Field Crops Research 219 (2018) 76–86

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Responses of soybean to water stress and supplemental irrigation in upper Indo-Gangetic plain: Field experiment and modeling approach

Prakash Kumar Jha[a], Soora Naresh Kumar[b], Amor V.M. Ines[a,c,*]

[a] Department of Plant, Soil, and Microbial Sciences, Michigan State University, MI 48824, USA
[b] Centre for Environment and Climate Resilient Agriculture, Indian Agricultural Research Institute (IARI), New Delhi 110012, India
[c] Department of Biosystems and Agricultural Engineering, Michigan State University, MI 48824, USA

ARTICLE INFO

Keywords:
Soybean
Water stress
Supplemental irrigation
Crop model
InfoCrop

ABSTRACT

Understanding better the impacts of extreme dry spell regimes is essential for optimizing water management under a changing and variable climate. Using field experiments and modeling studies, we examined the impacts of dry spells in soybean and identified better management of water resources under varying water-scarce conditions. Field experimental data from soybean (PUSA-2614) experiments (July–Oct 2014; IARI, New Delhi, India) were used to calibrate and validate InfoCrop-Soybean model. This model was used to simulate optimal timing of irrigation under different dry spell scenarios. Results showed that plants subjected to water stress during flowering and vegetative growth stages had significantly lower yields and total dry matter (TDM). Supplemental irrigation significantly increased TDM and yields. InfoCrop-Soybean could simulate plant responses to water stress, at various stages of crop growth, and to supplemental irrigation, with acceptable accuracy. The crop model was further used to simulate impacts of dry spells at different intensities and durations on soybean growth and yields by creating drought scenarios for the New Delhi region using 36 years of weather data (1978–2014). Simulations showed that a 20% reduction in rainfall during any fortnight (every 15th day) of the cropping season does not affect crop yield significantly. However, dry spells (50% reduction in rainfall or more) in August and early September led to reduced yields, while supplemental irrigation during those dry spells could reduce yield losses. We envisage that the results of this study can help better manage water in soybean cultivation under dryland condition.

1. Introduction

Quantifying the effects of dry spells on soil moisture availability and crop performance is of paramount importance in dryland agriculture (Steduto et al., 2012; Jones, 2013; Osakabe et al., 2014; Moshelion et al., 2015; Pessarakli, 2014, 2016; Sadras et al., 2016). This is particularly pressing nowadays because of the expected water scarcity that could impact South Asia in the near future due to global environmental change (IPCC, 2014). Evidence suggests that monsoon-break-days are increasing, and the frequency of monsoon depressions is declining (IPCC, 2014). Rainfall deficit of more than 20% from climatological mean could lead to meteorological drought, whose impacts on soil moisture availability could lead to substantial agricultural drought. In India, rainfall received during the southwest monsoon season is critical for a successful agricultural season (Revadekar and Preethi, 2012; Prasanna, 2014).

Soybean [*Glycine max* (L.) Merr.], the third most widely grown crop in India (after rice and wheat), produces 10.5 Mt (~10.9 Mha acreage) with a low productivity of 965 kg ha^{-1} (FAOSTAT, 2014), and is mainly cultivated as a rainfed crop. Water stress is the most dominant factor causing the yield gap (Sentelhas et al., 2015). Water stress is particularly damaging during flowering, seed setting and seed filling. It reduces yield by lessening the number of pods, seeds and seed weight (Pedersen and Lauer, 2004), which is enhanced by a simultaneous temperature stress (Hatfield and Prueger, 2011; Wiebbecke et al., 2012). Depending on the variety, soybean-growing period ranges from 90 to 120 days and requires 450–700 mm of water during the growing season (Doorenbos and Kassam, 1979; Ludwig et al., 2011). Under different agro-climates, cultivars may be improved by cultivar selection and genetic improvement to better adapt to the varying environmental conditions (Sinclair et al., 2007, 2008, 2010, 2014; Gilbert et al., 2011; Li et al., 2013; Lehmann et al., 2013; Devi et al., 2014).

