Field Crops Research 141 (2013) 38–46

Contents lists available at SciVerse ScienceDirect

Field Crops Research

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

Drought stress characterization of post-rainy season (*rabi*) sorghum in India

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ARTICLE INFO

Article history:
Received 13 August 2012
Received in revised form 31 October 2012
Accepted 31 October 2012

Keywords:
Sorghum
Drought stress characterization
Modelling

ABSTRACT

During the post-rainy (*rabi*) season in India around 3 million tonnes of sorghum grain is produced from 5.7 million ha of cropping. This underpins the livelihood of about 5 million households. Severe drought is common as the crop grown in these areas relies largely on soil moisture stored during the preceding rainy season. Improvement of *rabi* sorghum cultivars through breeding has been slow but could be accelerated if drought scenarios in the production regions were better understood. The sorghum crop model within the APSIM (Agricultural Production Systems sIMulator) platform was used to simulate crop growth and yield and the pattern of crop water status through each season using available historical weather data. The current model reproduced credibly the observed yield variation across the production region ($R^2 = 0.73$). The simulated trajectories of drought stress through each crop season were clustered into five different drought stress patterns. A majority of trajectories indicated terminal drought (43%) with various timings of onset during the crop cycle. The most severe droughts (25% of seasons) were when stress began before flowering and resulted in failure of grain production in most cases, although biomass production was not affected so severely. The frequencies of drought stress types were analyzed for selected locations throughout the *rabi* tract and showed different zones had different predominating stress patterns. This knowledge can help better focus the search for adaptive traits and management practices to specific stress situations and thus accelerate improvement of *rabi* sorghum via targeted specific adaptation. The case study presented here is applicable to other sorghum growing environments.

1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop world-wide (http://apps.fao.org/default.jsp) as well as an important source of feed, fibre, and biofuel (Doggett, 1988). Sorghum is well adapted to drought environments compared to other cereals (e.g. see reviews by Doggett, 1988; Ludlow and Muchow, 1990; Mullet et al., 2001; Sanchez et al., 2002; Borrell et al., 2006), making it suitable for semi-arid tropical (SAT) agricultural production systems. Sorghum is considered a staple food grain for some of the world's poorest and most food-insecure people across developing countries of Asia and Africa (Murty et al., 2007).

Across India, around 3 million tonnes of sorghum grain is produced from 5.7 million ha during the post-rainy (*rabi*) season (Project Directorate for Farming Systems Research database (www.pdfsr.ernet.in), www.indiastat.com, Murty et al., 2007). The stover is also highly valued as a livestock feed (Blümmel and Rao, 2006). The majority of *rabi* sorghum stover and grain production is concentrated in districts across the states of Maharashtra, Karnataka and Andhra Pradesh (Trivedi, 2008; Rana et al., 1999; Hosmani and Chittapur, 1997; Murty et al., 2007; Pray and Nagarajan, 2009, see Fig. 1). The *rabi* cropping season follows the hot, wet rainy season (*kharif*) and is characterized by limited rainfall, cooler average temperature and shorter days, resulting in lower potential crop evapo-transpiration (Fig. 2). After the rainy season, the soil profile is fully charged with moisture to support the *rabi* crop. However, the frequent occurrence of shallow Entisol and Vertisol soils across the production area limits the antecedent moisture storage capacity often resulting in exhaustion of available moisture early in the crop cycle leading to limited grain and stover production (Murty et al., 2007; Kassahun et al., 2010). The nature of crop water stress in this region has been described as "terminal drought" with variable timing of onset during the crop cycle (e.g. Kassahun et al., 2010; Murty et al., 2007; Sajjanar et al., 2011). However, no attention has been paid to quantifying the detailed nature of these drought patterns across seasons. A better analysis of drought patterns would aid in focusing crop improvement efforts towards

Abbreviations: S/D, supply demand ratio; APSIM, agricultural production systems simulator.

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http://dx.doi.org/10.1016/j.fcr.2012.10.020

