

SIMULATION OF MAIZE (*ZEA MAYS* L.) YIELD UNDER ALTERNATIVE NITROGEN FERTILIZATION USING INFOCROP-MAIZE MODEL

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ABSTRACT : A field study was conducted growing maize during monsoon season of 2013 and 2014 to simulate the grain yield under alternative nitrogen fertilization using InfoCrop-maize model. Seven treatments viz. (1) N0 (Control) (2) N120 (3) N140 (NST) (4) 50% urea + 50% FYM (5) 100% FYM (6) Urea + NI and (7) NOCU were tested. Application of urea and NOCU delayed crop phenology while, 50 and 100% substitution of urea by FYM advanced crop phenology. Grain yield among different treatment ranged from 1597-3993 kg ha⁻¹ during first season and 1514-3856 kg ha⁻¹, during second season. Grain yield increased by 0.80 and 0.21% in NOCU and 1.87 and 1.18% in Urea + NI, however it was reduced by 13.6 and 12.0% in 50% urea + 50% FYM and 46.7 and 46.8% in 100% FYM condition during first and second season, respectively. Model results showed that, days to 50% silking simulated well in all conditions. However, days to 50% physiological maturity was slightly overestimated. Grain yield was simulated reasonably well under all condition except 100% FYM where it was highly over estimated. Overall the InfoCrop maize model worked satisfactorily and calibrated well for most of conditions and it could be used for simulation of grain yield under alternate nitrogen fertilization situations.

Key words : Crop simulation model, phenology, grain yield, neem oil coated urea, nitrification inhibitor.

INTRODUCTION

Nitrogen (N) is the very important nutrient for high-yielding agriculture because it is required in large quantity. Therefore, external N application is required in high yielding agriculture to enhance productivity. Fertilizer consumption has increased about 17 times from less than 1 million tons (Mt) in mid 1960s to almost 17 Mt today (INDIASTAT, 2012-13). Nitrogen-fertiliser use will increase about several folds by 2050 to meet the demand of increased food production. More than half of total fertilizers nitrogen produced is applied to three major cereals namely maize, rice and wheat (Ladha *et al*, 2016). In India, food grain production is closely related to use of N fertiliser. Even though agricultural production has increased dramatically along with matching increase in the consumption of fertiliser, particularly N, it has led to decline in total factor productivity together with nitrogen use efficiency (NUE). The application of adequate N results in loss of reactive forms of N (ammonia, nitrate, and nitrogen oxides) to the environment, causing water pollution, climate change and loss of biodiversity (Ladha *et al*, 2016) and greenhouse gases (Gupta *et al*, 2015). Climate change and environmental pollution due to injudicious N-fertiliser use has become a global concern (Pathak *et al*, 2016).

Maize (*Zea mays* L.) is the third most important cereal crop and contributes 78.2 Mt to world total food grain production with an area about 150 Mha (McCann, 2007; Parihar *et al*, 2011). India is ranked sixth among maize producing countries having 9.4 Mha producing 23.29 Mt at a productivity of 2469 kg ha⁻¹ (FAO, 2013). In India Maize is the third most important food crop after rice and wheat (Bhatia *et al*, 2013). It is grown in 8.71 Mha with a production of 22.23 Mt and a productivity of 2552 kg ha⁻¹ (INDIASTAT, 2012-13). Monsoon season is the main maize growing season in northern India but it is also grown in winter season in large areas of Bihar and Andhra Pradesh. Maize crop have considerable area i.e. 1.8 Mha in the country under maize-wheat cropping system and its ranked 3rd after rice-wheat and rice-rice cropping systems, which contributes about 3% to the nation food production (Jat *et al*, 2014).

Simulating the crop growth and yield using crop models has been increasingly become valuable for decision support. Several crop models are being tested and validated for their performance for a given management, variety(ies) and climatic condition. However, their efficiency in simulating the maize crop yield under alternate nitrogen fertilization is not tested enough. In view of the maize, nitrogenous fertilizer used

and reduced NUE, it is important to simulate the impacts using a crop model so as to improve the decision making on crop management and for developing the adaptation strategies at regional level. InfoCrop is a decision support system which can simulate the crop growth, development and yield in response to weather, soil, agronomic management (including planting, nitrogen, residues and irrigation), and major pests and diseases (Aggarwal *et al*, 2006). In this paper we first calibrated the maize yield to alternative nitrogen fertilization (neem oil coated urea, nitrification inhibitors and farmyard manure) and then tested the efficacy of InfoCrop-maize model in simulating the grain yield in such situations.

