Water productivity and yield analysis of groundnut using CropSyst simulation model in hyper arid partially irrigated zone of Rajasthan**

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ABSTRACT

CropSyst is one of the most important process-oriented simulation models largely used for field crops all over the world to study the effect of climate, soil and management practices on crop productivity. In the present study, we have calibrated and validated the CropSyst model for groundnut crop grown at farmer’s field in IGNP Stage-II of Bikaner. CropSyst model was calibrated using the experimental data of crop parameters, soil profile data and observed daily weather data of experimental site for 2012 and validated the experimental data of crop growth and yield parameters for 2013. The results of the study showed that the CropSyst model simulated the crop growth parameter data viz. green area index, seed yield, above ground biomass and N-uptake of groundnut reasonably well. The seed yield, above ground biomass and N-uptake was validated well by the model with relative error of 3.3, 2.2 and 8.4 %, respectively. The total water applied in groundnut was 728.9 and 619.6 mm in 2012 and 2013, respectively out of this 664.9 and 530.5 mm consumed in evapotranspiration.

Key words: Calibration, CropSyst model, Groundnut, IGNP, Validation.

INTRODUCTION

The concept of water productivity is based on “producing more food from the same water resources” or “producing the same amount of food from less water resources”. In a broad sense, productivity of water is related to the value or benefit derived from the use of water. It includes various aspects of water management and is very relevant for arid and semi-arid regions (Molden and Sakhivadiel, 1999; Molden et al., 2001; Droogers and Bastiaanssen, 2002; Kijne et al., 2003). Water productivity can be expressed in terms of grain (or seed) yield per amount of water used in different processes such as transpiration, evapotranspiration and percolation and provides a proper diagnosis of where and when water could be saved. Increasing water productivity is particularly appropriate where water is scarce compared with other resources involved in production.

Groundnut is the major kharif crop grown by the farmers of Bikaner, Churu, nearest area of Sikar and Nagaur of IGNP stage II due to higher production and economically sound price in market. The crop is having very high water requirement and grown in interdunal plains with sprinkler irrigation systems. It has been observed that the farmers use over irrigation for growing the crops resulting in low crop water productivity. Hence technological interventions are required to improve yield and water productivity of the area. In order to improve water management and its productivity, it needs to reveal the cause effect relationships between hydrological variables such as evaporation, transpiration, percolation and biophysical variables such as dry matter and grain yields under different eco-hydrological conditions (Singh et al., 2006). Measurements of the required hydrological variables under field conditions are difficult and need sophisticated instrumentation. Moreover, field experiments yielding site-specific information are very expensive, laborious and time consuming. However, suitable models like the CropSyst (Cropping Systems Simulation Model) in combination with field experiments offer the great opportunity to gain detailed insights into the system behaviour in space and time. Simulation models are an important tool to understand plant–soil interactions on water balance components and their effects on crop growth. They can assist field experimentation because direct measurement of all elements of the crop water balance (evaporation, transpiration, drainage, runoff and profile water content change) is often not possible.

CropSyst (Stockle and Nelson, 1999) is a process-based model to simulate crop growth and water dynamics in
the soil-plant atmosphere continuum. It has been widely used for cereals and other cropping systems (Stockle et al., 1994). The accuracy of these predictive models depends upon the proper identification of input parameters. As the information pertaining to use simulation models to predict yield and water balance for groundnut are lacking for IGNP stage-II command area. Therefore, the study was planned to evaluate CropSyst model for simulation of crop yield and water productivity of groundnut.

