirements for DSSAT include weather and soil conditions, plant characteristics, and crop management.

The minimum weather input requirements of the model are daily solar radiation (MJ $m^{-2}d^{-1}$), maximum and minimum temperature (°C) and precipitation (mm). Soil inputs include albedo, evaporation limit, mineralization factor, pH, drainage and runoff coefficients. The model also requires water holding characteristics, saturated hydraulic conductivity, bulk density and organic carbon for each individual soil layer.

The genetic coefficients are the thermal time (°C–d) required by a crop to reach a particular growth stage, sensitivity to vernalization and photoperiod, maximum kernel filling rate, and kernel number per stem weight for cereal crops or maximum number of seeds per shell for legume crops. Required crop genetic inputs are PHINT (thermal time between the appearance of leaf tips), G3 (tiller death coefficient), G2 (potential kernel growth rate), G1(kernel number per unit weight of stem + spike at anthesis), P5 (thermal time from the onset of linear fill to maturity), P1D (Photoperiod sensitivity coefficient), P1V (vernalization sensitivity coefficient). Management input information includes plant population, planting depth, and date of planting. Latitude is required for calculating day length. The model simulates phenological development, biomass accumulation and partitioning, leaf area index, root-, stem-, and leaf-growth and the water- and N-balance from planting until harvest at daily time steps.

In the present study simulation models embedded in the DSSAT (Decision Support System for Agrotechnology Transfer) were employed. These were CERES-Wheat for wheat, CERES-Rice for rice, PNUTGRO for groundnut and SOYGRO for soybean crop. These models have been validated, calibrated and used for various applications under Punjab soil and climatic conditions (Hundal and Prabhjyot-Kaur, 1997; Hundal and Prabhjyot-Kaur, 1999; Prabhjyot-Kaur and Hundal, 1999; Singh *et al.*, 2004).

Site description

The soil, crop and weather data used in the study were collected at Punjab Agricultural University, Ludhiana (30°54′ N latitude; 75°48′ E longitude; elevation 247m above mean sea level). The area is characterized by subtropical, semiarid climate. Wheat-rice is the major cropping system and is grown under assured irrigation conditions in the state. Other important crops grown in the state are soybean, groundnut, maize, mustard, cotton etc.

Data description

Input data files of the models were as per IBSNAT standard input/output format and file structure (Hoogenboom *et al.*, 1999). The weather data for the study was collected from the meteorological observatory of the Punjab Agricultural University, Ludhiana. The crop management practices as recommended in the packages of practices of the Punjab Agricultural University based on field experiments were assumed in using the model in order to evaluate various range of agronomic practices. In this study, systematic simulations were done by changing one of the variables, while keeping the other variables constant.

Results and Discussion

Application of crop models as a research tool

CERES-Wheat model as a research tool

Wheat requires cool climate during its early growth stages for potential productivity. Any abrupt changes in weather parameters, especially an increase in maximum/minimum temperature from normal at any growth stage of crop adversely affects the growth and ultimately the potential yield of wheat. The simulation study was conducted using CERES-Wheat model to assess the effect of intra-seasonal increase in temperature above normal on yield of wheat sown on different dates (Prabhjyot-Kaur and Hundal, 2007). This study assumed that weather remained normal in rest of the crop growth period, and the crop remained free from water and nutrient stress and pest infestation. The simulation results revealed that in general, an increase in temperature from mid-February to mid-March adversely affected the yield of early, normal and late sown wheat. A further scrutiny revealed that early (October) sown crop was mostly affected by the temperature increase during 4th week of January, February and up to 1st fortnight of March; the timely (November) sown crop during February and March; the late (4th week of November) sown crop during March; and very late (December) sown crop during March and 1st week of April (Table 1).

CERES- and GRO- models in climate change study

With climate change crop productivity is affected by two main factors i.e. increased CO_2 and increased temperature. Of the two factors, CO_2 have synergistic and temperature has antagonistic relation with crop productivity. The crop productivity is increased with increased carbon dioxide and decreased with increased air temperature. The simulated interactive effects of increasing CO_2 concentration and increasing temperature on growth and yield of wheat, rice, soybean and groundnut crops are shown in Table 2.

