*Journal of Agrometeorology 6 (2) : 205 - 214 (Dec 2004)*

# Sensitivity analysis of CERES -Sorghum model for forage sorghum

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## ABSTRACT

Absolute and relative sensitivity analysis was performed with CERES-Sorghum model. Model sensitivity was compared with measured field data for Jhansi (U.P.) area in north India. Absolute analysis revealed that grain yield and dry biomass at anthesis were highly affected by change in planting date and maturity class. Caryopsis weight was insensitive to change in plant population in all planting dates. Relative sensitivity analysis showed in a wet season that total dry biomass decreased by 63 % at 2x $10^4$ plant $ha^{-1}$ from normal population, in contrast with observed total dry biomass which decreased by only 33 % during 1993 (a similar wet year). Overall, the sensitivity analysis showed poor yield prediction at low plant population under local conditions. To use CERES-Sorghum model to predict yield at lower plant population, modifications are needed to the relationship prescribed among yield components and the source sink relationship that determines caryopsis weight during water surplus and stress conditions.

***Key words:*** CERES-Sorghum absolute sensitivity, relative sensitivity, forage sorghum, yield and yield components

Sorghum is an important crop of the subtropics and tropics and widely used as food/feed and fodder. It is adopted to dry environments, particularly when rainfall and its distribution, do not allow consistent production of any other crop and is cultivated in India on 12.6 million hectare with a production of 11.0 m tonnes and productivity of 873 kg $ha^{-1}$ (Rana *et al.*, 1998).

Sorghum producers must decide whether to replant after reduction in plant population due to pest damage, adverse weather or other factors. Now a days, crop growth simulation models have proven to be useful tools for improving management practices and facilitating the transfer of agro technologies. To quantify and evaluate the management practices and generate replanting guidelines, a model must demonstrate accurate yield prediction over a wide range of planting dates, plant population, and hybrid maturity class and weather factors.

The response of the model to the input or system variable in terms of the desired output information can be determined using sensitivity analysis. This provide a means to assess the effect of input error (Arkin and Dugas, 1984; McCuen and Synder, 1986 ) and examines model

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reasonableness as input change (Nearing *et al.*, 1990). According to McCuen and Synder, (1986) the form of sensitivity analysis used depends on the intended application. Absolute sensitivity analysis measures small changes in a single input parameter. In contrast, relative sensitivity values are normalized by measurement units, permitting comparison of model responsiveness across input parameters. Recently absolute and relative sensitivity analysis was performed on SORKAM, a grain sorghum growth model to determine the responsiveness of yield, tiller number, caryopsis number and caryopsis weight to changes in planting date, plant population and maturity class by Heiniger *et al.* (1997).

A similar attempt has been made in the present study to analyze the sensitivity analysis of CERES-Sorghum model developed by Alagarswamy and Ritchie (1989) to change in system variables on yield and yield components of forage sorghum.

## MATERIALS AND METHODS

The CERES-Sorghum model is a process oriented crop growth model, which includes all major processes and simulates soil water balance and nitrogen balance on daily incremental basis during crop life cycle. Daily weather data (maximum and minimum temperature, rainfall, solar radiation derived from sunshine hours) for the years 1994 and 1996 of Jhansi (25.27 °N; 78.35 °E; 251 msl) was used to perform sensitivity analysis. The data on soil (sandy clay loam) physical characteristics of the area were the information regarding soil albed (0.18), soil water drainage constant (0.7) , pH (7.2) of the soil layer, drained upper limit (0.232 $cm^3 cm^{-3}$), drained lower limit (0.137 $cm^3 cm^{-3}$), saturated water content (0.355 $cm^3 cm^{-3}$) and initial soil moisture (0.210 $cm^3 cm^{-3}$), root depth (105 cm) and runoff curve number (76). Genetic coefficients of forage sorghum were same as given in Rai and Gupta (2004).

### *Sensitivity analysis*

Absolute sensitivity analysis was performed to measure the responsiveness of dry biomass, yield, caryopsis weight and caryopsis number to change in planting date, plant population and maturity class. The absolute sensitivity of the system output 'O' to variation of a system variable 'I' is defined (McCuen and Synder,1986) by the equation

$$S_A = (O_2 - O_1)/(I_2 - I_1)$$

Where, $I_1$ and $I_2$ are two slightly different input values with corresponding model outputs $O_1$ and $O_2$ respectively and $S_A$ is absolute sensitivity. It was calculated for 10 plant populations, four planting dates and for a change of maturity class from medium to late duration variety. Table 2 shows the levels and input differences, $(I_2 - I_1)$, used. The sensitivity analysis of CERES-Sorghum was performed by executing the model, allowing one/or two of the input variables described previously to vary by incremental portions of their respective normal values.

