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**Research Paper**

# Performance evaluation of CropSyst simulation model for pearlmillet (*Pennisetum glaucum*) – chickpea (*Cicer arietinum*) cropping system

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## ABSTRACT

CropSyst simulation model was tested during the rainy seasons of 2007 and 2008 and the winter seasons of 2007–08 and 2008–09 at New Delhi, to study the long and wide-spread adoptability of pearlmillet [*Pennisetum glaucum* (L.) R.Br. emend. Stuntz.]–chickpea (*Cicer arietinum* L.) cropping system by comparison of simulated and observed variables. The observed variables collected from the experimental data were used to study the effect of nitrogen (N) levels in pearlmillet and water levels in chickpea for pearlmillet – chickpea crop rotation. The calibration, validation and sensitivity analysis of CropSyst model was utilized to quantify and verify the interactive effect of different water and N treatments on the productivity of pearlmillet–chickpea crop rotation using measurements from field experiments. Results showed that CropSyst model performed well at lower levels of N treatments (60 kg/ha) whereas at higher levels of N treatments (90 kg/ha) the predicted values were lower than the observed values. The model also responded well to limited level of irrigation in pearlmillet, but in chickpea irrigation did not have a significant influence on biomass yield as predicted by the model. The model was tested for accuracy in determination of the crop parameters by conducting sensitivity analysis of the model, which depicted that crop parameters, viz. light to above-ground biomass conversion, specific leaf area, phenological degree-days, base temperature, stem/leaf partition coefficient needs more accuracy during its calibration and validation. Also, the root mean square error (RMSE) for biomass and grain yield was found to be 1.97 and 0.36 t/ha, being 5 and 7% of the observed mean, respectively, in pearlmillet whereas for chickpea it was 0.40 and 0.17 t/ha which, in turn, was 8 and 6% respectively. These low values of RMSE indicates that the CropSyst model is highly accurate in predicting grain yield and above-ground biomass of pearlmillet–chickpea crop rotation.

***Key words*** **:** CropSyst model, Pearlmillet–chickpea rotation, Sensitivity analysis, Simulation,

Crop simulation models are increasingly used to study the behaviour of complex agricultural systems and to understand the interactions between the factors affecting soil and plants under different climatic conditions. These tools can be used to compute the gaps between potential and actual yields, to evaluate management options and to determine likely environmental impacts (Dass *et al.,* 2012). These models estimate crop growth and development by mathematical representations of biophysical processes, which incorporate knowledge from several disciplines. Crop models are often used to evaluate the impact of management or climatic scenarios, and their reliability is still judged mainly on their accuracy in estimating the crop biomass at the end of the growing season and, consequently, the crop production. The suitability of a crop model is assessed, on one hand, by the authenticity of the basic equations describing the crop processes while, on the other hand, by the quality of its input data (Fodor and Kovács, 2003; Rivington *et al.*, 2006). Besides soil and weather inputs, the considerable details facilitated by these models often require the inclusion of a large number of input parameters, the values of which are often not known with certainty. The values of many parameters are set either as observed in local experiment or extracted from literature sources. Some crop parameters that tend to fluctuate among cultivars are often calibrated to match selected data with model out puts (Kijne *et al.,* 2003).

CropSyst simulation model, a multi-year, multi-crop, daily time step cropping system simulation model developed by Stockle *et al.,* (1994), serves as an analytical tool to study the effect of climate, soil and management on cropping system productivity and the environment. The

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objectives of model are to serve as an analytical tool to study the effect of cropping system management on crop productivity and the environment. CropSyst simulates the soil water budget, soil plant nitrogen budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water and salinity. These processes are affected by weather, soil characteristics, crop characteristics and cropping system management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation, water salinity, tillage operation and residue management.

Nitrogen (N) is often considered as the most important limiting factor for yield and biomass production in natural ecosystems, after water deficit. The N fertilization practices can provide a sufficient N supply for plants to achieve the potential yield allowed by the actual climatic conditions (Lemaire *et al.,* 2008). But the factors such as variation in climate and injudicious use of N fertilizers, often obstructs in achieving maximum yield. Passioura (2002) showed that for a typical region limited by water availability, poor nitrogen conditions have noticeably limited the yield. Therefore, it could be hypothesized that part of the gap between attainable and potential yield might be partially covered by increases in the availability of N, independently of the occurrence of water deficits (Abeledo *et al.,* 2008). It is essential to apply N fertilizers on adequate time and rate. The economically optimum rate of N fertilizer for crops may vary spatially due to variation in soil characteristics and temporally due to the interactions of environmental factors (Mamo *et al.,* 2003; Subedi and Ma, 2007).

