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Mustard model as an agronomic management tool for oilseed Brassica cultivation in Irrigated plains of Punjab state

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Abstract

A dynamic simulation model, "MUSTARD" was calibrated and validated under field conditions to be used as an agronomic tool to study uncertainties in crop production due to weather variability. Sensitivity analysis for MUSTARD model was done for cultivar specific five phenological and eight growth coefficients. The model was calibrated for oilseed *Brassica* species (*B. juncea* cv.RL-1359, *B. napus* cv. PGSH-51 and cv. PAC-401) with field observations from 1st date of sowing treatments and then validated for the remaining treatments. The model simulated the phenological events, i.e., flowering date, first pod date, first seed date and physiological maturity date for oilseed *Brassica* species in close agreement with field observations under different environments. The model simulated the growth (maximum leaf area index) and yield attributes (seed and biomass yield) for three oilseed *Brassica* cultivars in closed agreement with the field observations. The MUSTARD model was employed to simulate the influence of date of sowing on yield. The results revealed that if mustard crop is planted in the October month after the harvesting of rice crop, the optimum time for sowing falls in the second fortnight of October. However, if the crop is sown after early potato or cotton crop, the optimum sowing period is in the first fortnight of November. Further the simulation results revealed that the potential yield of mustard crop can be attained with a row to row spacing of 30 to 35 cm with a plant population stand of 33.3 plants / m^2. In view of such sample simulation studies, the overall benefit of the dynamic simulation model reveals that MUSTARD model can be used as an agronomic management tool in Punjab state**.**

Key words: *Agronomic tool, Calibration, MUSTARD model, Simulation, Validation*

Introduction

Plant and soil systems are very complex, with numerous factors influencing the results. However, advances in computer technology have made possible to understand effects of various factors of soil, plant and climate and their interactions quantitatively and predict crop yield more precisely. Thus, with the availability of inexpensive and powerful computers and with the growing popularity of the application of integrated systems to agricultural practices, a new era of agricultural research and development is emerging (James and Cutforth, 1996). Information needs for agricultural decision making at all levels are increasing rapidly due to increased demands for agricultural products and increased pressures on land, water, and other natural resources. The generation of new data through traditional agronomic research methods and its publication are not sufficient to meet these increasing needs. Traditional agronomic experiments are conducted at particular points in time and space, making results site and season-specific, time consuming and expensive (Jones *et al*, 2003). At this stage crop simulation models can be used as a tool to evaluate crop management options, to quantify the gaps between actual and potential yields and to determine the likely environmental impacts on crop growth and yield (Pathak and Wassmann, 2009). The models can be used to forecast yields prior to harvest and extrapolate the results from one season or location to other seasons, locations or management (Anapalli *et al*, 2005). A specific strength of these crop models is their ability to quantify variability of crop performance due to variability in seasonal weather conditions and to predict the long-term impacts of climate change and land use options (Timsina and Humphreys, 2006, Liu *et al*, 2010).

Oilseed *Brassica* (OSB) species, i.e., *B. juncea, B. napus* and *B. carinata* are commonly cultivated oilseed crops in Punjab. While modeling the growth and yield for oilseed Brassica crops, one has to consider its indeterminate flowering habit, branching pattern, generation of pod wall, lag between development of pod wall and seed growth and extent of canopy developed by crops. One of the earliest attempts to model growth and yield of oilseed brassica in Punjab state was made by Nigam (2004). He calibrated and validated BRASSICA model developed by Rao (1992) for the commonly sown cultivars namely PBR-91, Bio-902 and Pusa Bold under different dates of sowing treatments at Ludhiana. Then an attempt was made to adapt a dynamic simulation model namely, "MUSTARD" from CROPGRO models "SOYGRO" for soybean and "PNUTGRO" for groundnut at Ludhiana (Prabhjyot-Kaur, 2004).

The dynamic crop simulation models are based on crop phenology (development, growth, senescence, photosynthesis, and respiration), infiltration, drainage and evaporation on a daily basis and their dynamic interaction with weather inputs. Further, these models show considerable potential to evaluate crops, crop varieties, cropping practices and genetic potential patterns for yield. In the present study an attempt was made to calibrate and validate the MUSTARD model for commonly sown cultivars of OSB crops and then illustrate the application of the model as a tool to evaluate various agronomic practices for optimum crop production in the state of Punjab, India.

Materials and Methods

Site description

The soil, crop and weather data used in the study

Table 1: Monthly meteorological parameters during the oilseed *Brassica* crop seasons