Output and system variable values

**Table 1:** CERES-Sorghum model parameters and constant values used for sensitivity analysis

| |
|---|
| Planting Date, day of the year |
| Normalized value ($I_n$): 10th July |
| Individual test value, 25th June, 10th July, 25th July and 10th August |
| Increment, 1 day |
| Hybrid Maturity(1 : Medium; 2: Late) |
| Normalized value ($I_n$): (Medium(cv. Mp-Chari, 110 days to mature)) |
| Individual test value: Medium and Late (HC-136, 140 days to mature) |
| Increment: 1 class |
| Plant Population, plants ha$^{-1}$ |
| Normalized value ($I_n$): 200000 |
| Individual test value (plants x $10^4$ ha$^{-1}$): 2.5, 5.0, 10, 15, 20, 25, 30, 35, 40 and 45 |
| Increment : 1000 |

may be normalized (Table 1) to assess the relative sensitivity (Mass and Arkin,1984) using the formula

$$S_R=[(O_2-O_1)/O_N]/ [(I_2-I_1) /I_N]$$

Where, $I_1$, $I_2$, $O_1$ and $O_2$ are as above, $I_N$ and $O_N$ are normalizing input and output values, respectively. The normal values for system variables were chosen on the basis of agronomic practices recommended for forage sorghum crop such as plant population, planting date and maturity class. Relative sensitivities were worked out for dry (1994) and wet year (1996) for the same input variables. These years are considered on the basis of rainfall received during 1997 (569.1) and 1996 (968.8 mm) year during crop growing season. Normal rainfall of Jhansi is 781.6 mm during crop growing season. Relative sensitivity analysis of the simulated wet year was compared with observed relative sensitivity from 1993(a similar wet year) experiment, whereas simulated dry year was compared with the published relative sensitivity of dry year (Stickler and Wearden, 1965; Koch,1966). Normalising output values are depicted in Table 2 by running the model with normalized inputs.

## RESULTS AND DISCUSSION

### *Absolute sensitivity analysis*

Results of the absolute sensitivity analysis are shown in Fig.1 and Fig 2. Grain yield and dry biomass at anthesis were highly affected by changes in planting date and maturity class (when medium duration variety is replaced with late duration variety).

Dry biomass at anthesis and grain yield at physiological maturity is variable with date of planting and plants population (Fig. 1a and 1a'). Response in grain yield is similar for 10th and 25th July plantings. However, 10th August planting seems to be highly sensitive in response both in dry matter and grain yield. Further, if 1st August

Table 2 : Normalized values for forage sorghum yield and yield components for observed and simulated years used in the sensitivity analysis

| Yield components | 1993 | 1994 | 1996 |
|---|---|---|---|
| Plant population (ha$^{-1}$) | 20 x 10$^4$ | 20 x 10$^4$ | 20 x 10$^4$ |
| Grain yield (kg ha$^{-1}$) | 3000 | 1097 | 2326 |
| Total dry biomass (kg ha$^{-1}$) | 11570 | 8535 | 11550 |
| Grain No.plant$^{-1}$ | 781.6 | 365.6 | 775.2 |
| Caryopsis weight of 1000 seed (gm) | 19.2 | 15.0 | 15.0 |

is used for analysis result may show uniqueness or otherwise of the behavior of 10$^{th}$ August sowing. While dry biomass and grain yield sensitivity to 25$^{th}$ June planting date was mostly constant across plant population. Grain yield and dry biomass were least sensitive to plant population density (Fig. 1b and 1b'), dropping from 40 to 48 kg ha$^{-1}$ per change of 1000 plants ha$^{-1}$ at low population to nearly zero/or 10 kg ha$^{-1}$ as plant density increased.