The CropSyst model has been widely used for many crops under different pedoclimatic and management conditions (Jalota *et al*., 2008; Singh *et al*., 2008). However, studies on simulation of water levels in chickpea and nitrogen balance in pearlmillet under pearlmillet–chickpea cropping system are lacking. Pearlmillet is the crop mainly grown in rainfed conditions but fertilizer management has been the main limiting factors for the yield of pearlmillet which occupies the large area in central India. On the other hand, chickpea crop needs proper scheduling of irrigation. Therefore for scenario analysis of the different cropping systems, there is a need to carry out calibration and validation studies with large set of data on water and nitrogen levels under the specified cropping system for predicting the growth of the crop under varying water and nitrogen treatments. Thus, the study was planned to evaluate the performance of pearlmillet–chickpea crop rotation under varied water and nitrogen levels and to quantify its interactive effect by using CropSyst simulation model.

## MATERIALS AND METHODS

The field experiment was carried out on clay loam soils (*Typic haplustept*) at the research farm of Indian Agricultural Research Institute, Pusa, New Delhi, during the rainy (*kharif*) and winter (*rabi*) seasons of 2007–08 and 2008–09. Soil physico-chemical properties, viz. bulk density, hydraulic conductivity, field capacity (FC, 0.02 MPa); permanent wilting point (PWP, 1.5 MPa) and gravimetric soil moisture; and chemical properties, viz. $NH_4^+$-N, $NO_3^-$-N and organic C, of the experimental plot were determined up to a depth of 90 cm at an interval of 0–15, 15–30, 30–60 and 60–90 cm following standard procedures (Table 1) before the start of the experiment. Soil samples from different depths were taken at an interval of 1 month and also at harvest stage and before sowing of each crop and were analyzed for $NH_4^+$-N, $NO_3^-$-N and organic C.

**Table 1.** Physico-chemical properties of the experimental site (pearlmillet–chickpea cropping system)

| Soil properties | Depth | | | |
|---|---|---|---|---|
| | 0–15 cm | 15–30 cm | 30–60 cm | 60–90 cm |
| Sand (%) | 61.50 | 61.75 | 60.00 | 59.64 |
| Silt (%) | 22.12 | 21.25 | 20.74 | 20.38 |
| Clay (%) | 16.38 | 17.00 | 19.26 | 19.98 |
| *Textural class* | *Sandy loam* | *Sandy loam* | *Sandy loam* | *Sandy loam* |
| pH (1: 2; soil : water) | 7.22 | 7.28 | 7.35 | 7. 30 |
| Electrical conductivity (dS/m) | 0.377 | 0.248 | 0.159 | 0.166 |
| Permanent wilting point ($m^3/m^3$) | 0.058 | 0.062 | 0.064 | 0.066 |
| Hydraulic conductivity (m/day) | 0.125 | 0.138 | 0.102 | 0.090 |
| Field capacity ($m^3/m^3$) | 0.152 | 0.166 | 0.169 | 0.176 |
| Bulk density (g/cc) | 1.59 | 1.56 | 1.54 | 1.53 |
| Organic carbon (%) | 0.61 | 0.68 | 0.49 | 0.35 |
| $NH_4^+$-N (kg N/ha) | 6.94 | 5.10 | 4.42 | 4.54 |
| $NO_3^-$ N (kg N/ha) | 5.94 | 5.25 | 4.36 | 3.06 |

During the cropping seasons of *kharif* 2007 and 2008 and *rabi* 2007–08 and 2008–09, pearlmillet and chickpea crops were taken in their respective sequence. The experiments were conducted in a plot size of 7.5 m × 6.75 m. Rainfed pearlmillet is grown with 4 levels of nitrogen (0, 30, 60 and 90 kg/ha) imposing factorial randomized block design with 5 replications. The details of the treatments of each crop are given in Table 2. Pearlmillet was sown in August and harvested in the November, whereas chickpea was sown in the end of November and harvested in the mid of April next year during both the years of study. Pearlmillet variety 'Pusa 383' and Chickpea variety 'Pusa 372' were used in the study with row-to-row spacing of 30 cm and 45 cm and plant-to-plant spacing of 15 and 15 cm respectively. Daily weather data on maximum and minimum temperature, maximum and minimum relative humidity, solar radiation, wind speed and rainfall during crop-growth period were collected from the meteorological observatory located at a distance of 150–200 m from experimental site.