Meteorological Parameters	November	December	January	February	March	April
Crop season 2003-04						
Maximum temperature (°C)	25.8	19.5	17.3	22.9	30.9	37.0
Minimum temperature (°C)	10.5	8.8	7.8	8.7	13.9	20.4
Sunshine Hours (Hour)	7.8	4.7	4.2	9.2	10.2	8.5
Rainfall (mm)	4.4	8.4	67.8	0.0	0.0	28.8
Maximum Relative Humidity (%)	91	96	98	95	88	55
Minimum Relative Humidity (%)	35	65	76	51	36	24
Crop season 2004-05						
Maximum temperature (°C)	26.7	20.6	17.4	18.7	25.8	34.6
Minimum temperature (°C)	11.8	8.3	6.0	8.5	13.6	16.6
Sunshine Hours (Hour)	7.2	5.5	6.3	6.0	8.1	9.6
Rainfall (mm)	1.5	5.7	48.3	47.4	42.2	6.1
Maximum Relative Humidity (%)	92	97	97	92	90	67
Minimum Relative Humidity (%)	45	55	60	65	54.2	24
Crop season 2005-06						
Maximum temperature (°C)	27.0	20.8	19.2	26.1	27.0	36.0
Minimum temperature (°C)	10.1	4.4	5.9	11.3	13.1	18.2
Sunshine Hours (Hour)	8.1	6.2	6.8	7.4	8.8	9.8
Rainfall (mm)	0.0	0.0	16.8	0.8	32.5	5.1
Maximum Relative Humidity (%)	91	98	93	96	90	56
Minimum Relative Humidity (%)	33	41	48	49	44	17

were collected from research farm of Punjab Agricultural University at Ludhiana (30^0 54¢ N, 75^0 48¢ E, 247 m above mean sea level) (Table 1). This area is representative of the central irrigated plains of the Indian Punjab and is characterized by sub-tropical, semi-arid climate. The average maximum temperature, minimum temperature and rainfall during *Rabi* season are 24.5^{o}C, 9.7^{o}C and 127 mm, respectively at Ludhiana (Prabhjyot-Kaur and Hundal, 2008a, b).

Data description

Field experiments were conducted during three consecutive *rabi* seasons (2003-04, 2004-05 and 2005-06) with three OSB cultivars RL 1359 (*B. juncea*), PGSH-51 and PAC-401 (*B. napus*) sown under two dates (1st week of November and 1st week of December) and three irrigation regimes (I_1: Pre-sowing irrigation + irrigation at flowering, I_2: Pre-sowing irrigation + 30 DAS + at flowering, and I_3: Same as I_2 + at pod development) with row to row spacing of 30 cm and plant to plant spacing of 10 cm. The crop was sown after a common pre-sowing irrigation. Recommended fertilizers were applied to the crop, i.e., nitrogen @ 100 Kg/ha (½ at sowing and ½ at time of 1st irrigation) and phosphorous @30 Kg/ha (Anonymous, 2009).

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 and the recommended packages of practices for OSB of Punjab Agricultural University was used as standard in the model to evaluate various agronomic practices. In this study, systematic simulations were done by changing one of the variables and keeping the others constant.

MUSTARD model

The dynamic simulation model "MUSTARD" was adapted from "CROPGRO" models (SOYGRO for soybean and PNUTGRO for groundnut) whose several subroutines were used in the present model with suitable modifications to fit the physiology of *Brassica* species. The "MUSTARD" model was synthesized by adapting input and output data subroutines similar to those available in DSSAT (Decision Support System for Agrotechnology Transfer) Version 3.5 (Prabhjyot-Kaur, 2004).

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. Crop management input information includes date of sowing, row to row spacing, plant population and planting depth. Latitude is required for calculating day length.

Sensitivity analysis of MUSTARD model

The sensitivity analysis was performed for 5 coefficients (EM-FL, FL-SH, FL-SD, SD-PM and FL-LF) controlling the phenological development and 8 coefficients (LFMAX, SLAVAR, SIZLF, XFRT, WTPSD, SFDUR, SDPDV and PODUR) regulating growth and yield attributes of mustard crop by changing (increasing / decreasing) their value to determine their effect on pod and seed yield.

The pod and seed yield of the *Brassica* crop was found sensitive to the 5 phenological coefficients. When the value of EM-FL, SD-PM and FL-LF was increased, it resulted in increase in pod and seed yield and vice versa. Hence when the flowering and physiological maturity of the crop or time between first flower and end of leaf expansion was delayed, it led to an increase in pod and seed yield of the crop. However, with any change in FL-SH and FL-SD, the pod and seed yield decreased (Table 2).

The pod and seed yield of the *Brassica* crop was found sensitive to all growth coefficients except SIZLF, i.e., coefficient controlling maximum size of full leaf. When the value of coefficients controlling specific leaf area (SLAVAR) and maximum leaf photosynthesis rate (LFMAX) were changed both pod and seed yield were affected. XFRT, coefficient which controls the daily photosynthate partitioned to seed and shell, value was increased it