Dry biomass was highly sensitive to maturity class that is change of variety from medium to late duration and is inclined at higher plant population. The changes in dry biomass were least (200-500 kg ha$^{-1}$) at lower population (10x10$^4$ plants ha$^{-1}$), while 2000 - 4500 kg ha$^{-1}$ change in dry biomass was observed when plant population reached to 45x10$^4$ plants ha$^{-1}$ across different planting dates (Fig. 1c and 1c'). Similarly, grain yield response to 25$^{th}$ June planting was least at lower plant density upto 10x10$^4$ plants ha$^{-1}$ and the response increases as plant population increases upto 20 x10$^4$ plants ha$^{-1}$. Further increase in plant population shows a constant yield level. In 10$^{th}$ July planting response was more than 1000 kg ha$^{-1}$ and negative upto 20x10$^4$ plants ha$^{-1}$ and thereafter response becomes positive when plant population increases above 20 x 10$^4$ plants ha$^{-1}$. Response is high, variable and negative in case of 25$^{th}$ July and 10$^{th}$ august planting, due to the fact that late duration variety sown on these respective date may experience low temperature resulting in low seed setting as compared to medium duration variety. Overall the patterns of absolute sensitivity analysis of yield and biomass response to change in plant population are same as field observation (Grimes and Musick, 1960) and Heiniger *et al.* (1997) also found a similar pattern of response for grain yield when simulated with SORKAM model

Caryopsis number was practically insensitive to changes in plant population (Fig.2a) but the response was variable for very low plant population. A similar pattern was observed for sensitivity to changes in planting date (Fig 2b). Further, 10$^{th}$ August planting is more sensitive to higher plant population(>5x10$^4$ plants ha$^{-1}$) as plant is not able to escape from low temperature encountered at physiological maturity stage.