Plant samples were taken at monthly intervals and at harvesting of each crop for estimation of crop-based parameters, viz. leaf area, above ground biomass (dry weight at 70 $^{o}$C) and total plant nitrogen content. Grain yield was computed from crop cutting of 1 m × 1 m area at 3 different locations in each plot and is expressed in t/ha.

*Numerical experiment:* The CropSyst model is choosen to study the effect of cropping system management on crop productivity, water and N balance and the environment. Simulations were made by selecting a location and soil and building crop rotations with management schedule. The location parameters included longitude, latitude, weather files and ET models. The soil parameters included specification of soil layers thickness, texture, bulk density, cation exchange capacity, pH, and volumetric water content at water potentials of 0.02 M Pa (field capacity) and 1.5 M Pa (wilting point). The management options in the model included cultivar selection, crop rotation, irrigation regimes, nitrogen fertilization, tillage operations and residue management. The crop file comprised common set of parameters related to classification, growth, morphology, residue, nitrogen, harvest index and phenology of the crop to represent different crops and crop cultivars. Model outputs taken were biomass and grain yield at harvesting of the crop.

The model was calibrated during 2009–10 using the observed data on phenology, morphology, growth and harvest from the experiment conducted during 2007–08 for these cultivars in the crop file of the model. The other parameters for the crop file were taken as default with slight adjustments within the range chosen from the CropSyst model or reported by other researchers, so that periodic crop growth like phenological stages, periodic biomass production and final grain yield were matched with experimentally observed values. The crop parameters used in calibrating the model (Table 3) were used for validating the model for the next year same crop rotation except that of observed data on phenology.

The model performance was tested using the following expressions:

*Root mean square error* (RMSE): The RMSE is a frequently used measure of the difference between values predicted by a model and the values actually observed from the experiment that is being modeled. The RMSE values can be used to distinguish model performance in a calibration period with that of a validation period as well as to compare the individual model performance to that of other predictive models (Sommer *et al.,* 2008; Onofri *et al*., 2009).

$$RMSE = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{N}\left[O_i - S_i(b)\right]^2\right)}$$

where, $O_i$ and $S_i$ represent observed and simulated values, n represents number of observed and simulated values used in the comparison.

**Table 2.** Details of the treatments applied to pearlmillet-chickpea cropping system

| Pearl millet (Rainy season 2007 and 2008) | Chickpea (Winter season 2007–08 and 2008–09) | Symbol |
|---|---|---|
| | *Irrigation schedule* | |
| Rainfed | One (pre-sowing) | $I_1$ |
| | Two (pre-and post-sowing) | $I_2$ |
| | Nitrogen | |
| 0 kg/ha | - | $T_1$ |
| 30 kg/ha | - | $T_2$ |
| 60 kg/ha | - | $T_3$ |
| 90 kg/ha | - | $T_4$ |

*Mean absolute error* (MAE): The MAE measures the average magnitude of the errors in a calibrated and validated data, without considering their direction. It measures *accuracy* for continuous variables

$$MAE = \frac{\sum_{i}^{n} |Oi - Si|}{n}$$

*Mean biased error (MBE):* The MBE is a measure of overall bias error or systematic error between the observed and the simulated parameters

$$MBE = \frac{\sum_{i}^{n} (Oi - Si)}{n} \quad MBE = \frac{\sum_{i}^{n} (Oi - Si)}{n}$$