MATERIALS AND METHODS

Experimental site and weather condition

A field experiment was conducted growing maize crop during 2013 and 2014 at farm of Indian Agricultural Research Institute, New Delhi. Geographically the site is located in the Indo-Gangetic alluvial tract at 28°38'233 N and 77°09'273 E, at an altitude of 228.61 m. It has sub-humid and sub-tropical climate with hot dry summer and cold winter. Average annual rainfall of the area is about 700 mm. During the first crop growth period, the total rainfall was 841 mm. The mean maximum temperature was 33.0°C while, mean minimum temperatures was 23.2°C. The daily mean sun-shine duration was 5.1 hrs (Fig. 1.A). While, during succeeding crop growth period the total rainfall was 435.1 mm. The mean maximum and minimum temperatures was 35.3°C and 25.1°C; respectively. The daily mean sun-shine duration was 5.8 hrs (Fig. 1.B). The 2013 season was wet cropping season due to high and uniform rainfall while 2014 was drier cropping season due to scarce rainfall. The Yamuna alluvial soil of the experimental site was Typic Haplustep with sandy loam texture having pH 8.16, medium in organic carbon content, available potassium, available phosphorous and low in available nitrogen.

Treatments

The seven treatments *viz.* (1) N0 (control-no nitrogen applied) (2) N120 (120 kg N ha⁻¹ through urea) (3) N140 (NST), 140 kg N ha⁻¹ through urea on soil test basis (4) 50% urea + 50% FYM (120 kg N ha⁻¹, 50% N through urea and 50% N through FYM) (5) 100% FYM (120 kg N ha⁻¹ through FYM) (6) Urea + NI (120 kg N ha⁻¹, 90% N through urea and 10% N through nitrification inhibitor-DCE) (7) NOCU (120 kg N ha⁻¹ through NOCU) with three replicated field plot (25 m²) were tested in a completely randomized block design.

Crop variety

Maize variety Pusa composite-3 (PC-3) has adopted

for field experiments. It has medium maturity, stay green character and long ears with yellow-orange flint grains. It is tolerant to major foliar diseases and stalk borer and resistant to lodging. It matures in 85-90 days and its potential yield is about 4.0 t ha⁻¹.

Sowing of crop and its management

The seeds of maize composite (Pusa composite- 3) were dibbled along the rows spaced at 60cm apart with plant to plant spacing of 20cm at a depth of 5cm, using 20 kg seeds/ha. Sowing was done on 26 July in 2013 and on 7 July in 2014. All plots received phosphorus @60 P₂O₅ kg ha⁻¹ through SSP and potassium @ 60 K₂O kg ha⁻¹ through MOP as basal dose at the time of sowing. Nitrogen was applied in three split doses *viz.*, 1/2 as basal, 1/4 at knee high stage and 1/4 at tasseling stage. The farmyard manure (FYM) was incorporated in to soil at 10 days before sowing of the crops. Two-time manual weeding was done about at 25 DAS and 45 DAS in both seasons. Irrigation was provided uniformly as and when required in all the treatments in both the crops. The crop was harvested manually.

Sampling and observations

Observations on crop phenology *i.e.* days to 50% germination, 50% silking and 50% Physiological maturity were taken on plants in different treatments. Observations on grain and residue yield were also taken at the harvest. Mature cobs and stover were harvested manually from one square meter area and sun dried for few days. Then the dried cobs were dehusked and shelled manually and grain yield was recorded at 15% moisture content and expressed in kg ha⁻¹. The harvest index (HI) was calculated using following equation:

$$\text{Harvest index} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Grain + stover yield (kg ha}^{-1}\text{)}} \times 100$$

Statistical analysis

The data on various parameters were analyzed by applying the technique of 'analysis of variance (ANOVA)' for Randomized Block Design using SPSS 16.0 software. Critical difference (CD) was calculated at 5% level of significance for comparing the treatment means. CD values have been indicated, where the differences are significant.