Evaluating new genetic resources in the field under different agro-climatic conditions however requires a lot of resources (time, labor, money), but can be aided by crop simulation models. Crop models have been used in the past for estimating potential production of crops (Van

* Corresponding author at: Department of Plant, Soil, and Microbial Sciences, 1066 Bogue St., Michigan State University, East Lansing, MI 48824, USA.
E-mail address: inesamor@msu.edu (A.V.M. Ines).

https://doi.org/10.1016/j.fcr.2018.01.029
Received 19 May 2017; Received in revised form 24 January 2018; Accepted 25 January 2018

Wart et al., 2013; Espe et al., 2016; Morell et al., 2016); in yield gap analysis, to determine and correct factors that can increase actual crop yield (Bhatia et al., 2006; van Ittersum et al., 2013; Grassini et al., 2013, 2015; Zhang et al., 2016), in decision support (Guillaume et al., 2016; Robert et al., 2016), on climate change impact and adaptation assessments (Aggarwal et al., 2009; Rosenzweig et al., 2014; Kumar et al., 2014; Kumar et al., 2016; Boote et al., 2016; Gummadi et al., 2016; Fan et al., 2017; Fodor et al., 2017; Martre et al., 2017; Lobell and Asseng, 2017), among others. Soybean growth and its responses to water stress had been simulated using crop models (Dietzel et al., 2016; Battisti et al., 2017; Giménez et al., 2017). Nielsen et al. (2002) used RZWQM and CROPGRO-Soybean models to estimate water stress and its impacts on soybean yield under a dryland condition.

In this study, we evaluate soybean responses to water stress under different agro-climatic scenarios in the Upper Indo-Gangetic Plain. Specifically, this study aims (i) to quantify the responses of soybean to water deficits through field experiments, (ii) to simulate soybean growth and yield in response to soil moisture deficits, and (iii) to simulate suitable water management strategies for optimizing yield under drought scenarios. We envisage that this study would help better understand the management of water for soybean cultivation in rainfed conditions.

2. Materials and methods

Three activities were conducted to meet the objectives of the study. First, a field experiment was conducted to quantify the performance of soybean under water stress conditions at different growth stages. Second, the experimental data was used to calibrate and verify the InfoCrop-soybean model. Third, the calibrated model was applied to simulate optimal timing of irrigation under different drought scenarios.

2.1. Field experiment

2.1.1. Treatments

To study water stress effects on soybean, field experiments were conducted during monsoon season of 2014 at IARI, New Delhi (28°38′ N, 77.10′ E). A field experiment was conducted with a soybean variety DS 2614 during the monsoon season of 2014 with plot sizes of 6 m x 4 m. Pre-sowing seedbed was prepared by using a cultivator to till the soil (20–25 cm deep). Soybean seeds were sown on 14th July 2014 with a row spacing of 50 cm and plant spacing of 15 cm, and depth of planting was at 5 cm. An initial dose of nitrogen (20 kg/ha) was applied (urea; 45-0-0; N-P_2O_5-K_2O) to the seedbeds as the soil in the field was low in nitrogen. We did not inoculate an initial rhizobium culture, but later nodules were observed in roots as they associated with soil bacterium (Rhizobium) population found at experimental field. Analysis of microbial population and their impact on soybean nitrogen uptake is beyond the purview of our study.

Five field experimental treatments were laid out on a homogenous field, three for water stress at vegetative stage, flowering stage and pod filling stage, and two treatments as fully rainfed and with supplemental irrigation (Table 1). To provide water stress, plots were covered with a rainout shelters (6 m x 4 m) framed with polythene walls on the top and two sides to prevent rainfall water from entering. No irrigation was given to these plots during artificial stress periods (stress were provided by manual installation of shelters to the plots). To minimize the subsurface water flow and its effects, plots were surrounded by 0.5-m channels, which helped draining the lateral flow from rainfall; sampling plants to measure physiological responses were performed at the central locations of the plots to minimize the impacts of lateral flow to crop response. Each treatment had four replications.