*Sensitivity analysis:* Knowledge about model uncertainty is essential for crop modelling that provides the valuable information crucial for a real understanding of models behaviour and for parameterization purposes. Calibration and validation of a model is a complex process requiring large amount of input data and lack of measured data at appropriate scale is one of the primary sources of uncertainty in simulation of model (Quinton, 1997), thus sensitivity analysis was done to evaluate the response of the model to changes in input parameters and to gain an understanding of how much error could result by over-estimating and under-estimating the parameters values. The sensitivity analysis consists of uniformly increasing or decreasing the value of one model input parameter while keeping the value of the other parameter as constant and then noting the change in biomass yield (or any other output parameter) as a result of changes. The variation of above-ground biomass at physiological maturity (AGB), as model parameters change, was investigated. This was chosen as an indicator because it is a synthetic representation of the culmination of many different biophysical processes. Hence the sensitivity analysis was done for various crop input parameters, viz. phonological degree-days, light to above-ground biomass, N concentration at emergence, N concentration at maturity, Base temperature etc. over ±5, ±10, ±15 and ±20% with above-ground biomass as an output parameter to identify the input parameters to which the model is most sensitive.

## RESULTS AND DISCUSSION

### *CropSyst calibration and validation*

The model was initialized each time prior to pearlmillet sowing 2007. Crop parameters used for this simulation are presented in Table 3. For both crops, pearlmillet and chickpea, calibrated parameters were adjusted for the data set of first year 2007–08 for all fertilizer and water treatments.

After calibration of model for pearlmillet 2007 and chickpea 2007–08, the model was validated by taking the same crops in rotation during next year, i.e. 2008–09. Comparison of experiment and simulated results w.r.t. grain yield and biomass is given in Tables 4 and 5 for the 2 crops. Evaluation of model performance was carried out using statistical tools viz. mean biased error (MBE), mean absolute error (MAE), root mean square error (RMSE) and $R^2$ (Pearson's correlation coefficient). Table 6 summarizes the statistical analysis for these comparisons in pearlmillet and chickpea.

The performance of CropSyst model was quiet satisfactory at low levels of nitrogen, i.e. 0 kg/ha, 30 kg/ha and 60 kg/ha, in case of pearlmillet whereas there was a great deviation between experimental and simulated values in the response of CropSyst model to higher dose of nitrogen 90 kg/ha for all validated parameters, viz. grain yield and biomass. This deviation in the experimental values at higher levels of nitrogen for grain yield and biomass might be due to reduction in N losses in the form of $NH_3$ volatilization (Erguiza *et al.,* 1990) and also due to depletion in the form of exchangeable $NH_4^+$-N because of vigorous growth rate at vegetative stage of pearlmillet which tend to increase the rate of N uptake (Diehmann, 1990). These characteristics of pearlmillet crop might not have been captured in the model due to which simulated values were underestimated at higher levels of N i.e. 90 kg/ha for both the estimated parameters, viz. grain yield and biomass.

The model responded well to limited levels of irrigation with significant $r^2$ values between experimental and predicted in pearlmillet. In chickpea, irrigation did not show any significant influence on grain and biomass yield as predicted by model. This may be because chickpea is a low water-requiring crop and irrigation alone does not have any significant effect on the growth factors. Also, the CropSyst model did not take into account the effect of pre-sowing irrigation on the grain and biomass yield of chickpea. This parameter might not have been incorporated in the model due to which the predicted values of grain yield and biomass at $I_1$ and $I_2$ levels are more or less equal whereas in actual field condition, pre-and post-sowing irrigation had a significant difference in grain yield of chickpea. In pooled statistical analysis, $R^2$ values are lower for grain yield than biomass (Table 6). Also other statistical tools, viz. RMSE, MAE and MBE, are higher for biomass than grain yield. Thus, the model is potentially more accurate at predicting grain yield than biomass.

The root mean square (RMSE) for biomass and grain yield was 1.97 t/ha and 0.36 t/ha which was 5% and 7% of the experimental mean, respectively, for pearlmillet. The corresponding values for chickpea was 0.40 t/ha and 0.17 t/ha which was 8 and 6% respectively. These low values of

RMSE indicated that the CropSyst model is accurate at predicting yield and biomass for pearlmillet and chickpea in pearlmillet–chickpea crop rotation. Also, the higher $R^2$ values for biomass and yield showed that the model is fit for predicting these 2 initial parameters for pearlmillet, whereas for chickpea the model is not fit for prediction of irrigation effect. Also it had been reported that RMSE for spring wheat is 7, 13 and 13% of the observed mean for ET, grain yield and above-ground biomass, respectively (Wang *et al.,* 2006; Pannkuk *et al.,* 1998). Again the higher value of $R^2$ for biomass and yield indicated that the model is fit for predicting these 2 initial parameters (Jalota *et al.,* 2006). As compared to CERES-Wheat model, it has been found that CropSyst model is more appropriate in predicting growth and yield of wheat under different N and irrigation application situations, where RMSE was 0.36 t/ha and 0.63 t/ha.