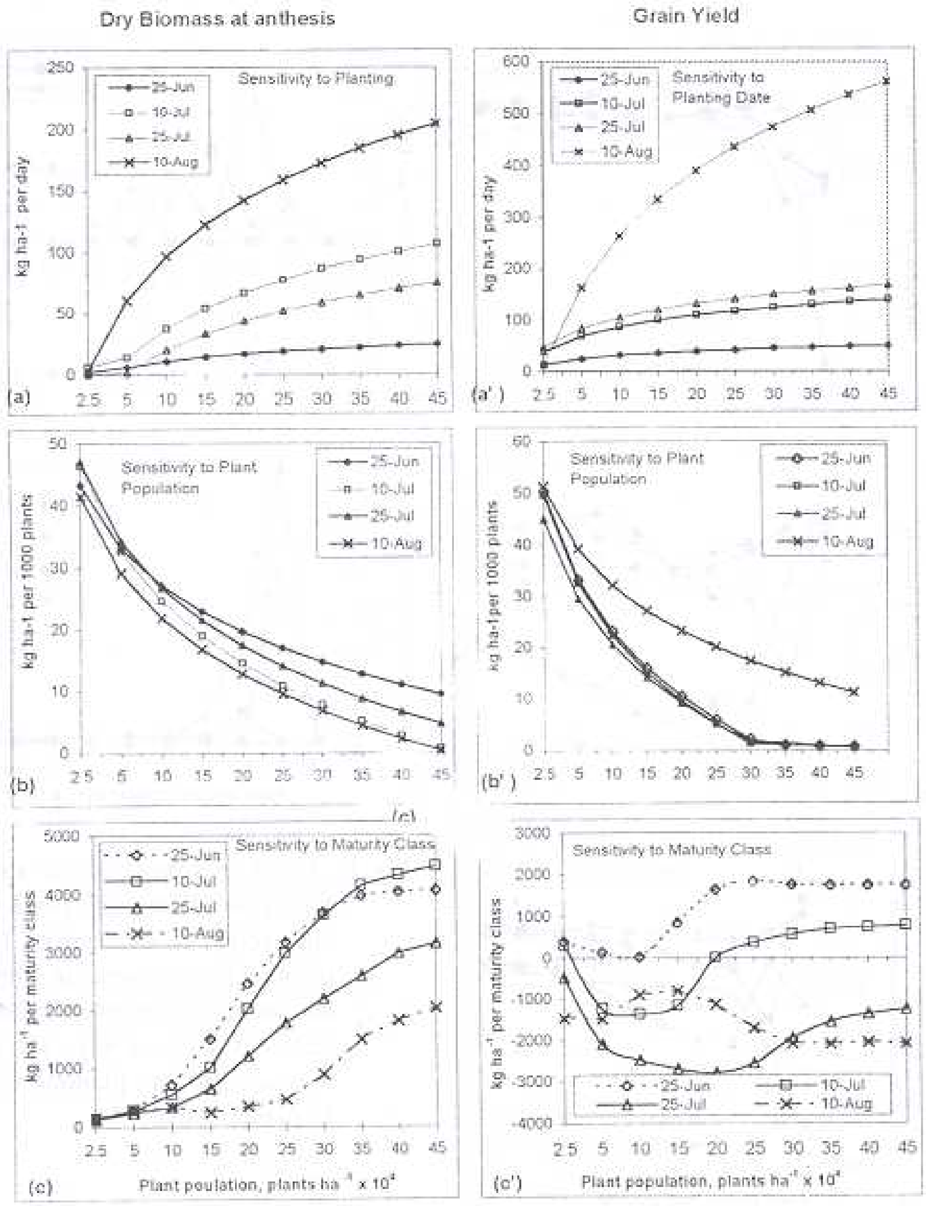
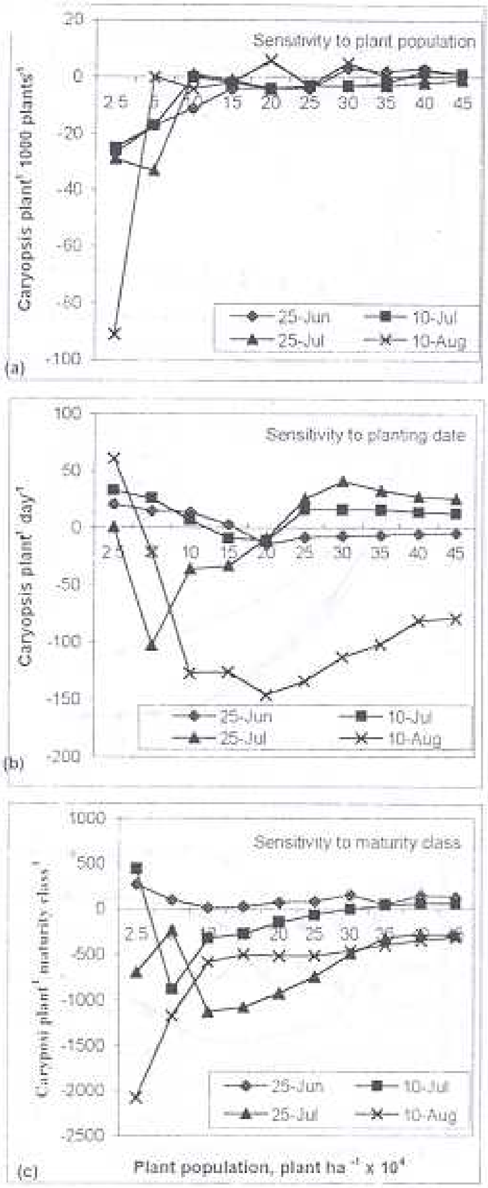



**Fig. 1:** Absolute sensitivity of simulated forage sorghum dry biomass at anthesis and grain yield to changes of 1 day in planting date, increase in 1000 plants ha$^{-1}$ and change from a medium to late maturity variety. Absolute sensitivities were measured at four planting dates and 10 plant populations.



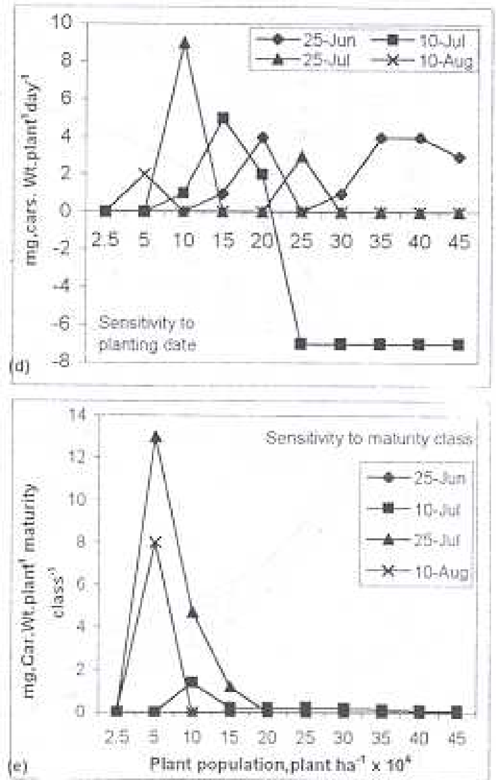




Fig.2: Absolute sensitivity of simulated forage sorghum caryopsies number and weight to changes of 1 day in planting date, increase in 1000 plants ha$^{-1}$ and a change from a medium to late maturity variety. These were measured at four planting dates and 10 plant populations.