MATERIALS AND METHOD

Site description: Field experiments were carried out on farmer field during kharif 2012 and 2013 at village Bajju (72°47'79"E longitude and 28°14'23"N latitude and 234.7 m above mean sea level) in Bikaner district of Rajasthan. Soil physical (texture and bulk density) and chemical (pH, electrical conductivity, cation exchange capacity, ammonical-nitrogen and nitrate - nitrogen) properties of experimental field were determined up to 1.0 m depth following the standard procedures (Table 1). The sand, silt and clay contents were determined with Hydrometer method (Bouyoucos, 1962), bulk density with core method (Blake and Hartge, 1986), EC was measured with conductivity meter and pH with pH meter (Richards, 1954), Organic carbon by Wet digestion method (Walkley and Black, 1934). Ammonical nitrogen was determined by Nessler's method (Peech et. al., 1947) and nitrate nitrogen was determined by Phenoldisulphonic acid method (Harper, 1924 and Prince 1945). The field capacity was determined in the field by covering the fully saturated soil surface with a polythene sheet and measuring the moisture content after 24 hours. Soil moisture up to 1 meter depth (at an interval of 0-10 cm.) was determined with a TDR-probe at regular interval during cropping season. In order to check the variability of field for soil properties, soil samples were collected from different spots of the experimental field. The ground water at the experimental site was less than 10 m deep and was determined with Piezometer. Daily weather data on maximum and minimum temperature, maximum and minimum relative humidity, wind speed and rainfall during the crop growth period were recorded at meteorological observatory situated at CAZRI, RRS, Bikaner (Table 2).

Crop management: A pre-sowing irrigation of 100 mm was applied on 23 May, 2012 and 22 June, 2013 during first year and second year, respectively. When water content in surface soil dried to field capacity, field was prepared with disking, followed by harrowing and planking. Groundnut cultivar TG-1with 100 kg ha⁻¹ seed rate was sown on 25th May 2012 in first year and on 23rd June 2013 in second year. The crop was sown at a spacing of 30 cm x 10 cm distance. Nitrogen @ 20 kg ha⁻¹ and P₂O₅ @ 40 kg ha⁻¹ were applied to the crop. Entire nitrogen and phosphorus was applied at the time of sowing of the crop. Disease and insect-pest control were practiced as required. Crop was harvested on 24th October 2012 and 14th November 2013, respectively during both the years.

Crop growth and yield data: Plant samples were taken at frequent intervals (once in a month) and at harvest of crop for estimation of crop-based phenological growth and yield parameters viz. leaf area, rooting depth, above-ground biomass (dry weight at 70°C) and total plant nitrogen content. Grain yield was computed from crop cutting of (1 x 1) m² area at five different locations in the field and is converted in kilogram/ha (kg ha⁻¹).

Model setting: CropSyst crop model (Stockle et al., 2003) version 4.15.24 was used to simulate seed yield, above ground biomass, water balance, N-uptake and water productivity for groundnut. The CropSyst model was calibrated using the observed data on phenological parameters/stages (emergence, flowering, pod formation and physiological maturity) and harvest index from the experiment conducted during 2012 for groundnut in the crop file of the model. The other parameters for the crop file were taken as default with slight adjustments. These adjustments were made within the range reported from elsewhere (Jalota et al., 2006), so that the periodic crop growth like

| Soil Depth (m) | 0-0.15 | 0.15-0.25 | 0.25-0.50 | 0.50-0.75 | 0.75-1.00 |
|---------------|--------|-----------|-----------|-----------|-----------|
| Sand (%)      | 86.5   | 85.4      | 85.3      | 84.4      | 84.1      |
| Silt (%)      | 7.8    | 8.4       | 8.6       | 9.0       | 9.3       |
| Clay (%)      | 5.7    | 6.2       | 6.0       | 6.5       | 6.5       |
| BD (Mg m⁻³)   | 1.55   | 1.53      | 1.53      | 1.54      | 1.52      |
| CEC [c mol (P⁺) kg⁻¹] | 4.2  | 4.5       | 4.5       | 4.8       | 5.0       |
| pH₂           | 7.6    | 7.8       | 7.9       | 7.9       | 8.0       |
| FC (m³m⁻³)    | 0.153  | 0.157     | 0.164     | 0.168     | 0.167     |
| PWP (m³m⁻³)   | 0.077  | 0.079     | 0.082     | 0.083     | 0.086     |
| Water content (m³ m⁻³) | 0.067 | 0.069   | 0.069     | 0.076     | 0.074     |
| NO₃-N (kg N ha⁻¹) | 13.15 | 11.09    | 11.49     | 11.01     | 9.13      |
| NH₄-N (kg N ha⁻¹)   | 33.43  | 29.12     | 28.45     | 26.97     | 22.51     |
| SOM (%)        | 0.13   | 0.07      | 0.08      | 0.12      | 0.11      |
| EC (d S m⁻¹)   | 0.18   | 0.11      | 0.12      | 0.15      | 0.10      |
Table 2: Monthly meteorological data