The accurate results obtained from running the model for the 2 crops under both growing seasons implied that the model can be used in simulating pearlmillet–chickpea crop rotation under varied situations. Although the above situation provides only a limited evaluation of the model,

**Table 3.** Crop parameters for CropSyst simulation of growth and yield of pearlmillet and chickpea

| Parameters | PM 2007 | PM 2008 | CP 2007–08 | CP 2008–09 |
|---|---|---|---|---|
| *Observed parameters* | | | | |
| Degree-days emergence (°C-day) | 116 | 109 | 115 | 120 |
| Degree-days peak LAI (°C-day) | 800 | 700 | 1,150 | 1,130 |
| Degree-days flowering (°C-day) | 720 | 730 | 1,123 | 1,148 |
| Degree-days maximum grain filling (°C-day) | 1,275 | 1,355 | 1,419 | 1,467 |
| Degree-days maturity (°C-day) | 1,458 | 1,720 | 1,785 | 1,743 |
| Maximum expected leaf-area index (LAI) | 5.0 | 5.0 | 4.0 | 4.0 |
| Maximum harvest index | 0.25 | 0.25 | 0.40 | 0.40 |
| N uptake adjustment (0–2) | 0.50 | 0.50 | 1.00 | 1.00 |
| Maximum nitrogen concentration at emergence (kg/kg) | 0.05 | 0.05 | 0.05 | 0.05 |
| Maximum nitrogen concentration at maturity (kg/kg) | 0.001 | 0.001 | 0.02 | 0.02 |
| Minimum nitrogen concentration at maturity (kg/kg) | 0.0005 | 0.0005 | 0.007 | 0.007 |
| *Extracted from CropSyst manual* | | | | |
| Maximum water uptake rate (mm/day) | 15 | 15 | 13 | 13 |
| Light to above ground biomass conversion (g/MJ) | 4.0 | 4.0 | 3.0 | 3.0 |
| *Parameter set by calibration* | | | | |
| Specific leaf area ($m^2$/kg) | 25.0 | 25.0 | 22.0 | 22.0 |
| Stem/leaf partition coefficient | 0.3 | 0.3 | 1 | 1 |
| Leaf duration(°C-day) | 700 | 700 | 700 | 700 |
| ET crop coefficient | 1.00 | 1.00 | 1.20 | 1.20 |
| Critical canopy water potential (J/kg) | –900 | –900 | –900 | –900 |
| Wilting canopy water potential (J/kg) | –1,800 | –1,800 | –1,800 | –1,800 |
| Biomass/transpiration coefficient (K Pa) | 7.0 | 7.0 | 5.0 | 5.0 |
| *Site -specific data from literature* | | | | |
| Cutoff temperature (°C) | 40 | 40 | 20 | 20 |
| Optimum mean daily temperature (°C) | 20 | 20 | 10 | 10 |
| Maximum root depth (m) | 1.8 | 1.8 | 0.8 | 0.8 |
| Base temperature | 10 | 10 | 5 | 5 |

**Table 4.** Calibration (2007) and validation (2008) of CropSyst in pearlmillet under rainfed (R) condition and different nitrogen regimes treatments for grain yield and biomass

| Treatment | Grain yield 2007(t/ha) | | Biomass 2007(t/ha) | | Grain yield 2008(t/ha) | | Biomass 2008(t/ha) | |
|---|---|---|---|---|---|---|---|---|
| | Observed | Predicted | Observed | Predicted | Observed | Predicted | Observed | Predicted |
| RT1 | 1.649 | 1.443 | 7.275 | 5.770 | 1.634 | 1.565 | 7.767 | 6.162 |
| RT2 | 2.222 | 2.441 | 9.014 | 9.645 | 2.198 | 2.001 | 9.883 | 8.003 |
| RT3 | 2.740 | 2.776 | 10.053 | 11.103 | 2.732 | 2.200 | 11.667 | 8.800 |
| RT4 | 2.999 | 2.783 | 11.369 | 11.133 | 3.019 | 2.256 | 12.634 | 9.022 |