Table 2: Sensitivity test results for genetic coefficients of MUSTARD model

Genetic coefficients	Range	Simulated yield (Kg/ha)	
		Pod yield	Seed yield
Phenological coefficients			
EM-FL : Time between plant emergence and flower appearance (photothermal days)	32 37* 44	1026 2390 2579	627 1345 1462
FL-SH : Time between first flower and first pod (Photothermal days)	1 2* 3	1567 2390 1810	953 1345 1101
FL-SD : Time between first flower and first seed (photothermal days)	4 9* 14	1082 2390 1857	664 1345 1120
SD-PM : Time between first seed and physiological maturity (photothermal days)	60 65* 70	2197 2390 2591	1235 1345 1465
FL-LF : Time between first flower and end of leaf expansion (phothermal days)	45 50* 55	2372 2390 2427	1337 1345 1362
Growth coefficient			
LFMAX : Maximum leaf photo-synthesis rate at 30 °C, 350 ppm CO_2, and high light (mg CO_2/m^2-s)	0.950 1.050* 2.050	1507 2390 2501	919 1345 1419
SLAVR : Specific leaf area of cultivar under standard growth conditions (cm^2/g)	300 340* 380	1645 2390 2289	1004 1345 1279
SIZLF : Maximum size of full leaf (cm^2)	180 200* 220	2390 2390 2390	1345 1345 1345
XFRT : Maximum fraction of daily growth that is partitioned to seed + shell	0.60 0.70* 0.80	1448 2390 2536	882 1345 1431
WTPSD : Maximum weight per seed (g)	0.003 0.004* 0.005	1800 2390 2283	1099 1345 1284
SFDUR : Seed filling duration for pod cohort at standard growth conditions (Photothermal days)	20 25* 30	2184 2390 1665	1264 1345 1006
SDPDV : Average seed per pod under standard growth conditions (#/pod)	8.0 9.0* 10.0	2491 2390 2371	1403 1345 1334
PODUR : Time required for cultivar to reach final pod load under optimal conditions (photothermal days)	18 20* 22	2557 2390 1499	1437 1345 913

* *Original coefficient values*

increased pod and seed yield and vice versa. Similarly, when the coefficient controlling average seed per pod, i.e., SDPDV, value was decreased, it increased pod and seed yield and vice versa.

Calibration of MUSTARD model

The MUSTARD model was calibrated for *B. juncea* cv RL-1359, *B. napus* cv PGSH-51 and *B. napus* cv Hyola for one of the crop season actual field data. At first the model simulated and field observed value of flowering date, first pod date, first seed date, physiological maturity date, maximum LAI, pod yield, seed yield, seed weight, biomass yield and stalk yield were tabulated and the differences between the two values were compared. Then the value of each phenological and growth coefficient which minimized the differences between the observed and simulated values or all those parameters were selected for using in the model separately for three varieties. The calibrated values of phenological and growth coefficients used in the MUSTARD model for *B. juncea* cv RL-1359 are : EM-FL -37.0, FL-SH –2.0, FL-SD –9.0, SD-PM –65.0, FL-LF –50.0, LFMAX–1.050, SLAVAR-340, SIZLF-200.0, XFRT-0.70, WTPSD-0.004, SFDUR-25.0, SDPDV-9.00 and PODUR-20.0, *B. napus* cv PGSH-51 are: EM-FL -62.0, FL-SH –9.0, FL-SD –15.0, SD-PM – 50.0, FL-LF –50.0, LFMAX–1.050, SLAVAR-310, SIZLF-200.0, XFRT-0.70, WTPSD-0.004, SFDUR-35.0, SDPDV-9.00 and PODUR-20.0 and *B. napus* cv Hyola PAC-401 are : EM-FL -55.0, FL-SH –9.0, FL-SD –18.0, SD-PM – 57.0, FL-LF –50.0, LFMAX–1.050, SLAVAR-320, SIZLF-200.0, XFRT-0.70, WTPSD-0.004, SFDUR-25.0, SDPDV-9.00 and PODUR-20.0.

Results and Discussion

Validation of the MUSTARD model

The MUSTARD model was validated by comparing the model simulated and actual observations *w.r.t.* to phenology, growth and yield of oilseed *Brassica* cultivars, *viz*., RL-1359, PGFH-51 and Hyolla PAC-401 for different environments.

Crop phenology

The phenological events, *i.e*., flowering date, first pod date, first seed date and physiological maturity date simulated by MUSTARD model and those actually observed in the field for *Brassica* species under different environments are given in figure 1, 2, 3 and 4, respectively. The model gave overestimation as well as underestimation of these

Fig 1 - Comparison of observed and simulated flowering date (days after sowing) of brassica species under different environments (Rabi 2003-04 to Rabi 2005-06)

