Field Crops Research 133 (2012) 186–196

Contents lists available at SciVerse ScienceDirect

Field Crops Research

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

Identifying plant traits to increase chickpea yield in water-limited environments

Afshin Soltani[a,*], Thomas R. Sinclair[b]

[a] Agronomy Group, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan 49138-15739, Iran
[b] Department of Crop Science, North Carolina State University, Raleigh, NC 27695-7620, USA

ARTICLE INFO

Article history:
Received 27 June 2011
Received in revised form 30 March 2012
Accepted 11 April 2012

Keywords:
Chickpea
Drought
Yield
Trait
Crop improvement
Simulation

ABSTRACT

Average chickpea (*Cicer arietinum* L.) yield is low in major producer countries, which in nearly all cases is a consequence of water-deficit conditions. A first step in increasing crop yield under drought is to identify drought traits that are likely to be beneficial. In this study, we examined potential benefits of six modified drought traits in chickpea in two contrasting water-limited environments. Simulations were performed over 30 seasons for two soil depths (120 and 80 cm) at Tabriz and Gonbad, Iran, representing the environmental diversity among major chickpea producing areas. Delayed stomata closure with respect to soil drying resulted in decreased yield. A slower rate of leaf development did not lead to yield improvement. Four other traits increased crop yield. Increased depth of water extraction from the soil provided the greatest yield increase that varied from 14% in a deep soil at Gonbad (wetter environment) to 45% in a shallower soil at Tabriz (drier environment). Slower rate of growth (crop mass production) was the second important trait which resulted in 6–8% yield increase in 120-cm-soil and 21% yield increase in 80-cm-soil. The priority of other traits to increase crop yield depended on soil depth. In 120-cm-soil, reduced maximum transpiration rate improved crop yield (5–7%). Yield enhancement as a result of early stomata closure with respect to soil drying was ≤3% in this soil. In 80-cm-soil, however, early stomata closure with respect to soil drying was the third most beneficial drought traits in increasing yield (13–16%). Reduced maximum transpiration rate resulted in 3 and 6% yield increase at 80-cm-soil in Tabriz and Gonbad, respectively. It was concluded that deeper rooting, slower rate of growth, early stomata closure and reduced maximum transpiration rate are key target traits for genetic improvement in chickpea in water-limited environments with terminal droughts.

1. Introduction

Chickpea (*Cicer arietinum* L.), a cool season grain legume crop, is cultivated across the world including the Mediterranean basin, the near east, central and south Asia, east Africa, South America, North America and Australia. About 90% of the world's chickpea is grown under rainfed conditions where the crop grows and matures on a progressively depleting soil moisture profile and experiences terminal drought (Kumar and Abbo, 2001). Yield losses because of drought are reported being from 30 to 100% of irrigated yield, depending on cultivar, previous rainfall, atmospheric evaporative demand, and soil characteristics such as depth and texture (Singh, 1993; Leport et al., 1999; Canci and Toker, 2009). Soltani et al. (2001) estimated that if the soil water deficit is alleviated, chickpea yield could be improved from 91 $g\,m^{-2}$ under rainfed conditions to 277 $g\,m^{-2}$ under irrigated conditions in Maragheh, north-eastern of Iran. Water deficit is, therefore, one of the major constraints limiting chickpea productivity and yield stability (Kashiwagi et al., 2008).

Despite growing demand and considerable investment in breeding, chickpea yield is unstable and productivity is stagnant at unacceptably low levels (Saxena et al., 1996; Millan et al., 2006). World average yields of chickpea have ranged from 65 $g\,m^{-2}$ in 1961 to 77 $g\,m^{-2}$ in 2006 (FAO, 2006). Major yield increases might be achieved by identifying and incorporating plant traits into commercial cultivars that could result in higher yields under water-limiting conditions. Various traits have been proposed to increase yield under water-limited conditions (Ludlow and Muchow, 1990; Loomis and Connor, 1992).

Traditional approaches to identifying desired plant traits involve evaluation of advanced lines over a number of sites and years. As the impact of traits on yield depends on environmental conditions, many site-by-year trials are required and may still not cover the full range of environments to be experienced by the genotypes after release (Shorter et al., 1991; Asseng et al., 2002). Plant traits that influence crop yield have differing opportunities for expression in different seasons, and it would be expensive, and likely impractical, to assess the value of different plant types using conventional multi-site, multi-season cultivar trails (Muchow and

* Corresponding author. Tel.: +98 171 4426845; fax: +98 171 4420438.
E-mail address: afsoltani@yahoo.com (A. Soltani).

0378-4290/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fcr.2012.04.006

Carberry, 1993). Saxena (2003) and Gaur et al. (2008) concluded that in chickpea efforts to breed drought tolerance varieties in the past have not been rewarded because of imperfect understanding of drought manifestation and selection based solely on empirical yield selection. Alternatively, an evaluation of possible trait changes could be examined by using a crop model to simulate yield for a number of locations and many growing seasons.