R, Rainfed; $T_1$, 0 kg N/ha (control); $T_2$, 30 kg N/ha; $T_3$, 60 kg N/ha; $T_4$, 90 kg N/ha

**Table 5**. Calibration (2007–08) and validation (2008–09) of CropSyst in chickpea under varied water regimes for grain yield and biomass under pearlmillet–chickpea cropping system

| Treatment | Grain yield 2007–08 (t/ha) | | Biomass 2007–08 (t/ha) | | Grain yield 2008–09(t/ha) | | Biomass 2008–09(t/ha) | |
|---|---|---|---|---|---|---|---|---|
| | Observed | Predicted | Observed | Predicted | Observed | Predicted | Observed | Predicted |
| $I_1N_{20}$ | 0.922 | 1.140 | 3.317 | 2.848 | 0.925 | 1.191 | 3.320 | 2.992 |
| $I_2N_{20}$ | 1.173 | 1.139 | 3.300 | 2.848 | 1.164 | 1.197 | 3.311 | 2.992 |

$I_1$, 1 pre-sowing irrigation; $I_2$, 2 irrigation (pre- and post-sowing); $N_{20}$, 20 kg N/ha

**Table 6.** Statistical summary comparing observed data with simulated values

| Crop | Parameter | N | Observed mean | Predicted mean | $R^2$ | MSE | MAE | MBE |
|---|---|---|---|---|---|---|---|---|
| Pearlmillet | Biomass (t/ha) | 8 | 9.96 | 8.10 | 0.96 | 1.97 | 1.67 | 1.25 |
| | Grain (t/ha) | 8 | 2.40 | 2.18 | 0.90 | 0.36 | 0.28 | 0.22 |
| Chickpea | Biomass (t/ha) | 4 | 3.31 | 2.95 | 0.70 | 0.40 | 0.39 | 0.39 |
| | Grain (t/ha) | 4 | 1.05 | 1.17 | 0.62 | 0.17 | 0.14 | -0.12 |

N, Number of observations; $R^2$, Pearson's correlation coefficient; RMSE, root mean square error; MBE, mean biased error; MAE, mean absolute error

the model should be further tested as and when more data from more treatments in different locations and years if become available for practical and real time application. However, for the purpose of this study we are confident in that the model worked sufficiently well to warrant the exploration of the effect of different N levels on the yield of pearlmillet and different water regimes on the yield of chickpea in pearlmillet – chickpea crop rotation.

### *Sensitivity analysis*

To test the model (CropSyst) sensitivity to several crop input parameters, sensitivity analysis was done by varying the values of crop input parameters by ±5, ±10, ±15 and ±20%, to find the per cent change in predicted biomass yield. There was no change in biomass upon sensitivity analysis for crop input parameters, i.e. maximum harvest index and cut-off temperature (Table 7; Fig. 1). While the model is very much sensitive to light to above-ground biomass conversion (g/MJ), specific leaf area ($m^2$/kg), base temperature, biomass/ transpiration coefficient and phenological degree-days which account for more than ± 10% variation in biomass yield (Table 7; Fig. 1). In this range of more than ± 10% variation in biomass yield, some of the parameters also account for 90–100% variation in biomass yield. These parameters are base temperature and phenological degree-days which have a more pronounced effect on negative side than on positive side and parameter light to above biomass coefficient had more effect on per cent change in biomass on positive side than on negative side. Thus, light to above-ground biomass conversion and phenological degree-days needs more accuracy in determination of biomass yield. Specific leaf area almost has a same effect on per cent change in biomass on both positive and negative side. Specific leaf area corresponds to leaf area per unit of leaf biomass. It is used to determine the amount of green area index produce in a day. Biomass yield increases with the increase in specific leaf area and vice versa. With the decrease in phenological degree-days, biomass yield decreases as because the leaf area decreases