Caryopsis number is least sensitive to maturity class at higher plant population for 25th June and 10th July plantings (Fig. 2c) but the response was variable. Moreover, 25th July and 10th August plating are highly sensitive in response to maturity class at low plant population.

Caryopsis weight was insensitive to change in plant population. However it was sensitive to maturity class at lower plant population (i:e below $15\times10^4$ plants $ha^{-1}$) for 25th July and 10th August planting (Fig.2d, e) . Overall, insensitiveness of caryopsis weight to plant population in contrast with literature reports of modest decrease in caryopsis weight at higher plant population (Stickler and Wearden, 1965; Koch,1966) as well as field observation (Bhatt,1995). Thus resulted in a lack of grain yield response to changing plant population.

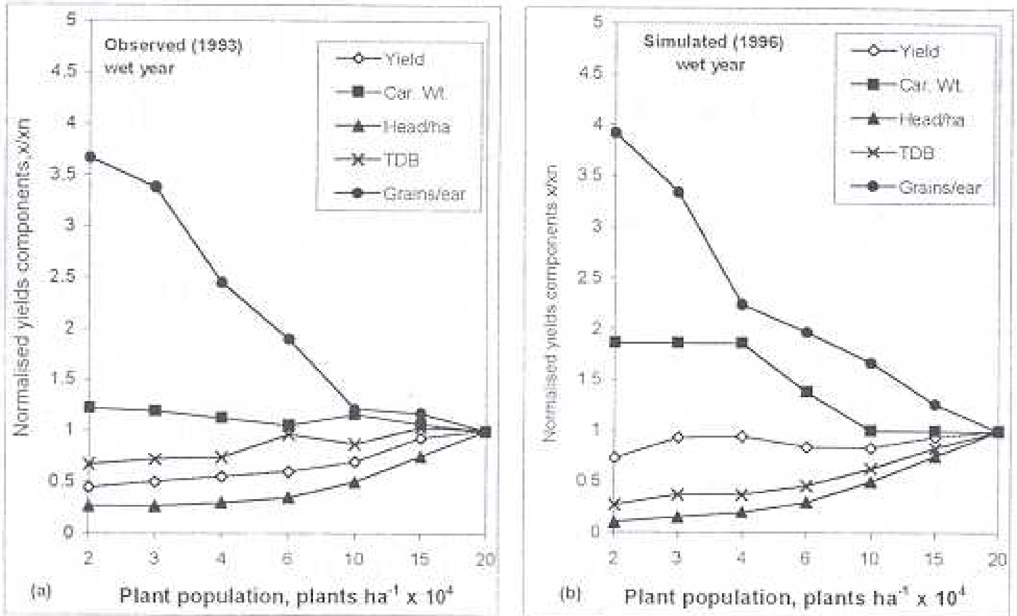
*Relative sensitivity analysis*

The relative sensitivities of yield and yield components to plant population using 1994 (dry year) and 1996 (wet year) simulations are shown in Fig.3, along with values determined from 1993 field data (Bhatt, 1995). Simulated and observed responses to plant population differed for grain yield, total dry biomass (TDB), number of heads $ha^{-1}$, caryopsis weight (Car.Wt.) and grains number $ear^{-1}$ at physiological maturity. Simulated grain yield during wet year decreases slightly from the normal and remained constant as plant population decreased, a forecast not matching with the field data (Fig. 3a). Furthermore during 1994 (dry year) simulated yields increased at lower plant population (below $4\times10^4$ plants $ha^{-1}$), contradicting field data as reported in the literature (Stickler & Wearden, 1965 ; Koch, 1966) in which yield slightly decreases as plant population fell during dry year and is shown in Fig.3c.