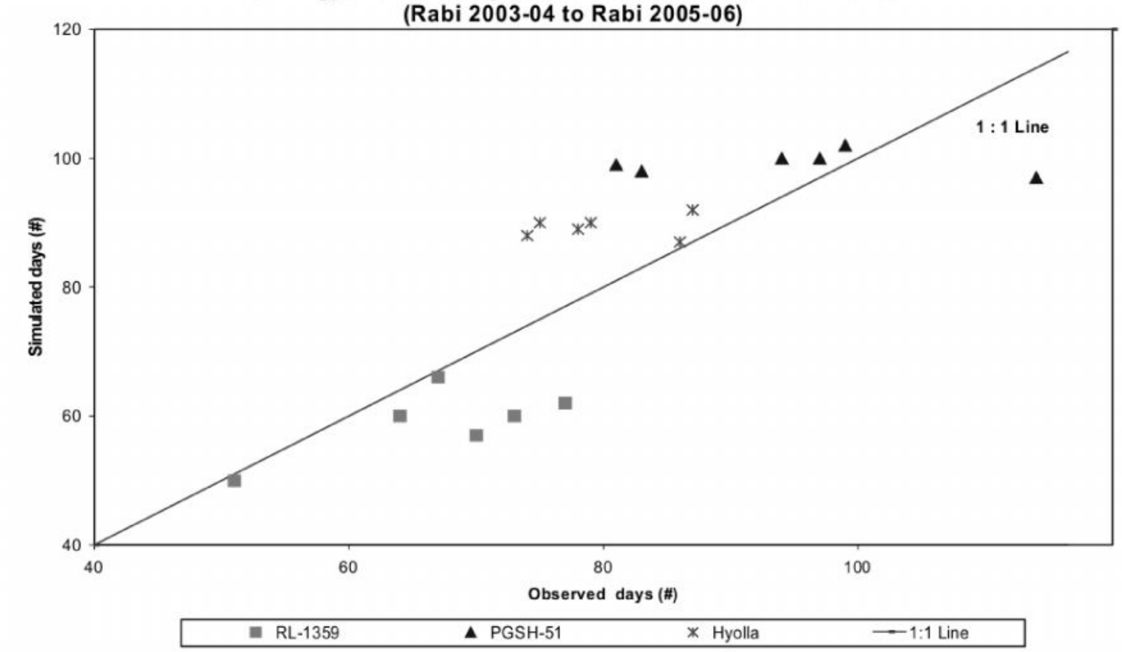


Fig 2 - Comparison of observed and simulated First pod date (days after sowing) of brassica species under different environments (Rabi 2003-04 to Rabi 2005-06)

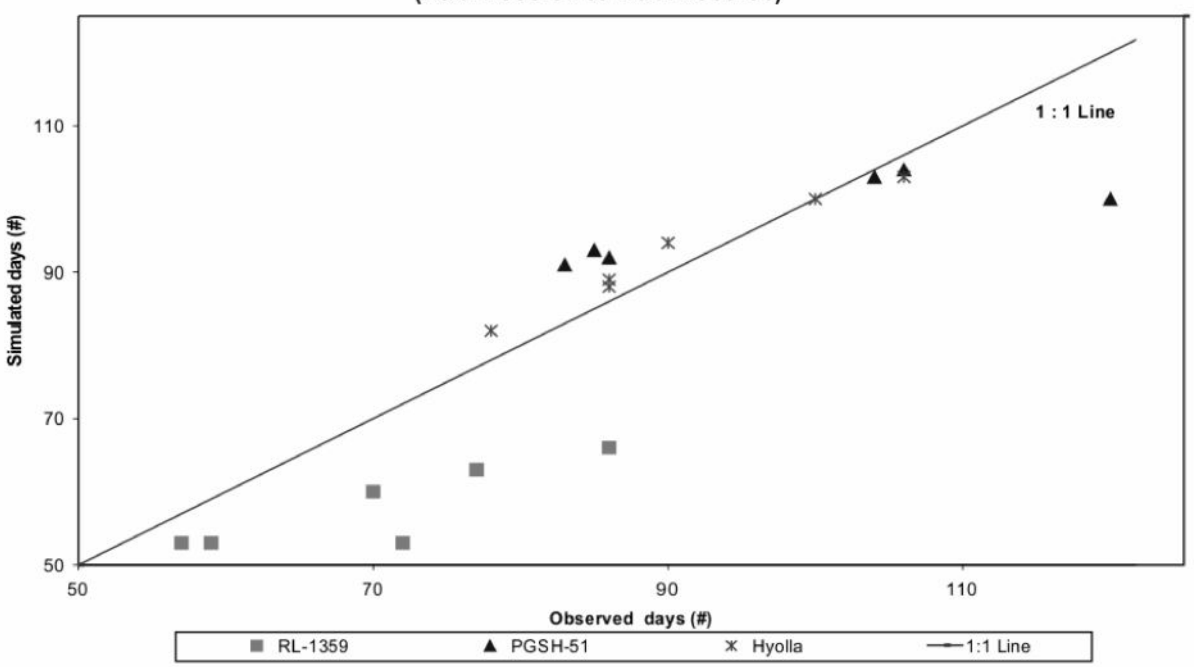
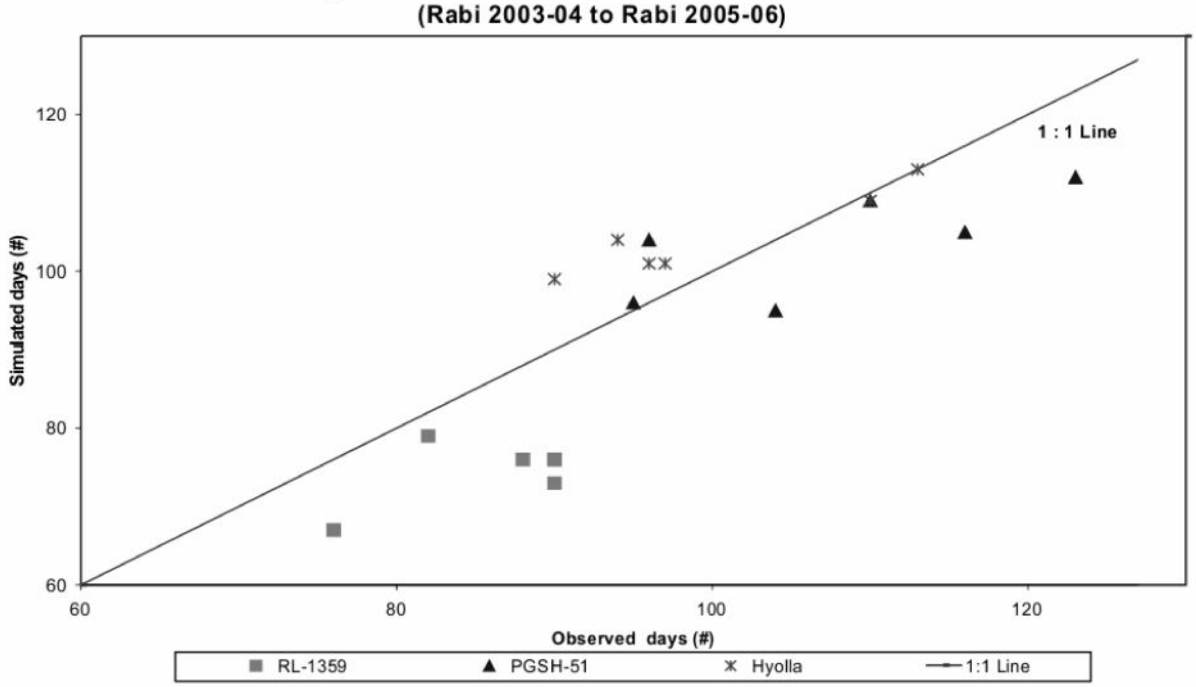