**Table 7.** Per cent change in biomass of the various crop input parameters by varying the parameter in CropSyst model

| Change in biomass (%) | Crop input parameter |
|---|---|
| 0 % | Maximum harvest index |
| | Cut off Temperature |
| ± 0-10% | Optimum mean daily temperature (°C) |
| | Maximum N concentration at emergence |
| | Maximum N concentration at maturity |
| | Leaf duration (°C-day) |
| ± >10% | Critical canopy water potential (J/kg) |
| | Wilting canopy water potential (J/kg) |
| | N uptake adjustments (0–2) |
| | Base temperature (°C) |
| | Maximum rooting depth (m) |
| | Maximum expected leaf-area index (LAI) |
| | Stem/leaf partition coefficient |
| | Biomass/transpiration coefficient (KPa) |
| | Light to above-ground biomass conversion (g/MJ) |
| | Specific leaf-area ($m^2$/kg) |
| | Phenological degree-days |
| | ET crop coefficient |
| | Maximum water uptake rate (mm/day) |

due to which the yield decreases. So the model is also sensitive to this parameter.

Biomass variation of ± 0–10% is due to, optimum mean daily temperature, leaf duration, maximum N concentration at emergence and maturity (Table 7; Fig. 1). Biomass/transpiration coefficient represents the above-ground biomass production/m of transpiration under given condition of atmospheric vapour density deficit. Crop growth occurs during active growth until maturity and only when evapotranspiration model has determined potential transpiration. In sensitivity analysis of the model, it has been found that biomass/transpiration coefficient for pearlmillet–chickpea crop rotation accounts for almost 100% variation in biomass yield. Thus, this parameter needs more accuracy in predicting biomass yield for pearlmillet–chickpea crop rotation.

In the model, above-ground crop growth is represented in terms of above-ground biomass accumulation, which is dependent on intercepted radiation, transpiration (water dependent) and plant nitrogen uptake (nitrogen dependent). Each of these factors is capable of limiting growth. The optimum temperature for growth is the temperature above which growth will not be affected which affects the biomass accumulation indirectly. Yield decreases with increase in optimum temperature and vice-versa. The ET crop coefficient and stem leaf partition coefficient also had more effect on biomass production than the other coefficients/parameters. Yield decrease with the increases in ET crop coefficient at full canopy and vice versa. Wilting canopy water potential is the leaf water potential at the