The simulation revealed that increasing CO_2 levels were able to counteract the adverse effects of temperature increase on growth and yield of

Table 1. Rate of change (increase/decrease) from normal in the grain yield of wheat sown on different dates due to intra-seasonal temperature increase from normal using CERES-Wheat model

Time period of temperature increase	Date of sowing	Rate of change in grain yield (%/°C)
Fourth week of January	Early Sown (28th October)	-0.99
	Normal Sown (8th November)	-0.66
	Normal Sown (15th November)	-0.70
	Late Sown (25th November)	+0.98
	Late Sown (2nd December)	+0.48
First fortnight of February	Early Sown (28th October)	-2.88
	Normal Sown (8th November)	-1.87
	Normal Sown (15th November)	-
	Late Sown (25th November)	+1.19
	Late Sown (2nd December)	+0.76
Second fortnight of February	Early Sown (28th October)	-2.40
	Normal Sown (8th November)	-3.30
	Normal Sown (15th November)	-2.15
	Late Sown (25th November)	-1.26
	Late Sown (2nd December)	-0.69
First fortnight of March	Early Sown (28th October)	-2.40
	Normal Sown (8th November)	-2.10
	Normal Sown (15th November)	-2.98
	Late Sown (25th November)	-3.51
	Late Sown (2nd December)	-3.15
Second fortnight of March	Normal Sown (15th November)	-1.24
	Late Sown (25th November)	-2.15
	Late Sown (2nd December)	-3.40
First week of April	Late Sown (2nd December)	-0.38

Table 2. Effect of increasing temperature and CO_2 above normal on deviations (percent) in the maximum LAI, grain yield and biomass yield of crops using CERES- and GRO- models

Growth and yield attributes	Temperature change from normal +1 °C CO_2 concentration (ppm)				Temperature change from normal +2 °C CO_2 concentration (ppm)			
	330 (Normal)	400	500	600	330 (Normal)	400	500	600
Wheat (CERES-Wheat model)								
Maximum LAI	-18.3	-11.2	-2.3	+7.8	-29.1	-17.6	-4.5	+2.8
Grain yield	-9.9	-5.6	+2.1	+10.4	-18.0	-10.4	-1.4	+5.6
Biomass yield	-13.7	-10.7	-1.4	+8.6	-22.9	-12.5	-3.3	+3.9
Rice (CERES-Rice model)								
Maximum LAI	-9.3	-6.1	-4.0	+0.8	-12.3	-11.9	-7.8	-5.5
Grain yield	-6.6	-4.3	-2.8	+0.5	-7.5	-7.2	-4.4	-2.8
Biomass yield	-6.0	-4.0	-2.9	+0.8	-7.3	-7.1	-4.0	-2.6
Soybean (SOYGRO model)								
Maximum LAI	-0.3	+12.3	+23.3	+27.8	-3.0	+11.4	+19.6	+25.6
Seed yield	+2.4	+12.5	+25.9	+35.0	+2.4	+12.6	+25.9	+35.2
Biomass yield	-1.2	+11.6	+23.4	+31.6	-3.4	+11.4	+22.9	+28.6
Groundnut (PNUTGRO model)								
Maximum LAI	-3.4	+17.3	+34.5	+47.2	-5.8	+15.4	+28.3	+35.6
Seed yield	-4.5	+14.1	+29.0	+38.4	-10.6	+12.0	+25.7	+30.1
Biomass yield	-2.8	+14.9	+29.9	+40.6	-5.4	+12.1	+25.6	+31.4

crops to some extent. A temperature increase of 2.0°C from normal and doubled CO_2 concentration of 600 ppm in rice crop reduced the maximum LAI by 5.5%, biomass yield by 2.6% and grain yield by 2.8% from normal. However, a similar increase in temperature and CO_2 concentration increased the maximum LAI of wheat, soybean and groundnut by 2.8, 25.6 and 35.6% from normal; biomass yield of wheat, soybean and groundnut by 3.9, 28.6 and 31.4% from normal; and grain yield of wheat, soybean and groundnut by 5.6, 35.2 and 30.1% from normal, respectively.

Application of CERES- and GRO- models as agronomic tool

A well-validated and calibrated dynamic simulation model of the crop can be used as a tool for evaluating the agronomic management of the crops. The calibrated and validated simulation models namely CERES-Rice for rice, SOYGRO model for soybean crop and PNUTGRO model for groundnut crop were employed to conduct sample simulation studies to demonstrate the applicability of these simulation models as an agronomic and user friendly tool. The comparisons were made for simulated response of various agronomic management strategies such as dates of sowing, row to row spacing, plant to plant spacing, fertilizer application etc on the crop yield.