Fig 3 - Comparison of observed and simulated First seed date (days after sowing) of brassica species under different environments (Rabi 2003-04 to Rabi 2005-06)



events. The flowering date, first pod and first seed date was generally underestimated for cultivar RL-1359 and overestimated for cultivar Hyola PAC-401. On the other hand, it was both underestimated as well as overestimated for cultivar PGSH-51. The physiological maturity date was generally overestimated by the MUSTARD model.

Fig 4 - Comparison of observed and simulated physiological maturity date (days after sowing) of brassica species under different environments (Rabi 2003-04 to Rabi 2005-06)

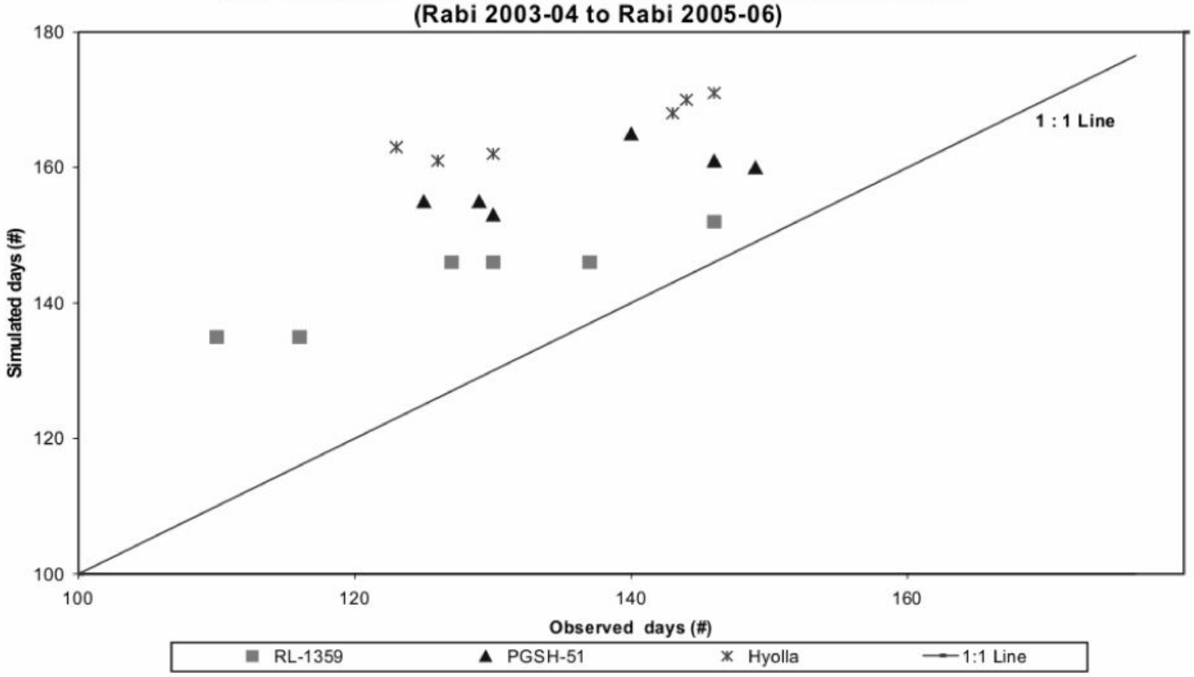
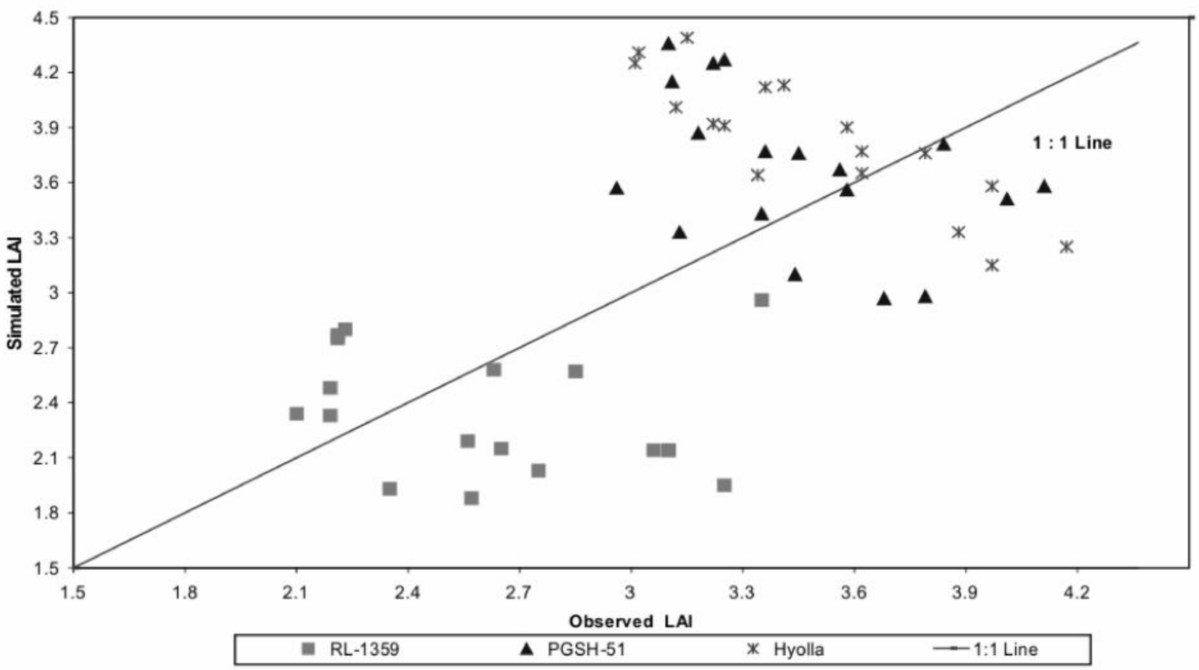
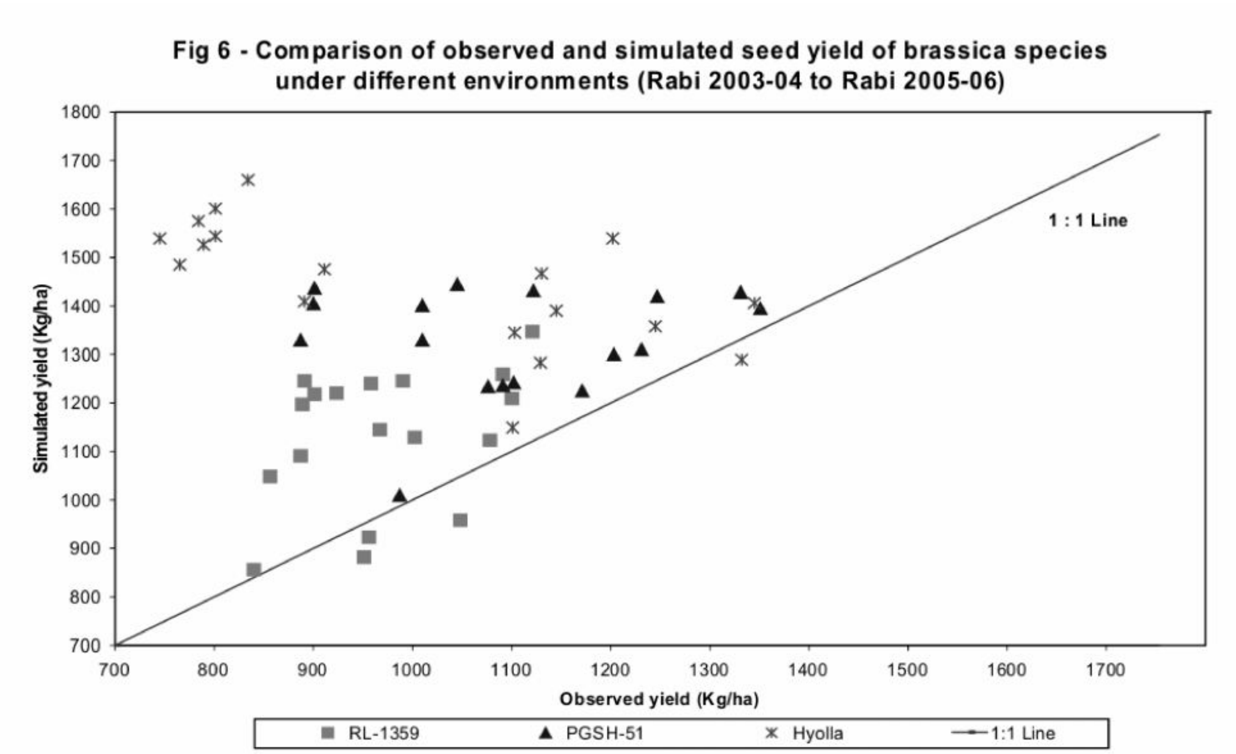


