Europ. J. Agronomy 83 (2017) 1–14

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Assessment of soybean yield with altered water-related genetic improvement traits under climate change in Southern Brazil

Rafael Battisti[a], Paulo C. Sentelhas[a,*], Kenneth J. Boote[b], Gil M. de S. Câmara[c], José R.B. Farias[d], Claudir J. Basso[e]

[a] Department of Biosystems Engineering, ESALQ, University of São Paulo, Piracicaba, SP, Brazil
[b] Agronomy Department, University of Florida, Gainesville, FL, USA
[c] Department of Plant Production, ESALQ, University of São Paulo, Piracicaba, SP, Brazil
[d] National Soybean Research Center, EMBRAPA, Londrina, PR, Brazil
[e] Department of Agricultural and Environmental Sciences, Federal University of Santa Maria, Frederico Westphalen, RS, Brazil

ARTICLE INFO

Article history:
Received 21 April 2016
Received in revised form
11 November 2016
Accepted 15 November 2016
Available online 23 November 2016

Keywords:
Glycine max L.
Crop adaptation
Water deficit
Soybean breeding
Crop model
CSM-CROPGRO-Soybean

ABSTRACT

Water deficit is a major factor responsible for soybean yield gap in Southern Brazil and tends to increase under climate change. An alternative to reduce such gap is to identify soybean cultivars with traits associated to drought tolerance. Thus, the aim of this study was to assess soybean adaptive traits to water deficit that can improve yield under current and future climates, providing guidelines for soybean cultivar breeding in Southern Brazil. The following soybean traits were manipulated in the CSM-CROPGRO-Soybean crop model: deeper root depth in the soil profile; maximum fraction of shoot dry matter diverted to root growth under water stress; early reduction of transpiration under mild stress; transpiration limited as a function of vapor pressure deficit; N_2 fixation drought tolerance; and sensitivity of grain filling period to water deficit. The yields were predicted for standard and altered traits using climate data for the current (1961–2014) and future (middle-century) scenarios. The traits with greater improvement in soybean yield were deeper rooting profile, with yield gains of ≈300 kg ha^{-1}, followed by transpiration limited as a function of vapor pressure deficit and less drought-induced shortening of the grain filling period. The maximum fraction of shoot dry matter diverted to root and N_2 fixation drought tolerance increased yield by less than 75 kg ha^{-1}, while early reduction of transpiration resulted in a small area of country showing gains. When these traits were combined, the simulations resulted in higher yield gains than using any single trait. These results show that traits associated with deeper and greater root profile in the soil, reducing transpiration under water deficit more than photosynthesis, creating tolerance of nitrogen fixation to drought, and reducing sensitivity of grain filling period to water deficit should be included in new soybean cultivars to improve soybean drought tolerance in Southern Brazil.

1. Introduction

Brazil is one of the most important soybean producers in the world, supplying around 30% of this commodity in the global market in 2013 (FAOSTAT, 2015), while Southern Brazil, the five-state region of this study, contributes 47% of the Brazilian soybean production (IBGE, 2015). Soybean yield is highly dependent on weather conditions, as most of the soybean areas in the country are produced as rainfed crop, and water deficit is the main driver for soybean yield gaps (Sentelhas et al., 2015). Under climate change, water deficit is projected to be more frequent and intense, especially in the tropics and subtropics due to increased air temperature and altered rainfall patterns (Li et al., 2013; IPCC, 2015), which will require adaptation measures in agriculture.

A better cultivar can be developed by adjusting its morphological and physiological functions for adapting the crop to the environment (Sinclair et al., 2010; Gilbert et al., 2011; Li et al., 2013). Soybean genetic variability enables one to identify cultivars with different growth and physiological characteristics to face adverse climatic conditions, such as water deficit and extreme temperatures, in order to improve yield and reduce the yield gap for the current and future climates (Boote et al., 2011).

The first step to mitigate yield losses is to identify soybean breeding lines with advantageous traits that can help the crop to

* Corresponding author.
E-mail addresses: pcsentel.esalq@usp.br, paulo.sentelhas@pq.cnpq.br (P.C. Sentelhas).

http://dx.doi.org/10.1016/j.eja.2016.11.004
1161-0301/

adapt to adverse conditions, such as water deficit (Lehmann et al., 2013; Devi et al., 2014). Cultivar characteristics, such as deeper and greater root system (Benjamin and Nielsen, 2006 Bortoluzzi et al., 2014), soil water conservation (Sinclair et al., 2008; Gilbert et al., 2011), nitrogen fixation drought tolerance (Sinclair et al., 2007), and less sensitivity of grain filling acceleration under drought (Specht et al., 1986; Ruíz-Nogueira et al., 2001) can be used to develop cultivars adapted to drought.

The time between identification of one of these traits in a soybean breeding line and its application in a new cultivar is very long, and in some cases, the traits selected may not show a good effect in the field under specific climate and soil conditions. An alternative is to test these traits through crop models (Sinclair et al., 2010; Boote, 2011), evaluating how these traits can affect yield for a specific region (Sinclair et al., 2014). After that, selection of cultivars with desirable traits can be done more effectively since crop models allow simulations of multiple crop seasons under a great diversity of climates (Egli and Cornelius, 2009; White et al., 2011).