Calibration and validation of InfoCrop-maize model

In order to test the model performance in simulating the yield under alternative nitrogen fertilization, Infocrop-maize model was used. The simulated values on phenology (days to 50% flowering, days to 50% physiological maturity) and grain yield (GY) were compared with those of observed values. The observed

data set from the field experiment pertaining to first season of maize crop was used for the calibration of the model. Initially, the model was calibrated for varietal performance using the varietal characteristics for N120 condition. For attaining the proper phenology and grain yield several iterations were done and simulations runs were made. After satisfactory performance of model in N120 condition, the simulations were done for N140 (NST) and N0 (control) and calibrations was repeated through less iteration so as to get proper simulation results and finally model was calibrated for other treatment also in similar way. Thereafter, the model inputs were changed to suit the different N conditions and simulations were carried out. Simulation results on phenology and grain yield from second season of maize crop were compared with those from the field experiment.

Evaluation of model performance

Four statistical measures and indices were applied to evaluate the model that included mean bias error (MBE) (Addiscott and Whitmore, 1987); root mean square error (RMSE) (Fox, 1981), index of agreement (IA) (Willmott, 1982) and modelling efficiency (ME) (Nash and Sutcliffe 1970).

$$MBE = \frac{1}{n} \sum_{i=1}^n (S_i - O_i) \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (S_i - O_i)^2} \quad (2)$$

$$IA = 1 - \frac{\sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (|S_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (3)$$

$$ME = 1 - \frac{\sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (|O_i - \bar{O}|)^2} \quad (4)$$

Where, n is the number of samples, S_i and O_i are the simulated and observed values, respectively, and \bar{O} is the mean of the observed data. The MBE indicates bias of model error as it accounts for positive and negative deviations. The RMSE describes mean absolute deviation between simulated and observed values. Accuracy of simulation is characterized by lower RMSE. The IA, is an additional method for evaluation of model performance, which ranges between 0 and 1, the closer IA is to 1, the better the simulation. Another parameter, ME allows negative values and compares deviation between simulated and observed state variables with the variances

of observed values of development, growth and yield.

RESULTS

Crop phenology

Maize crop took 5-6 days for germination in all condition in both seasons, which shows that germination was not affected significantly by the alternate nitrogen fertilization (Table 1). However days to 50% silking and days to 50% physiological maturity were affected significantly. Silking was delayed by 1 to 2 days in all the treatment as compared to that of control (N0) (Table 1). Highest days to maturity were recorded in the N140 (NST) treatment. In NOCU treatment maturity was at par with N140 (NST) treatment. Days to maturity were at par in control crops (N0) and 100% FYM treatment. It was observed that days to maturity were in between control and 50% urea + 50% FYM (Table 1).

Grain yield

Grain yield was affected significantly in both the season. Grain yield ranged from 1597 kg ha⁻¹ in control (N0) to 3993 kg ha⁻¹ in N140 (NST) treatment during first season while, during second season it ranged from 1514 kg ha⁻¹ in control (N0) to 3856 kg ha⁻¹ in N140 (NST) treatment (Table 2). In Control (N0), 100% FYM and 50% urea + 50% FYM treatments grain yield was lower as compared to over N120 treatment (Table 2). There was 13.6 and 12.0% lower yield recorded in 50% urea + 50% FYM while, in 100% FYM treatment reduction in grain yield was much higher and it reduced by 46.7 and 46.8% as compared to N120 treatment during first and second season respectively (Table 2). NOCU and Urea + NI treatment showed slightly higher yield as compared to N120 treatment (Table 2). The yield was increased by 0.80 and 0.21% in NOCU treatment in first and second season respectively while, in Urea + NI yield was increased by 1.87 and 1.18% in first and second season respectively as compared to N120 treatment. However, this increase in yield was insignificant (Table 2). Harvest index in first season affected significantly, however harvest index in second season and 100 grain weight in both the season were not affected significantly (Table 2).

Calibration of InfoCrop-maize model

It was observed that the simulated values on days to 50% silking matched with the observed values in soil test basis N140 (NST) and NOCU conditions (Table 4.3). It was one day higher in urea N120 and 100% substitution of urea by FYM (100% FYM) and two days higher in 50% substitution of urea with FYM (50% urea + 50% FYM) and urea + NI conditions. The simulated value of 50% silking was two days lower than observed one in

Table 1 : Effect of alternate nitrogen fertilization on phenology of maize crop.