| Month | Temperature (°C) | Relative humidity (%) | Total rainfall (mm) | Evaporation (mm) | Solar Radiation (MJ m\(^{-2}\) d\(^{-1}\)) |
|-------|------------------|-----------------------|---------------------|-----------------|------------------------------------------|
|       | Maximum          | Minimum               | Maximum             | Minimum         | Maximum                                  |
| May   | 43.5             | 25.2                  | 33.4                | 18.7            | 23.0                                     |
| June  | 38.2             | 25.0                  | 31.8                | 20.5            | 26.0                                     |
| July  | 39.1             | 25.8                  | 32.7                | 20.8            | 26.0                                     |
| August| 38.0             | 28.4                  | 31.6                | 21.8            | 24.0                                     |
| September | 31.0          | 20.4                  | 31.4                | 19.6            | 21.0                                     |
| October | 26.0             | 20.1                  | 31.0                | 19.5            | 20.0                                     |
| November | 22.1             | 9.4                   | 27.6                | 16.6            | 19.0                                     |
| December | 24.1             | 9.4                   | 28.6                | 16.6            | 19.0                                     |
| January | 24.1             | 9.4                   | 28.6                | 16.6            | 19.0                                     |
| February | 24.1             | 9.4                   | 28.6                | 16.6            | 19.0                                     |
| March  | 37.5             | 27.6                  | 37.6                | 27.6            | 37.6                                     |

Data taken from meteorological observatory of Regional Research Station, Central Arid Zone Research Institute, Bikaner. Y1 = year 2012-13, Y2 = year 2013-14

Table 3: Crop parameters used for calibration of groundnut

| Parameters                                      | Value |
|------------------------------------------------|-------|
| Thermal time accumulation                       |       |
| Base temperature (°C)                          | 10    |
| Cutoff temperature (°C)                        | 40    |
| Phenology                                       |       |
| Degree days emergence (°C day)                  | 210   |
| Degree days maximum rooting depth (°C day)      | 215   |
| Degree days end of vegetative growth            | 220   |
| Degree days begin flowering (°C day)            | 250   |
| Degree days begin filling (boll opening) (°C day)| 350   |
| Degree days physiological maturity (°C day)     | 1200  |
| Canopy growth                                   |       |
| Initial green leaf area index (m\(^2\) m\(^{-2}\)) | 0.011 |
| Maximum expected LAI (m\(^2\) m\(^{-2}\))       | 4.0   |
| Specific leaf area, SLA (m\(^2\) kg\(^{-1}\))   | 20    |
| Fraction of max. LAI at physiological maturity  | 0.50  |
| Leaf/stem partition coefficient, SLP             | 2     |
| Leaf water potential that begins reduction of canopy expansion (J/kg) | -800 |
| Leaf water potential that stops canopy expansion (J/kg) | -1200 |
| Harvest                                         |       |
| Unstressed harvest index (HI)                   | 0.36  |
| Biomass translocation to grain fraction         | 0.34  |
| Root                                            |       |
| Maximum rooting depth (m)                       | 1.50  |
| Root length per unit root mass (km/kg)          | 100   |
| Max. surface root density at full rooting depth (cm cm\(^{-3}\)) | 3 |
| Curvature of root density distribution          | 2     |

Phenological stages, periodic biomass and final seed yield were matched with the experimentally observed values. The crop parameters used in the model are given in table 3. During the first step of calibrating the CropSyst model, simulated phenological stages (degree days) were calculated from the observed weather data, soil characteristics and the base temperature of the crops. Morphological parameters observed from the experiment and extracted from the literature were also adjusted in the CropSyst model. Harvest index (HI) parameter was calculated from the observed data. The calibrated model was validated for grain yield, above-ground biomass (AGB), N uptake and soil moisture content using the observed data on crop parameters of groundnut in 2013 by comparing simulation outputs with observed data. Statistical test was used to calculate the percentage of difference between measured and predicted values of the crop in each growing season.