Based on the above rationale and literature, the hypothesis of this study is that through selection of soybean traits specific to drought tolerance, it is possible to develop better cultivars for both the current and future climates in Southern Brazil for improving soybean yield. Therefore, the aims of this study were to assess soybean yield response and total production for the traits related to drought tolerance and to provide guidelines for genetic breeding programs in order to improve the tolerance of soybean cultivars to drought, for the current and future climates in Southern Brazil.

2. Materials and methods

2.1. Study region

The region of this study covers most of Southern Brazil and is located between latitudes 20° and 34°S and longitudes 47° and 58°W. The Koopen's climate classification of the region includes the following climate types for most of the region: humid subtropical zone without dry season with hot summer (Cfa) and with temperate summer (Cfb) (Alvares et al., 2013). During the soybean growing seasons, the average air temperature ranges between 18.7 °C and 26.2 °C, respectively, for the coolest and hottest sites, as shown in Fig. 1. More details about the climate are shown in Appendices A (Table A.1). In this region, soybean is produced on 15 million hectares and the total production is near 45 million tons (CONAB, 2015).

2.2. Climate and soil data

The yield responses for the different traits related to drought tolerance were simulated for 30 sites in Southern Brazil (Fig. 1). For yield simulation, the inputs for the crop model were current and future climates and soil conditions for these sites. Current climate data used were from 1961 to 2014, considering a [CO_2] of 380 ppm. Weather data comprised maximum and minimum air temperature, rainfall, solar radiation, sunshine hours, wind speed, maximum and minimum relative humidity in a daily timescale, which were obtained from Brazilian Meteorological Service (INMET), Agronomic Institute of Paraná (IAPAR), Brazilian Agricultural Research Company (EMBRAPA), "Luiz de Queiroz" Agricultural College (ESALQ/USP), and Brazilian Water Agency (ANA). Details about how missing data in the weather series were fill up are presented in Appendix A.

Future climate scenarios were created for the same 30 sites, using the baseline of 1961–2014 and the projections for delta of mean air temperature, which is the difference between the future air temperature and baseline air temperature. The delta of air temperature between future and present periods were obtained from the ECHAM-Eta and HadCM-Eta models with Eta refined model, which generated climate conditions for Brazil based on the A1 B scenario (IPCC, 2015). National Institute of Space Research (INPE, 2015) simulated these projections for each season (Appendices A, Table A.1). HadCN3 was the border condition adopted by INPE, using high model sensitivity for the simulation of weather data. The [CO_2] adopted was 600 ppm for the period of 2041–2070. Changes for rainfall were not considered since the future projections for this variable present a high degree of uncertainty (Marengo et al., 2010; Chou et al., 2012) and also because the rainfall variability from the 53-year series provides enough changes of this variable for testing the response of the traits. Solar radiation and wind speed were also not changed, while relative humidity was recalculated using the projected air temperature, following Tetens' equation (Pereira et al., 2002).

Soil profiles were created for each site, identifying the main soils surrounding the weather stations, considering a radius of 50 km. For this, we used the soil map from IBGE (2012) and the software QGIS 2.6.1. By this analysis, the predominant soil type of each site was identified and considered as the corresponding soil to the study. After that, data from RADAM-Brazil Project (1974) were used to provide information on clay, silt and sand contents, drainage, pH, carbon and nitrogen contents for the corresponding soil type (Appendices A, Table A.2).

2.3. Crop model

The soybean crop model used in the present study was CSM-CROPGRO-Soybean, present in the software Decision Support System for Agrotechnology Transfer (DSSAT). More details about the CSM-CROPGRO can be found in Boote et al. (1998, 2001), and Jones et al. (2003). In the simulations, the reference evapotranspiration was estimated by Penman-Monteith FAO 56 method (Allen et al., 1998) and infiltration of water into the soil by soil conservation service method through soil curve number (Soil Conservation Service, 1972). The Ritchie tipping-bucket approach was used for soil water balance (Ritchie, 1998) and Suleiman-Ritchie approach (Suleiman and Ritchie, 2003) for soil water evaporation, while the leaf-level photosynthesis response approach was used to simulate soybean photosynthesis (Boote and Pickering, 1994).

2.4. Crop model calibration and evaluation

Two data sets of measured soybean growth and development were used to calibrate and evaluate the crop model. For calibration, the cultivar coefficients were adjusted in the model using experimental data from three sites located in Southern Brazil: Frederico Westphalen, RS (27°21′38" S; 53°23′48" W; 540 m); Londrina, PR (23°11′34" S; 51°10′59" W; 634 m); and Piracicaba, SP (22°42′14" S; 47°37′30" W; 569 m). Cultivar BRS 284 was used in all sites. The sowing dates of these field experiments were: 18 Oct, 14 Nov, and 08 Jan in Piracicaba, SP; and 10 Oct, 31 Oct, and 19 Nov in Londrina, PR. In Londrina and Piracicaba, the soybean fields were grown under irrigated and rainfed conditions, in order to increase the environmental variability (Appendices A, Table A.3). Drip irrigation was used at Piracicaba and Londrina for the 2013/2014 crop season. Piracicaba had full irrigation, a condition that kept the crop without water deficit, while in Londrina the rainfall associated with irrigation supplied 75% of crop evapotranspiration. In Frederico Westphalen, soybean was grown only under rainfed conditions, with field experiments being sowed in 01 Oct, 18 Oct, 08 Nov, 25 Nov and 15 Dec. The crop management followed the EMBRAPA recommendations, keeping the plants free of pests and diseases (EMBRAPA, 2013).