Fig 5 - Comparison of observed and simulated maximum Leaf area index (LAI) of brassica species under different environments (Rabi 2003-04 to Rabi 2005-06)





Crop growth and yield

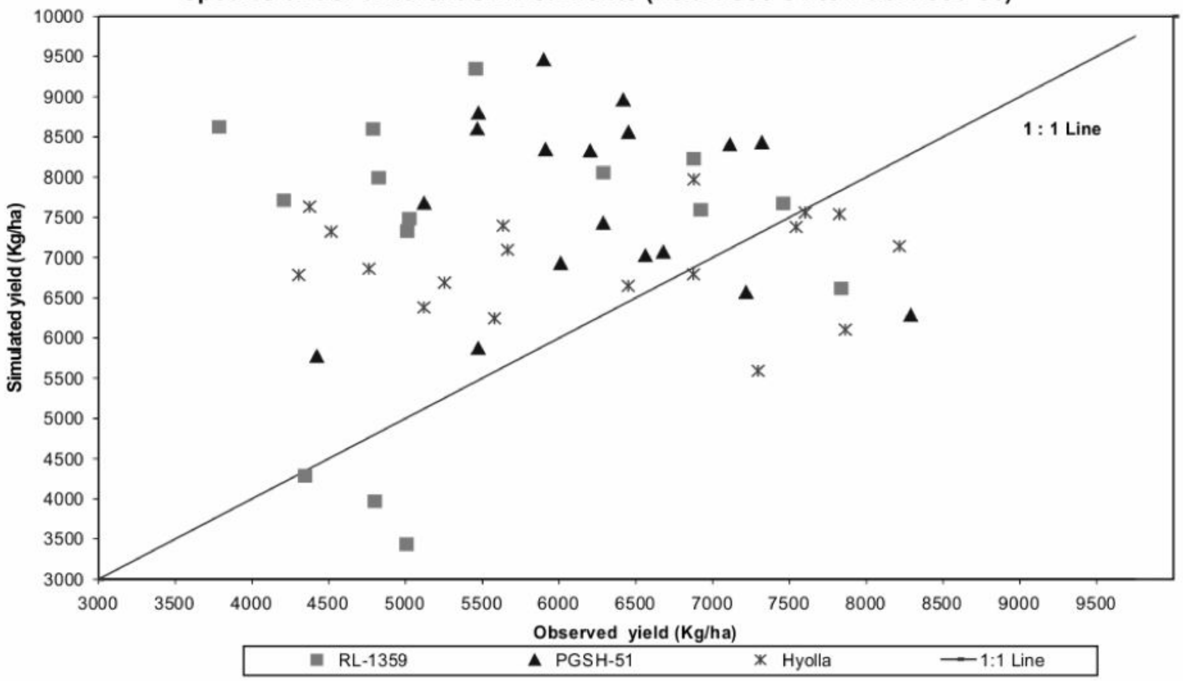
The MUSTARD model simulated crop growth and yield attributes such as maximum LAI, seed yield pod yield and biomass yield for three *Brassica* species in close agreement with field observations under different environments. The comparison of model simulated and actual maximum LAI, seed and biomass yield for *Brassica* cultivars under different environments are shown in figure 5, 6 and 7, respectively.

Out of 18 environments, the maximum LAI was underestimated in 12 environments and overestimated in 6 environments for RL-1359; underestimated in 7 environments and overestimated in 11 environments for PGSH-51; and underestimated in 5 environments and overestimated in 13 environments for Hyola PAC-401. In case of RL-1359, out of 12 underestimated environments the maximum LAI were underestimated upto 10 % in 2 and above 10 % in 10 environments; and out of 6 overestimated environments the maximum LAI were overestimated upto 10% in 2 and above 10% in 4 environments. In case of PGSH-51, out of 7 underestimated environments the maximum LAI were underestimated upto 10% in 3 and above 10% in 4 environments; and out of 11 overestimated environments the maximum LAI were overestimated upto 10% in 4 and above 10% in 7 environments. In case of Hyola-PAC401, out of 5 environments the maximum LAI were underestimated upto 10% in 2 and above 10% in 3 environments. Similarly, out of 13 environments the maximum LAI were overestimated upto 10% in 4 and above 10% in 9 environments (figure 5).