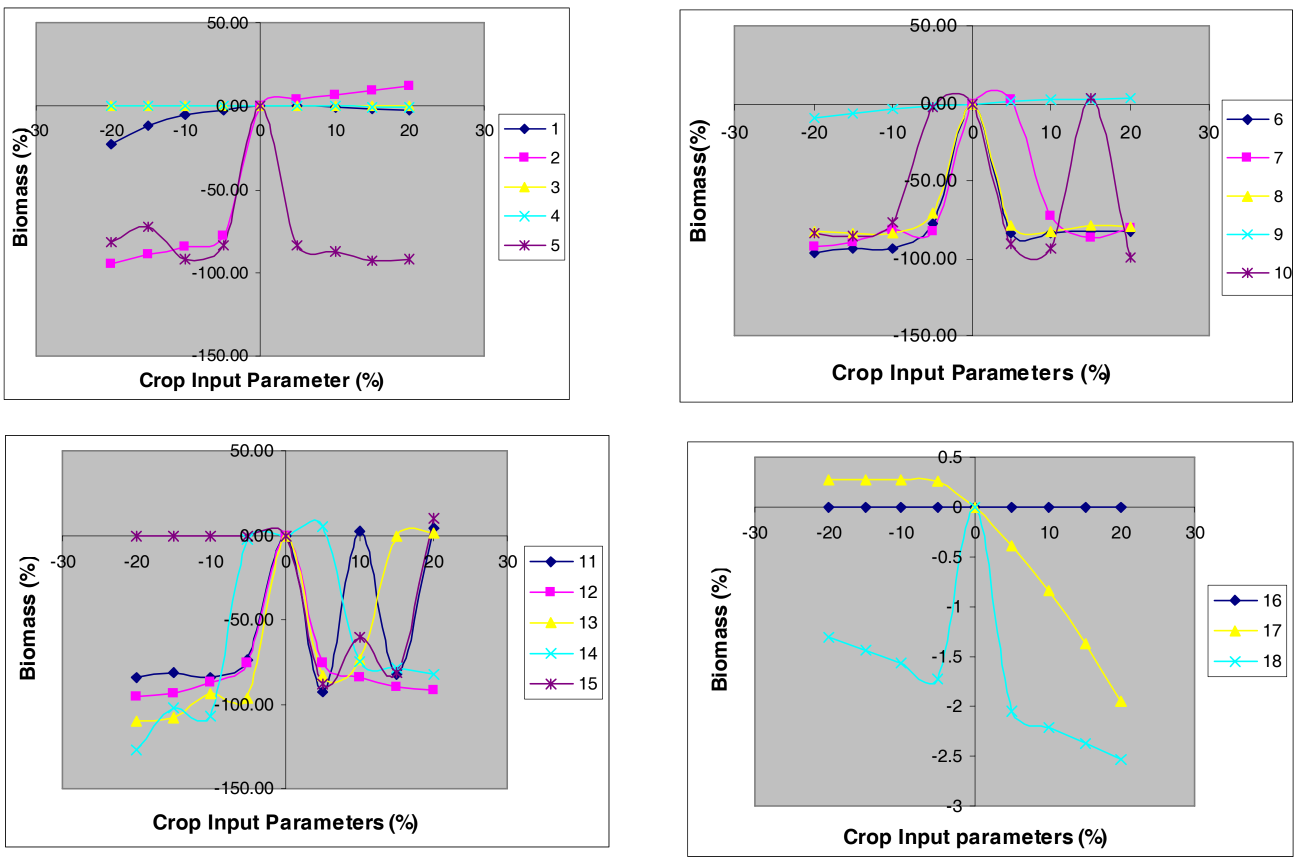


**Fig. 1.** Schematic representation of the sensitivity analysis of input parameters used in CropSyst model

| | | | |
|---|---|---|---|
| 1 | Phenology degree-days (°C-days) | 10 | ET crop coefficient |
| 2 | Base temperature (°C-days) | 11 | Maximum water uptake rate (mm/day) |
| 3 | Cut off temperature (°C-days) | 12 | Critical canopy water potential (J/kg) |
| 4 | Optimum mean daily temperature (°C-days) | 13 | Wilting canopy water potential (J/kg) |
| 5 | Maximum rooting depth (m) | 14 | Biomass/ transpiration coefficient (KPa) |
| 6 | Maximum expected leaf-area index | 15 | Light to above ground biomass conversion (g/MJ) |
| 7 | Specific leaf area ($m^2$/kg) | 16 | Maximum harvest index |
| 8 | Stem/ leaf partition coefficient | 17 | Maximum N concentration at emergence (kg/kg) |
| 9 | Leaf duration (°C-days) | 18 | Maximum N concentration at maturity (kg/kg) |

point when the crop can no longer extract water from the soil and is used in calculation of actual transpiration in the model. The maximum water uptake is the maximum water uptake for the fully developed green crop, completely covering the ground unstressed, fully watered, with unrestricted root growth and under environmental conditions providing large atmospheric demand. Stem/ leaf partition coefficient adjusts the proportion of cumulative biomass that is partitioned to green leaf area production as the crop accumulates biomass during the active growth stage. The yield decreases with increase in critical canopy water potential, stem/leaf partition coefficient and vice versa.

Thus, CropSyst introduces several conceptual simplifications and works with a smaller set of input parameters. The core of the simulation engine for crop growth is based on 2 simple functions for radiation and transpiration-dependent growth (Stockle and Nelson, 2003), which rely on two input parameters, i.e. the light-to-biomass conversion coefficient (*LtBC*, as kg/MJ), and the water: biomass conversion ratio (*BTR*, as kg/m$^3$ kPa).

Thus, CropSyst model simulates biomass and grain yield well for pearl millet and chickpea in pearlmillet–chickpea crop rotation. The model underestimates the biomass and grain yield at higher doses of nitrogen in case of pearmillet under rainfed condition, but simulated well the yield and biomass at all irrigations levels in case of chickpea. The model is sensitive to parameters like light to above-ground biomass conversion, specific leaf area, base temperature and phenological degree-days and is not sensitive to parameters like maximum harvest index and cut-off temperature. The scenario in this work was limited to pearl millet and chickpea at one site only, different scenarios can be considered in future work to let possible interactions with soil and weather inputs to come up.

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