Treatments	50% germination		50% silking		50% Physiological maturity	
	Season I	Season II	Season I	Season II	Season I	Season II
N0	5	5	57	57	85	87
N120	5	6	58	58	87	89
N140 (NST)	6	6	58	59	88	90
50% urea + 50% FYM	6	5	57	58	86	88
100% FYM	6	6	57	59	85	87
Urea + NI	5	5	57	58	87	88
NOCU	6	6	58	59	88	89
CD p=0.05	N/A	N/A	1.11	1.04	1.23	1.85
SE(d)	0.49	0.5	0.51	0.47	0.47	0.84

Where, N0 = control (no nitrogen); N120 = N @ 120 kg ha⁻¹ through urea; N140 (NST) = N @ 140 kg ha⁻¹ through urea on soil test basis; 50% urea + 50% FYM = N @ 120 kg ha⁻¹; 50% N through urea and 50% through FYM; 100% FYM = N @ 120 kg ha⁻¹ through FYM only; Urea + NI = N @ 120; 90% N through urea and 10% N through nitrification inhibitors (DCD); NOCU = N @ 120 through neem oil coated urea.

Table 2 : Effect of alternate nitrogen fertilization on grain and residue yield, harvest index and 100 grain weight of maize crop.

Treatments	100 grain weight		Grain (kg ha ⁻¹)		Residue (kg ha ⁻¹)		Harvest Index	
	Season I	Season II	Season I	Season II	Season I	Season II	Season I	Season II
N0	16.93	16.93	1597	1514	6037	6044	28.99	30.04
N120	19.67	19.27	3894	3723	11873	11867	39.88	37.86
N140 (NST)	19.93	19.52	3993	3856	12577	12469	40.16	38.56
50% urea + 50% FYM	17.93	17.98	3364	3277	11786	11699	38.72	36.33
100% FYM	17.13	17.53	2076	1979	9123	8573	38.57	38.86
Urea + NI	19.60	19.56	3967	3767	11889	11840	37.90	35.69
NOCU	18.80	18.28	3925	3731	12337	12639	36.41	35.28
CD p=0.05	N/A	N/A	274	833	624	1502	6.28	N/A
SE(d)	1.42	1.42	124	378	283	682	2.85	3.7

*For treatment details refer the foot note of table 1.

control condition (N0) (Table 3). The simulated values on days to 50% physiological maturity was two to six days higher than the observed values in different condition (Table 3). It was two days higher in control (N0); four days higher in N140 (NST), 100% FYM and NOCU conditions; while, it was six days higher in 50% urea + 50% FYM (Table 3). The simulated values of days to 50% physiological maturity was 92 days in N120, N140 (NST), 50% urea + 50% FYM, urea + NI and NOCU conditions (Table 3). The simulated values on yield were lower than observed values in control (N0) and 100% FYM conditions. The observed values on yield were 1597 and 2076 kg ha⁻¹ while, that of simulated were 1404 and 2015 kg ha⁻¹ under control and 100% FYM conditions (Table 3). The simulated values on yield in N120, N140 (NST), 50% urea + 50% FYM, urea + NI and NOCU conditions were higher than the observed values (Table 3).

Simulating the crop phenology and grain yield

The simulation result of crop phenology and grain

yield are shown in figure 2. Comparison of both observed and simulated results showed that the simulated values of days to 50% silking and 50% physiological maturity were higher than the observed values (Fig. 2.A&B). Days to 50% silking simulated well by the model in all treatments (Fig 2A). However, days to 50% physiological maturity were simulated reasonably well. Days to 50% physiological maturity were simulated very well under control (N0) condition. While, under all other treatments model slightly overestimated the days to 50% physiological maturity (Fig. 2.B). The simulated value of days to 50% physiological maturity were three to five days higher than the observed one under different situation (Fig. 2.B). Simulated values on grain yield were higher than the observed one in all the treatments (Fig. 2.C). Grain yield was simulated very well under control condition. Under N120, N140 (NST), 50% urea + 50% FYM, urea + NI and NOCU conditions grain yield were simulated reasonably well and it was slightly overestimated (Fig. 2.C). However, grain yield was highly