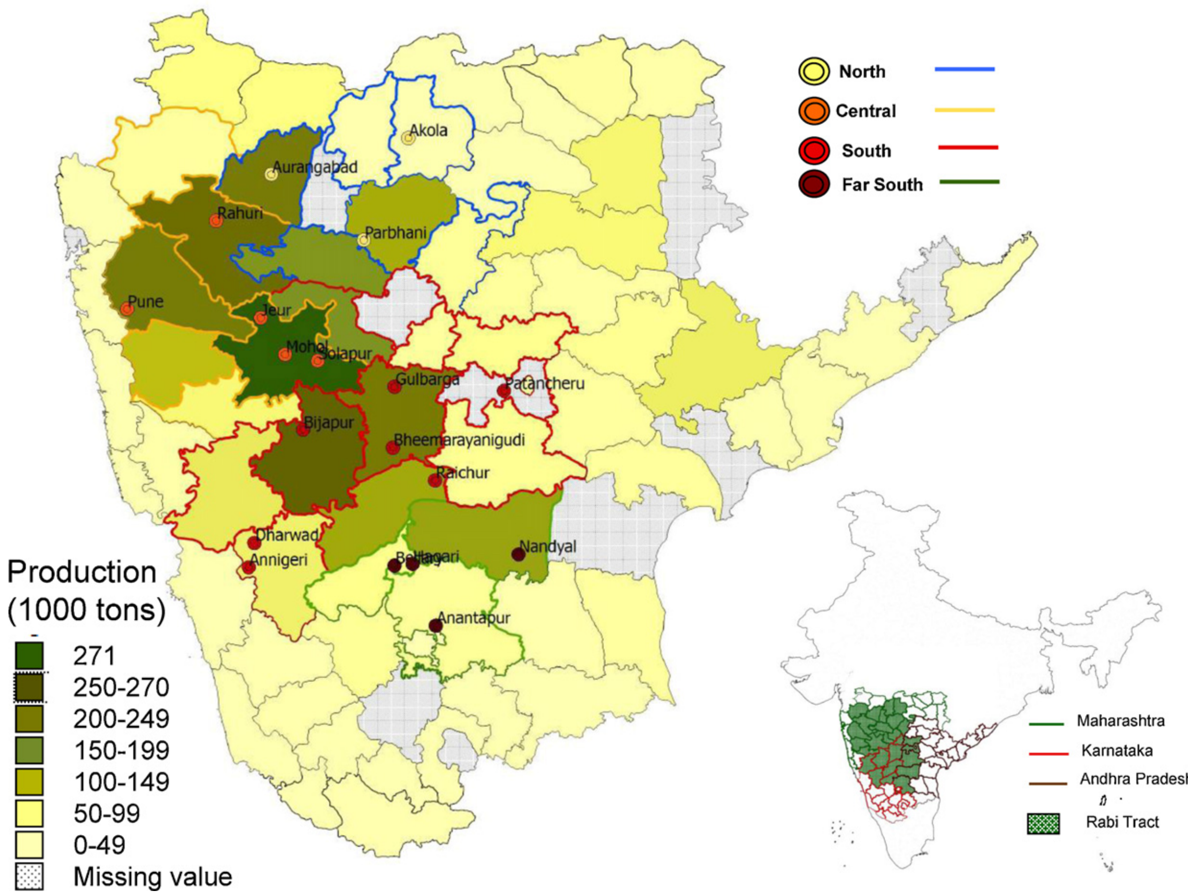

Fig. 1. Map of the sorghum *rabi* production tract in India with highlighted four major production zones – Central, Northern, Southern and Far South. The inset map shows the location of the Indian states (Maharashtra, Karnataka and Andhra Pradesh) and the major *rabi* tract. The main map shows the level of average total grain production in the *rabi* sorghum areas and the location of the 19 weather stations used in the simulation analysis.

combinations of genotype and management that are most suited to specific drought patterns. Improved knowledge on stress patterns may, in fact, prove crucial in the current situation where water availability is extremely limited while food and fodder demands rise (Blümmel and Rao, 2006; Balota et al., 2008; Chenu et al., 2011).

Lack of knowledge on drought stress scenarios is, at least partially, caused by the obvious difficulties in generating sufficient field experimental data to capture the dynamics of crop water status over a sufficient number of years to credibly classify stress categories. There is, however, an emerging capability for characterizing crop stress environments across broad regions, management practices, and crop cultivars via crop modelling. The modelling approach has been used previously to characterize water stress patterns in sorghum (Hammer and Jordan, 2007; Chapman, 2008) and wheat (Chenu et al., 2011) across Australia. In those studies the concept of a crop water status index based on the ratio (S/D) of potential soil water uptake (supply, S) to crop transpiration demand (D) was introduced as a pragmatic way to evaluate and classify the water stress environment experienced by the crop through its life cycle. However, the virtual crop model can be useful only if it sensibly reflects the real situation in farmers' fields and therefore requires knowledge on local management practices, good estimates of regional soil properties, and reliable weather records.

The aim of this study was to characterize the type of water stress patterns experienced by *rabi* sorghum crops across the major production area in India. We use the sorghum model (Hammer et al., 2010) and soil water balance within the cropping system simulation platform APSIM (Keating et al., 2003) to simulate patterns of crop water status through the crop cycle at representative sites using the soil characteristics and local field management practices for those areas.

2. Materials and methods

2.1. Overview

The cropping area contributing the majority (around 75%) of the Indian *rabi* sorghum grain production was identified using long term district production and yield averages from 1966 to 2007 (Project Directorate for Farming Systems Research database (www.pdfsr.ernet.in), www.indiastat.com). This included districts in the states of Maharashtra, Karnataka, and Andhra Pradesh (Fig. 1), in which on average 2.26 million tonnes of sorghum grain was produced from 4.43 million ha. This distribution was consistent with that noted previously by Rana et al. (1999), Hosmani and Chittapur (1997), and Murty et al. (2007). This "*rabi* sorghum belt" was divided into four production zones based on similarities in their geographical position, average yields, and similarity in broad environmental conditions (Table 1). Within these zones, historical weather records from 19 weather stations were collated from available databases (Indian Meteorological Department in Pune). The number of years of data available at each location ranged from 8 to 36. Soil properties for key production areas were collated from available databases (National Bureau of Soil Survey and Land Use Planning, International Soil Reference and Information Centre). Crop simulations were conducted for the key locations in each production zone, using the sorghum model in APSIM (version 7.3; Keating et al., 2003; Hammer et al., 2010) and local