Out of 18 environments the seed yield was under-estimated in three environments and overestimated in 15 environments for RL-1359; underestimated in one environment and overestimated in 17 environments for PGSH-51 and Hyola PAC-401. In case of RL-1359, out of 15 overestimated environments the seed yield were overestimated upto 15% in 5 environments. In case of PGSH-51 and Hyola PAC-401, out of 17 overestimated environments the seed yield were overestimated upto 20% in 10 and 6 environments, respectively (figure 6). The biomass yield out of 18 environments was underestimated in 7 environments and overestimated in 11 environments for RL-1359 and

Hyola PAC-401; underestimated in 2 environments and overestimated in 16 environments for cv PGSH-51. In case of RL-1359 and Hyola PAC-401, out of 11 overestimated environments the biomass yield were overestimated upto 20% in 3 environments. In case of PGSH-51, out of 16 overestimated environments the biomass yield were overestimated upto 20% in 7 environments (figure 7).

Fig 7 - Comparison of observed and simulated biomass yield of brassica species under different environments (Rabi 2003-04 to Rabi 2005-06)



Application of MUSTARD model as an agronomic management tool

The MUSTARD model can be used to simulate the effect of different agronomic management practices on growth and yield of *Brassica* crop. The results of some sample case studies using the genetic coefficients of *B. juncea* cv RL-1359 are presented in Table 3.

In cool season crops like mustard time of sowing is a very important parameter. The simulation study was conducted to evaluate the influence of date of sowing of mustard crop from start October to end November. The simulation results indicate that if mustard crop is planted in the October month after the harvesting of rice crop, the optimum time for sowing falls in the second fortnight of October (table 3). However, if the crop is sown after early potato or cotton crop, the optimum sowing period is in the first fortnight of November. Very late sowing of mustard crop, *i.e.*, after second fortnight of November to mid December progressively decreases the pod and seed yield of the crop.

Crop geometry, i.e., row to row and plant to plant spacing is a very important variable which influences the growth of crop. When the row spacing was increased from 30 cm to 35 cm it increased pod and seed yield of the crop. However further increase in row to row spacing decreased the pod and seed yield of mustard crop. The simulation results revealed that the potential yield of mustard crop can be attained with a row to row spacing of 30 to 35 cm (table 3). Also 33.3 plants / m^2 were the most appropriate plant population stand for the mustard crop.

Mustard is a *Rabi* season crop and during its sowing time the soil temperature is quite low. So the influence of variable seeding depth was also simulated for November sown mustard crop. The

Table 3: Effect of agronomic management practices on simulated yield of *Brassica juncea* cv RL-1359 using MUSTARD model

Cultural management	Estimated yield (Kg/ha)	
	Pod yield	Seed yield
Date of sowing		
8 October	2390	1345
23 October	3162	1926
8 November	2365	1420
23 November	1516	879
Row-row spacing (cm)		
20	2413	1361
25	2403	1351
30	2390	1345
35	2409	1358
40	1555	948
45	1558	950
Plant population (No. of plants /m^2)		
22.2	1701	1036
33.3	2390	1345
44.4	2285	1285
Seeding depth (cm)		
2.5	2224	1251
5.0	2390	1345
7.5	1728	1052

simulation results revealed that when the seeding depth was increased from 5 cm to 10 cm pod and seed yield were decreased by nearly 17 and 10 %, respectively. Hence the optimum seeding depth of 5.0 cm yields the potential pod and seed yield of mustard crop (table 3). The agronomic management options which led to the potential yield of oilseed *Brassica* 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 *Brassica* crop (Anonymous, 2009).

Crop growth models contain quantitative information about major processes involved in the growth and development of a plant by integrating the current knowledge of plant growth and development from various disciplines, such as crop physiology, agrometeorology, soil science and agronomy. A dynamic crop model simulates or imitates the behaviour of a real crop by predicting the phenological development, growth of its components and the final state of total biomass or harvestable yield. After proper validation, the models may be in Decision Support System (DSS) to predict the effects of changes in environment and management on crop yield (James and Cuthforth, 1996, Jones *et al*, 2003).

The MUSTARD model for oilseed *Brassica* crop was calibrated for commonly sown cultivars in the Indian Punjab state and then validated using the actual field data for the phenology, growth and yield of oilseed *Brassica* cultivars. The model was then employed to simulate the influence of different cultural management practices on yield of crop. The simulation results indicate that if mustard crop is planted in the October month after the harvesting of rice crop, the optimum time for sowing falls in the second fortnight of October. However, if the crop is sown after early potato or cotton crop, the optimum sowing period is in the first fortnight of November. Very late sowing of mustard crop, i.e., after second fortnight of November to mid

December progressively decreases the pod and seed yield of the crop. Further the simulation results revealed that the potential yield of mustard crop can be attained with a row to row spacing of 30 to 35 cm with a plant population stand of 33.3 plants / m^2. The optimum strategies of agronomic crop management simulated by the model have been found to agree with the strategies recommended by the agricultural university after conduct of multi year field experiments (Anonymous, 2009). Earlier studies by various workers have been done to demonstrate the applicability of dynamic crop growth models as a research and crop management tool under present agricultural scenario as well as anticipated climate change scenarios (Hundal and Prabhjyot-Kaur, 1999, 2007, Singh *et al*, 2004, Timsina and Humpreys, 2006). The result of the present study also indicate that after proper calibration and validation under wide range of growing environments the MUSTARD model can be used as an agronomic tool to find answer's to "**What if ?"** scenarios in oilseed *Brassica* crop management in Indian Punjab.

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