Sinclair (2011) proposed a four-step, top-down approach for crop yield improvement under water-limited conditions in which the first step is assessing the benefits of promising traits by means of a crop simulation model. Hammer et al. (2002) discussed the role of crop simulation modeling in finding desired plant traits. Simulation models have been used for determining critical traits for higher yield under water-limited conditions, including studies on wheat (*Triticum aestivum* L.) (Soltani and Galeshi, 2002; Manschadi et al., 2006; Semenov et al., 2009; Ludwig and Asseng, 2010), sorghum (*Sorghum bicolor* L.) (Sinclair et al., 2005), maize (*Zea mays* L.) (Muchow and Carberry, 1993; Sinclair and Muchow, 2001), rice (*Oryza sativa* L.) (Aggarwal et al., 1997; Yin et al., 1997) and soybean (*Glycine max* (L.) Merr.) (Sinclair et al., 2010). Different drought traits have been evaluated in the above mentioned studies including rate of phenological development, rate of leaf area development, early vigor, early/delayed stomata closure with respect to soil drying, lower/higher radiation use efficiency, rooting depth, rate and efficiency of water uptake by roots, reduced maximum transpiration rate, and grain growth rate and duration. Comparing results from a range of crop models and environmental conditions may lead to a better understanding of drought resistance and highlight gaps in our knowledge (Semenov et al., 2009).

In chickpea, however, such analysis has not been published, except for the study of Soltani et al. (2000) who only evaluated the importance of early or delayed stomata closure with respect to soil drying in chickpea. On the other hand, the value of traits may differ among crop species and environments as the relative importance of different growth processes in determining final yield vary (Muchow and Carberry, 1993). This information is required to better focus chickpea breeding programs. Therefore, the objective of this study was to assess the benefits of different drought traits in chickpea in two contrasting water-limited environments. The locations chosen are representative of the diversity of environmental conditions, including terminal drought. In another paper, we evaluated the optimal phenology of chickpea in these environments (Soltani and Sinclair, 2012a).

2. Materials and methods

2.1. Locations

Two contrasting locations were chosen for this study: Tabriz (38°5′N, 46°17′E and 1361 m asl) in the north west and Gonbad (37°15′N, 55°10′E and 37 m asl) in the north east of Iran. These two locations represent major chickpea producing areas in Iran. Most chickpea growing areas of Iran are located in the north west of the country and are responsible for nearly 50% of total production (Sadri and Banai, 1996). The Dryland Agricultural Research Institute (DARI) of Iran is located in this region near Tabriz.

Gonbad has mild winters so chickpea is sown in autumn, but in Tabriz with cold winters the crop is sown in spring. Average temperature during the growing season in Gonbad (December–June) is 14 °C and in Tabriz (April–July) it is 19 °C. Both sites are characterized by mid to late season drought, but the intensity of the drought is on average higher at Tabriz than at Gonbad. Average rainfall during the chickpea growing period is 353 mm for Gonbad and 120 mm for Tabriz. Soltani and Sinclair (2012a) presented more details on comparing the environmental conditions of these two sites.

2.2. Crop model

The chickpea model of Soltani and Sinclair (2011) was used in this study. The model accounts for the effects of water deficit on phenological development, leaf area development and mass and nitrogen accumulation by the crop and the grain. The model includes daily phenology progress, leaf area development and senescence, dry matter production and partitioning, plant nitrogen balance, yield formation and soil water balance. Responses of crop processes to environmental inputs of solar radiation, temperature, nitrogen and water availability and genotype differences are included in the model. The model also accounts for the effect of freezing temperatures on plant leaf area that might take place in early spring sowings or in winter sowings.

The model also accounts for the termination of crop growth under severe drought. Two criteria were used to identify termination of crop growth based on aridity of the air and the severity of soil water deficit. One criterion for termination was a combination of atmospheric vapor pressure deficit (VPD) greater than 2.2 kPa and fraction of transpirable soil water (FTSW) less than 0.02. The second criterion was VPD greater than 1.8 kPa and FTSW less than 0.0. For more detailed description of the model refer to Soltani and Sinclair (2011, 2012b). The model (SSM-Chickpea) can be downloaded from "http://sites.google.com/site/CropModeling".

The robustness of the chickpea model has been tested extensively. Soltani et al. (2006) specifically tested the phenology component of the model and Soltani and Sinclair (2011) tested the whole model for robustness. These tests included a wide range of growth and environmental conditions. In testing the model, observed days to maturity ranged from 78 to 228 d and observed grain yield varied between 20 and 325 g m^{-2}. In most cases, simulated grain yield were similar to observed yield with a correlation coefficient of 0.97 and a root mean square root of 26 g m^{-2} (15% of average measured yield). In addition, the model has been used successfully in simulation of a 3-year, line-source irrigation experiment under drought conditions of India (V. Vadez et al., unpublished data).

The consequences of altered drought traits on chickpea yield were assessed by altering the value of the parameters in the model related to these traits (Table 1). For modified cultivars the rest of the model parameters were those of the standard cultivars. Standard cultivars were 'Jam' at Tabriz and 'Hashem' at Gonbad. For detailed information about these cultivars refer to Soltani and Sinclair (2011). Below we discuss the specific drought traits that were examined for improving crop yield.

Table 1
Drought traits and the manner that they were included in the model.

Modified cultivar	Symbol	Description
Deeper root	EED × 1.2	Effective water extraction depth (120 cm) was increased by 20%
Slower leaf development	MXNOD × 0.8	Maximum node appearance rate (0.72 d^{-1}) was decreased by 20%
Lower RUE	RUE × 0.8	Radiation use efficiency (1 g MJ^{-1}) was decreased by 20%
Early stomata closure	WSSG × 1.2	Threshold of transpiration rate to fraction transpirable soil water (0.31) was increased by 20%
Delayed stomata closure	WSSG × 0.8	Threshold of transpiration rate to fraction transpirable soil water (0.31) was decreased by 20%
Reduced maximum transpiration rate	RMTR	Hourly transpiration at vapor pressure deficit higher than 2 kPa was limited to that of 2 kPa