2.1.2. Measurements

Weather parameters (rainfall, minimum and maximum temperature, solar radiation) were recorded and collected at the IARI meteorological observatory, New Delhi.

Table 1
Period of stress given within a particular treatment.

Treatment	Condition	Period of stress (DAS)
T_1 (RF-VS-RF)	Rainfed	Up to 18
	Stress during Vegetative stage	19–53 (shelter application)
	Rainfed	54–101
T_2 (RF + BS)	Rainfed[a]	actual rainfall distribution
T_3 (RF-FS-RF)	Rainfed	Up to 53
	Stress during Flowering stage	54–79 (shelter application)
	Rainfed	80–103
T_4 (RF-PFS)	Rainfed	Up to 79
	Stress during Pod Filling stage	80–105 (shelter application)
T_5 (SI)	Supplemental Irrigation on 45 and 86 DAS	No stress

Note: DAS- Days after sowing, RF- Rainfed, VS- Stress during vegetative stage, RF + BS- Rainfed with biotic stress, FS- Stress during flowering stage, PFS-Stress during pod filling stage, SI-Supplemental Irrigation.

[a] These rainfed plots are heavily infested by soybean aphids and hence tagged as RF + BS; two applications of Mustang insecticide (200 g/ha) were applied to control aphids infestation (48 DAS and 64 DAS).

For soil measurements, soil samples were air-dried, sieved through a 2 mm screen, mixed and used to determine various physico-chemical properties following soil science standard procedures (soil organic carbon (%) by Walkley and Black, 1934; field capacity and wilting points (% w/w) by Richards, 1947; soil available K (kg/ha) by Hanway and Heidel, 1952; soil available P (kg/ha) by Olsen et al., 1954; soil available N (kg/ha) by Subbiah and Asija, 1956; soil texture by Bouyoucos, 1962; bulk density by Blake, 1965 and pH and EC (dS/m) by Jackson, 1973). The soil in the experimental site is slightly alkaline with low electrical conductivity and is well drained. The Yamuna alluvial soil of the experimental site is typical Haplustept with a pH of 8.16 and sandy loam in texture (sand, clay and silt percentages of 61%, 20% and 19%, respectively). The soil field capacity is 17.26% by volume while the permanent wilting point is 7.85%. Soil is medium in organic carbon content and low in available nitrogen, medium in available potassium and available phosphorous.

Daily soil moisture was monitored using a FieldScout TDR 300 soil moisture meter. Daily soil moisture in terms of available water volume (%) at a depth of 0–20 cm soil was recorded from five random places, in every plot, for each treatment. Thus, a total of 20 recordings were made from each treatment. Mean of all readings was considered representative soil moisture of that treatment. Observations of crop canopy and physiological parameters, such as leaf area index (LAI), gas exchange parameters, dry matter production and partitioning were taken on a weekly interval. Observations of yields and yield components were recorded at the time of harvest. Five plants were selected randomly in each plot at an interval of 5–7 days as "sample plants" for measuring crop parameters. Gas exchange parameters were recorded using a portable photosynthesis system − IRGA (LI-6400XT, LI-COR, USA) at 7 days interval during the cropping season. Observations were taken from 9:00 AM to 11:00 AM on physiologically mature leaves (generally top 4th–5th leaf). Leaf area index was recorded using plant canopy analyzer (LAI-2000; LI-COR, USA) at 5 days interval. Five plants were uprooted from each plot at 7 days interval for estimating dry matter production. The recoverable roots were washed and cleaned, and leaves and roots were separated from the stem. After that, they were kept in a pre-heated oven at 95 °C for 48 h, and weighed. During the growing season, sampling was done 11 times from each treatment.

2.1.3. Statistical analysis

The experimental data were tabulated and statistically analyzed