The results of simulation study using CERES-Rice model revealed that the maximum yield of direct seeded rice was simulated under mid May to mid June sowing treatments (Table 3). However, transplanted rice performs better when transplanted from mid June to July. Due to rapid decline in water table under Punjab conditions it is being strongly recommended that rice varieties should be transplanted after mid June when the monsoon season is about to begin in the state. The optimum age for transplanting rice crop was found to be 30 days after sowing. When row-row spacing of 15 cm and plant to plant spacing of 15 cm were tested, the model simulated a grain yield of 4766 kg ha^{-1} as compared to 4486 kg ha^{-1} with a row-row spacing of 30 cm and plant to plant

Table 3. Effect of cultural management practices on simulated yield of Rice (cv PR-111) using CERES-Rice model

S. No.	Cultural management options: Date of transplanting/ sowing	Planting method	Estimated grain yield (kg ha^{-1})
1.	20 May	Transplanted	4705
		Direct seeded	4890
2.	1 June	Transplanted	4678
		Direct seeded	5173
3.	10 June	Transplanted	4542
		Direct seeded	4819
4.	20 June	Transplanted	5674
		Direct seeded	4656
5.	1 July	Transplanted	5539
		Direct seeded	4602
6.	10 July	Transplanted	5530
		Direct seeded	4358
7.	Transplanting age, days :	30	4542
	(10 June transplanting)	35	4217
		40	3742
		45	3258
		50	2787
8.	Plant population (No. of plants /m^2)		
	(10 June transplanting)		
	(Row spacing × Plant spacing)		
	22.2 (30 cm × 15 cm)		4486
	26.6 (25 cm × 15 cm)		4563
	33.3 (20 cm × 15 cm)		4626
	44.4 (15 cm × 15 cm)		4766

spacing of 15 cm. The agronomic management options which led to the potential yield of rice crop in the simulation study were found to be in concurrence with those tested in the field conditions and included in the "Package of Practices for crops" of the agricultural university for the rice crop (Anonymous, 2015).

The simulations using SOYGRO model revealed that the maximum yield of soybean was obtained with 5th June as optimum date of sowing for and minimum yield was obtained with late sowing of 5th July (Table 4). When row spacing of 35 cm and plant to plant spacing of 3.5 cm were tested, the model for optimum date of sowing of 5th June simulated seed yield of 2049 kg/ha. Again when row spacing of 45 cm and plant spacing of 4.5 cm were used the model simulated seed yield for the same 5th June date of sowing to be 1985 kg ha^{-1}. The simulated results showed that the optimum date of sowing for soybean was 5th June. However, earlier sowing (20th May) and late sowing (20th June) of soybean may perform better if the plant-to-plant distance is decreased from 5.5 to 3.5cm. Also a decrease in plant to plant distance from 7.5 to 3.5 cm and a decrease in row spacing from 60 to 35 cm, revealed an increasing trend in soybean yields as simulated by the model. Similar agronomic management options for soybean crop have been suggested in the "Package of Practices for crops" of the agricultural university (Anonymous, 2015) for obtaining potential soybean yield under Punjab conditions.

The simulations using PNUTGRO model indicate that the optimum time for sowing of groundnut is in the month of May and upto mid June (Table 5). The pod and seed yield decreased when the sowing of groundnut was done in the month of July. In Punjab the normal onset of monsoons is in the last week of June to first week of July. The sowing of groundnut crop under rainfed conditions can be accomplished from last week of June upto mid July. Further delaying of sowing of groundnut crop decreases the yield of the crop. When the groundnut crop is sown in first fortnight of May, row to row spacing of 30 cm with plant to plant spacing of 22.5 cm or 30 cm gave comparable pod and seed yield. If the sowing of groundnut crop is done in June and July then the optimum row to row spacing is 30 cm and plant to plant spacing is 22.5 cm giving a plant population of 14.80 plants per m^2 gave zero potential yield. The influence of variable seeding depth was also simulated for the 20 June sown groundnut crop. The optimum seeding depth of 5 cm gave the potential yield of groundnut crop. The effect of application of nitrogen fertilizer at different times during the growth period of groundnut crop was simulated for 20 June sown crop. The simulations revealed that a split dose of nitrogen fertilizer, i.e., one half at the time of sowing and remaining one half about 60 days after

Table 4. Effect of cultural management practices on seed yield (kg ha^{-1}) of soybean (cv PK-416) using SOYGRO model

Date of sowing / Plant to plant spacing (cm)	Row spacing (cm)					
	30	40	45	50	55	60
			20th May			
3.5	1924	1921	1916	1911	1906	1902
4.5	1918	1912	1906	1901	1886	1891
5.5	1911	1904	1898	1892	1881	1871
6.5	1906	1898	1891	1873	1868	1857
7.5	1901	1892	1874	1865	1855	1845
			5th June			
3.5	2049	2020	2014	2000	1986	1973
4.5	2027	1993	1985	1968	1951	1933
5.5	1990	1968	1959	1938	1911	1899
6.5	1972	1943	1934	1912	1889	1866
7.5	1952	1927	1914	1888	1861	1834
			20th June			
3.5	1932	1903	1874	1846	1819	1719
4.5	1888	1851	1816	1781	1747	1715
5.5	1848	1804	1762	1723	1686	1651
6.5	1811	1762	1716	1673	1633	1594
7.5	1778	1725	1675	1629	1585	1545
			5th July			
3.5	1580	1533	1487	1447	1408	1372
4.5	1507	1453	1403	1403	1318	1280
5.5	1445	1387	1335	1335	1245	1206
6.5	1384	1332	1278	1278	1186	1146
7.5	1351	1286	1230	1180	1180	1095

sowing was optimum for obtaining the potential yield of groundnut crop. The agronomic management options which led to the potential yield of groundnut crop in the simulation study were found to be in concurrence with those tested in the field conditions and included in the "Package of Practices for crops" of the agricultural university for the groundnut crop (Anonymous, 2015)