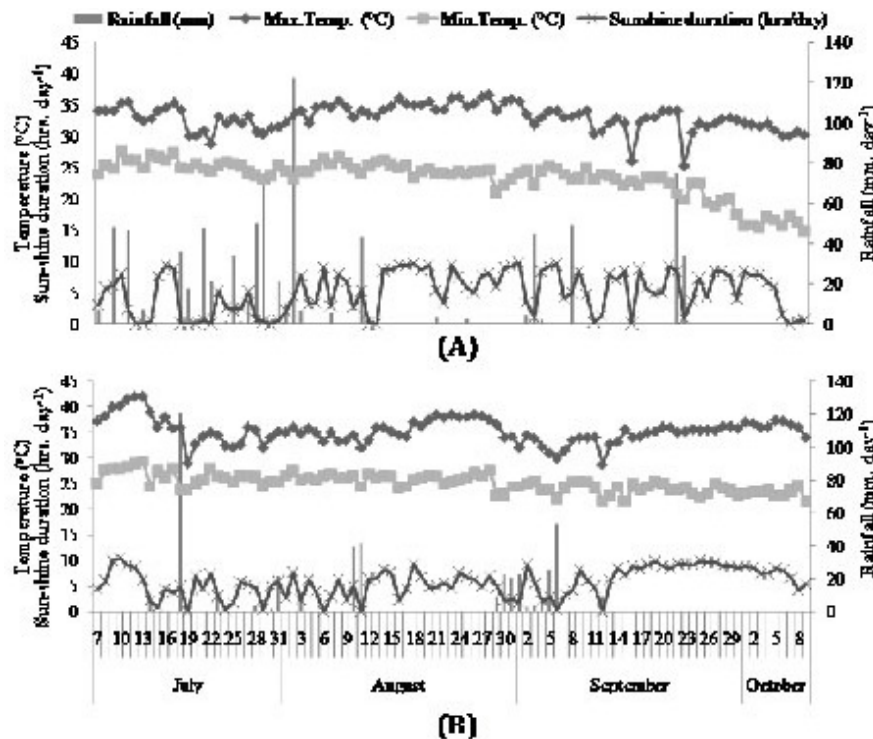


Fig. 1 : Daily weather during the experimental wheat crop growth: A) Season-I and B) Season-II.

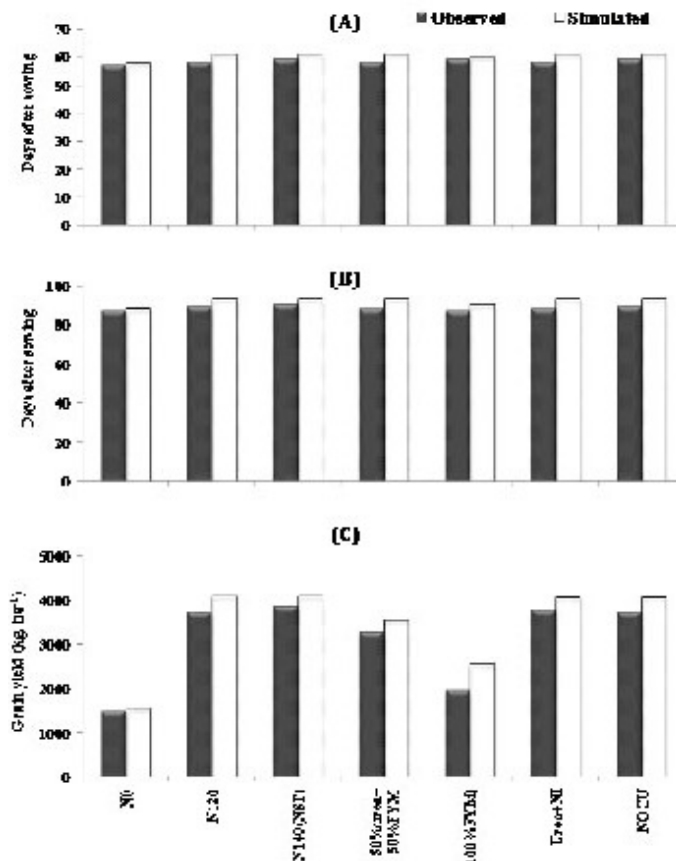


Fig. 2 : Validation results on InfoCrop-Maize model for simulating the effect of alternate nitrogen fertilization on maize crop on (A) days to 50% silking from DAS, (B) days to 50% physiological maturity from DAS and (C) grain yield (kg. ha⁻¹).

overestimated in 100% FYM condition. The simulated and observed values on grain yield were 2563 and 1979 kg ha⁻¹ respectively under 100% FYM condition (Fig. 2.C).