RESULTS AND DISCUSSION

Soil characteristics: The physical and chemical characteristics of the soil of the experimental site are given in Table 1. The soil was loamy sand (87.7% sand, 7.5% silt and 5.5% clay) with low soil organic carbon, alkaline in reaction and non saline in nature. The bulk density, Cation exchange property (CEC), pH, permanent wilting point (PWP) and field capacity (FC) ranged between 1.51 to 1.55 Mg m\(^{-3}\), 4.1 to 5.1 cmol (p\(^+\)) kg\(^{-1}\), 7.5 to 8.0, 0.076 to 0.086
m$^{-3}$m$^{-3}$ and 0.152 to 0.168 m$^{-3}$m$^{-3}$, respectively. CEC, pH, PWP, FC and water content of soil increased with increase in soil depth whereas, bulk density, NO$_3$-N, NH$_4$-N, soil organic matter and electrical conductivity decreased with increase in soil depth. The initial water content, nitrate-nitrogen and ammonical-nitrogen, soil organic carbon and electrical conductivity ranged between 0.061 to 0.073 and 0.072 to 0.079 m$^{-3}$m$^{-3}$, 9.12 to 14.37 and 9.13 to 11.92 kg ha$^{-1}$, 25.09 to 37.28 and 19.92 to 29.57 kg ha$^{-1}$, 0.06 to 0.13 and 0.07 to 0.12 per cent and 0.09 to 0.17 and 0.11 to 0.18 dSm$^{-1}$, respectively during 2012 and 2013.

**Weather data:** The climate of Bikaner is characterized by its dryness, extremes of temperature and scanty rainfall. The observed meteorological data during the growing season of groundnut indicated that total rainfall was 314 mm and 329 mm and pan evaporation was 702 mm and 588 mm for 2012 and 2013, respectively. In 2012 and 2013, the total amount of irrigation applied was 405 mm and 420 mm, respectively. Due to light soil texture, more number of irrigation was required.

**Calibration and validation of the model for yield and N-uptake:** The model was calibrated by using the observed data on morphology, phenology, growth and harvest parameters from the experiment conducted during the year 2012.

The calibrated model was implemented to generate data on periodic biomass, green area index (GAI), seed yield and N-uptake of the groundnut. For calibration and validation of model in groundnut crop, the observed data of green area index (GAI), seed yield, above ground biomass (AGB) and N-uptake were used to compare the simulated output of model during 2012 and 2013, respectively. The simulated GAI, seed yield, above ground biomass and N-uptake were closer to the observed values of groundnut during both years. The simulated GAI agreed well with field measurements from 50 days after sowing (DAS) to maturity (Table 4). The maximum GAI 2.8 and 3.8 m$^2$m$^{-2}$ was observed at 60-65 DAS which was slightly lower than simulated GAI during calibration (3.0 m$^2$m$^{-2}$) and validation (4.3 m$^2$m$^{-2}$), respectively. The observed and simulated GAI matched well with a RMSE of 0.241 and 0.305 during 2012 and 2013, respectively.
Seed yield of groundnut calibrated and validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. The calibrated and validated yield (2942 and 3023 kg ha\(^{-1}\)) of groundnut simulated by the model was agreed to the observed groundnut yield of 2856 kg ha\(^{-1}\) and 2926 kg ha\(^{-1}\) in 2012 and 2013, respectively, with mean absolute error of 86 and 97 kg ha\(^{-1}\). The relative error between simulated and observed seed yield was 3.0 % and 3.3 % during 2012 and 2013, respectively (Table 5) which shows that the predictions of seed yield by the CropSyst model is very good. Similar to seed yield, the simulated AGB during validation also matched with field data with relative error of 2.2 %. The simulated N-uptake of groundnut (108.3 kg ha\(^{-1}\)) during calibration was also matched moderately with the observed N-uptake (122.3 kg ha\(^{-1}\)) with the absolute and relative error of 14 kg ha\(^{-1}\) and 11.4 %, respectively. Simulated N-uptake (145.5 kg ha\(^{-1}\)) during validation was higher than observed N-uptake (134.2 kg ha\(^{-1}\)) with absolute and relative error 11.3 and 8.4 %, respectively (Table 5). Increased uptake of N during 2005 seems to be due to the fact that uptake of nutrient is a product of biomass accumulated by particular part and its nutrient content. Simulations of early groundnut AGB development matched the field data reasonably well. Final aboveground biomass, however, was overestimated by the model. The drop in aboveground biomass of the groundnut around maturity time was not properly captured by the model. As it was set for optimal conditions, CropSyst could not properly simulate the late season plant stress that impaired growth on these sites.

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