A well calibrated and validated dynamic simulation model can be used to study the uncertainty in crop production due to the weather variability, as a research tool and as an agronomic tool to evaluate cultural management practices. The CERES-Wheat model for wheat, CERES-Rice model for rice, SOYGRO model for soybean crop and PNUTGRO model for groundnut crop were employed to conduct sample simulation studies to demonstrate the applicability of these simulation models in Indian Punjab. The results revealed that CERES- and GRO- models simulated the growth and yield of crops in a realistic manner under different scenarios of intra-seasonal as well as whole season changes in weather parameters. These models can also be employed for comparisons of the simulated response of various agronomic management strategies such as dates of sowing, row to row spacing, plant to plant spacing, fertilizer application etc on the crop yield. The optimum strategies of agronomic crop management simulated by the models have been found to agree with the strategies recommended by the agricultural university after conduct of multi year

Table 5. Effect of cultural management practices on simulated yield of Groundnut (cv M-522) using PNUTGRO model

S. No.	Cultural management scenarios		Estimated pod yield (kg ha^{-1})	Estimated seed yield (kg ha^{-1})
	Date of sowing	Plant population (No. of plants m^{-2}) and Row × Plant spacing (cm)		
1.	1 May	14.80 (30 × 22.5)*	2795	2195
		11.11 (30 × 30)	2796	2196
		9.87 (45 × 22.5)	2804	2202
		7.41 (45 × 30)	2800	2199
2.	10 May	14.80 (30 × 22.5)	2707	2125
		11.11 (30 × 30)	2690	2113
		9.87 (45 × 22.5)	2683	2108
		7.41 (45 × 30)	2636	2071
3.	20 May	14.80 (30 × 22.5)	2731	2144
		11.11 (30 × 30)	2650	2080
		9.87 (45 × 22.5)	2640	2072
		7.41 (45 × 30)	2562	2011
4.	1 June	14.80 (30 × 22.5)	2738	2128
		11.11 (30 × 30)	2495	2026
		9.87 (45 × 22.5)	2649	2056
		7.41 (45 × 30)	2728	2064
5.	10 June	14.80 (30 × 22.5)	2758	2064
		11.11 (30 × 30)	2714	2025
		9.87 (45 × 22.5)	2674	1993
		7.41 (45 × 30)	2573	1911
6.	20 June	14.80 (30 × 22.5)	2495	1826
		11.11 (30 × 30)	2424	1770
		9.87 (45 × 22.5)	2374	1729
		7.41 (45 × 30)	2224	1610
7.	1 July	14.80 (30 × 22.5)	2124	1514
		11.11 (30 × 30)	1993	1409
		9.87 (45 × 22.5)	1939	1366
		7.41 (45 × 30)	1812	1264
8.	10 July	14.80 (30 × 22.5)	1746	1202
		11.11 (30 × 30)	1639	1115
		9.87 (45 × 22.5)	1584	1072
		7.41 (45 × 30)	1461	975
9.	20 July	14.80 (30 × 22.5)	1250	809
		11.11 (30 × 30)	1139	725
		9.87 (45 × 22.5)	1091	688
		7.41 (45 × 30)	972	600
10.	Seeding depth (cm) :	5.0	2495	1826
	(20 June sown crop)	10.0	2400	1745
		15.0	2292	1653
11.	Dose of N fertilizer (Urea)	17 kg ha^{-1} at sowing & 17 kg ha^{-1} at 30 DAS	2460	1802
	in kg ha^{-1}	17 kg ha^{-1} at sowing & 17 kg ha^{-1} at 45 DAS	2518	1845
	(20 June sown crop)	17 kg ha^{-1} at sowing& 17 kg ha^{-1} at 60 DAS	2557	1871

*Row – Row × Plant – Plant spacing

field experiments (Anonymous, 2013). Hence, they can be used as an important tool to find answer's to "**What if?**" scenarios in crop management.

Acknowledgements

The study was funded by Indian Council of Agricultural Research (ICAR) under research project entitled, "All India Co-ordinated Research Project on Agrometeorology" in the School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana.

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Received: January 5, 2018 ; Accepted: March 29, 2018