During wet year both simulated and observed total dry biomass declined gradually as plant population decreases with different rates. Simulated total dry biomass decreased by 63% at $2\times10^4$ plant $ha^{-1}$ from normal population, in contrast with the observed value during 1993 (a similar wet year), when observed total dry biomass decreased by only 33% (Fig.3a). CERES Sorghum model predicted linear declines in panicle per hectare with decreasing plant population, a forecast not matched by the field observation. In real field situation during 1993, increase in real tiller numbers compensated for population reduction below $6\times10^4$ plants $ha^{-1}$ leaving panicles per hectare constant (Table 3). Similar observation was reported by Heingier *et al.* (1997) and Koch (1966).

Simulated caryopsis number $ear^{-1}$ was in good agreement with observed values during wet years. It can be seen that simulated grains $ear^{-1}$ increases rapidly as plant population decreases below $10\times10^4$ plants $ha^{-1}$ and becomes 3.5 times from normal grains $ear^{-1}$ at 2 x $10^4$ plants $ha^{-1}$. However, in 1994 a dry year, simulated caryopsis number $ear^{-1}$ increases rapidly below $6\times10^4$ plants $ha^{-1}$ and becomes 6.42 times than the normal values of grains $ear^{-1}$, a response not matched with real field situation as reported in literature by Stickler & Wearden (1965) and Koch (1966) in which caryopsis number did not change below 80,000 plants $ha^{-1}$.

In 1993, real caryopsis weight increased slightly as plant population fell, a response not duplicated by the 1996



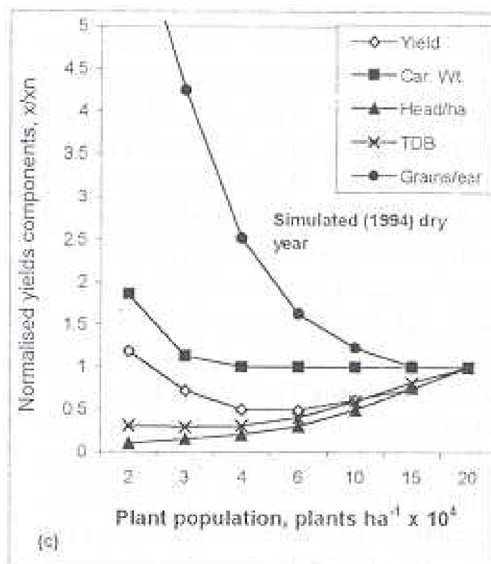




Fig. 3: Relative sensitivity of forage sorghum yields and yield components observed in the field and yield and yields components simulated by CERES -Sorghum in a wet and dry year.

simulation. Simulation showed that caryopsis weight rising rapidly when plant population reduced below 6 $\times 10^4$ plants $ha^{-1}$ and remained constant. During dry years simulated caryopsis weight followed the similar pattern upto $4 \times 10^4$ plants $ha^{-1}$ (Fig.3c) but thereafter there is an increase in simulated caryopsis weight which did not

Table 3: Growth characteristics of sorghum (Var. MP. Chari) at 50% flowering stage

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Plant populations (x $10^{-4}$ $ha^{-1}$) | 20 | 15 | 10 | 6 | 4 | 3 | 2 |
| Plant height (cm) | 335 | 340 | 340 | 345 | 348 | 335 | 330 |
| No of tillers $plant^{-1}$ | - | - | - | 1.0 (0.0) | 2.0 (0.0) | 2.30 (0.5) | 3.30 (0.47) |

After Bhatt, 1995. (Values in parenthesis indicate SD)

mimic the field observation (Stickler & Wearden, 1965 ; Koch, 1966). The increases in simulated caryopsis weight during wet and dry year were too large to be explained by water surplus and water stress respectively. Evidently the model overcompensated for water surplus/ and water stress at lower population by increasing C (carbohydrates) translocation to the grain during grain filling stage, thus elevating yields at lower population to a degree not seen by the observed yield values. Over all the results of sensitivity analysis of CERES-sorghum model implicate improper tillering response to population change. Also caryopsis weight overcompensation when water surplus /or stress occurs during grain fill especially when plant population reduced below 60,000 plants per hectare. From the analysis it may be concluded that improvement in caryopsis weights and re-examination of tiller number calculation from the tiller subroutines could result in better yield prediction under local conditions and make the model more sensitive to plant density.

## ACKNOWLEDGEMENT

The author is thankful to the Director, IGFRI, Jhansi for encouragement and support.

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