Statistical performance of model

From the data set, it was observed that mean bias error (MBE) showed the positive deviation for the days to 50% silking, days to 50% physiological maturity and grain yield (Table 4). Root mean square error (RMSE) values showed that the accuracy of model was higher for the grain yield; however it was lower for days to 50% silking and days to 50% physiological maturity (Table 4). Modeling efficiency also showed slight under estimation of model for days to 50% silking and days to 50% physiological maturity (Table 4). Values of IA showed that the grain yield was simulated with highest accuracy (IA=0.98) followed by days to 50% physiological maturity (IA=0.38), days to 50% silking (IA=0.36) (Table 4).

DISCUSSION

Results on phenology, grain yield and yield components indicate that the maize plants responded differentially to alternative nitrogen fertilization. Days to 50% germination was not affected among different treatment. However days to 50% silking and 50% physiological maturity differed among nitrogen doses and sources. Application of nitrogen through chemical fertilizers delayed phenology while farmyard manure enhanced it by 3-4 days. The yield and yield parameters

Table 3 : Observed and simulated value of the Calibration of InfoCrop-Maize model.

Treatments	Days to 50% anthesis		Days to 50% physiological maturity		Grain yield (kg ha ⁻¹)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
N0	57	55	85	87	1597	1404
N120	58	59	87	92	3894	4147
N140 (NST)	59	59	88	92	3993	4279
50% urea + 50% FYM	57	59	86	92	3364	3542
100% FYM	57	58	85	89	2076	2015
Urea + NI	57	59	87	92	3967	4150
NOCU	59	59	88	92	3925	4149

*For treatment details refer the foot note of table 1

Table 4 : Statistical indices showed performance of InfoCrop-Maize model.

Parameters	MBE	RMSE	IA	ME
Days to 50% anthesis	2.14	2.3	0.36	-9.79
Days to 50% physiological maturity	3.57	3.8	0.38	-12.60
Grain yield (kg ha ⁻¹)	306.17	389.89	0.98	0.81

Where,

MBE = Mean bias error; RMSE = Root mean square error; IA = Index of agreement; ME = Modeling efficiency.

were also influenced by the alternative nitrogen fertilization. In this study slight higher yield of maize crop under Urea + NI and NOCU treatments has been reported as compared to N120 treatment, however, these differences were insignificant. In many studies it has been observed that the application of nitrification inhibitors (NIs) enhanced the crops yield (Majumdar *et al*, 2002; Bhatia *et al*, 2010 and Hu *et al*, 2014; Gupta *et al*, 2016 a&b). The higher yield of wheat, rice, barley, rapeseed, potato and maize crops under N fertilization with NIs compare to conventional N fertilization at a particular N rate (Bhatia *et al*, 2013). Smith *et al* (1998) also reported the effectiveness of the NI (DCD) and nitrapyrin on reducing N₂O emissions and slight increase in yield of crops. Bhatia *et al* (2010) also reported the increase in yield of wheat crop as results of use of nitrification inhibitors. Majumdar *et al* (2002), also reported 4-12% increase in yield of wheat crop due to use of NIs at different places in Gujarat and these results are in line with different places in New Delhi (Bhatia *et al*, 2010). The simulation analysis indicated that the InfoCrop model on maize worked satisfactorlly for alternative nitrogen fertilizationand calibrated well for the experiemntal conditions for these treatments. In this study days to 50% silking simulated well by the model in all treatments of alternative nitrogen fertilization. However days to 50% physiological maturity were simulated reasonably well. The grain yield was also simulated reasonably well under all the treatments except 100% FYM, where it was

overestimated in 100%FYM condition. The temperature and rainfall interaction influnces were satisfactrily simuated using InfoCrop maize (Byjeah *et al*, 2010) and sorghum (Srivastava *et al*, 2010) models.

CONCLUSION

Nitrogen fertilizers application increased by many fold since green revolution which result decreased nitrogen use efficiency and enhance N losses. In this study, an attempt has been made on simulation of maize crop yield under alternate nitrogen fertilization. Application of NI with urea and NOCU results in slightly higher yield however, these differences were insignificant. On the other hand, 50 and 100% substitution of urea by FYM results in reduction of grain yield during initial period. Simulation analysis of InfoCrop maize model indicated that these models worked satisfactorily for alternate nitrogen fertilization and calibrated well for the experiemntal conditions. Model is efficient in simulating the phenology of crop. The simulated grain yield (GY) was satisfactory in most of the conditions. However, it overestimated the grain yield in 100% FYM condition. Overall the InfoCrop maize model worked satisfactorily and calibrated well for most of conditions and it could be used for simulation of grain yield under different nitrogen management situations.

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