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Analysis of chickpea yield gap and water-limited potential yield in Iran

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ABSTRACT

Iran is one of the major chickpea (*Cicer arietinum* L.) producing countries of the world. Average chickpea yield in Iran is about 500 kg ha^{-1} while the world average is 900 kg ha^{-1}. The objective of this study was to investigate chickpea water limited potential yield (Y_w) and yield gap in Iran. The analysis was based on data from five representing chickpea producing locations of Iran. Estimated country Y_w and yield gap were 991 and 463 kg ha^{-1}, respectively, indicating that farmers have reached 53% (range: 38–64%) of Y_w. If farmers could reach 80% of Y_w of their locations, by improving agronomy practice, country average yield would increase by 50%, from 528 to 793 kg ha^{-1}. A key finding of the study was that chickpea yield in Iran is largely limited by inefficient use of environmental resources and not the genetics of the current cultivars. Much higher yield increase is obtainable via an agronomic option than a genetic improvement option: using shorter duration cultivars increased Y_w to 1237 kg ha^{-1} (25% increase), but applying a single irrigation of 60 mm at first-pod alone or in combination with shorter duration cultivars increased Y_w to 1804 kg ha^{-1}(85% increase) and to 1997 kg ha^{-1} (104% increase), respectively. Thus, tripling chickpea production would be feasible using a single irrigation with or without shorter duration cultivars (from 528 to 1443 or 1598 kg ha^{-1}). The availability of water for the single irrigation is discussed.

1. Introduction

The global population is predicted to increase to 9–10 billion by 2050 (O'Neill et al., 2010), which will require 70–110% rise in food production (Tilman et al., 2011; FAO, 2009; Ray et al., 2013). Ensuring global food security and protecting the environment at the same time is perhaps the single greatest scientific challenge facing humankind (Cassman, 2012). A number of options have been proposed to help address the food security challenge (Foley et al., 2011; Smith, 2013), among them one promising option is bridging the yield gap (van Ittersum et al., 2013), especially in developing countries (Cassman, 2012). The yield gap is the difference (gap) between yield currently achieved on farms and those that can be achieved by using the best agronomy practice (van Ittersum et al., 2013). Increasing food production via closing yield gap has less environmental consequences than expanding food production area (van Wart et al., 2013; Soltani et al., 2013, 2014). On the other hand, increasing cultivated areas is difficult or virtually impossible in population-dense area like most of the middle- and far- East, where suitable land for agricultural production is limited and in competition with non-agricultural uses (Bruinsma, 2009). Increased production per unit area through genetic improvement may be a suitable solution to increase food production and improve food security, but achievement in a short period of time is also very difficult (Hall and Richards, 2013; Meng et al., 2013).

Yield gap analysis has been under attention since old time (Alberda, 1962), but it has attracted much attention recently due to global food security concern (Lobell et al., 2009; Foley et al., 2011; van Ittersum et al., 2013; Wang et al., 2015). van Ittersum et al. (2013) in a review of yield gap analysis, emphasizing the need for sustainable intensification, stated that identifying regions with greatest potential to increase food supply is critical. Quantifying the yield gap is also essential to inform policies and prioritize research to achieve food security without environmental degradation (van Wart et al., 2013). Therefore, worldwide studies are required to fulfill this need.

Most of the research on yield gap analysis has been done on cereals, especially wheat, maize and rice which provide a large part of the human food (e.g. Hochman et al., 2013; Meng et al., 2013; Lu and Fan, 2013; Schulthess et al., 2013; Tanaka et al., 2013). Yield gap studies on pulse crops are rare, except for the work of Bhatia et al. (2006) that analyzed yield gap of chickpea (*Cicer arietinum* L.) and some other legume crops in India. Monzon et al. (2013) also conducted yield gap analysis for soybean in Argentina.

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Pulse crops, including chickpea, increase sustainability of agricultural production systems (Soltani et al., 2006), thus, evaluation of their production situation appears essential due to their importance in feeding and their role in cropping system patterns and sustainability. Yield gap of chickpea has not been investigated in Iran.

According to FAO, Iran is one of the major chickpea producing countries of the world (FAO, 2012). In Iran, chickpea is the most important pulse crop with respect to production and area under cultivation (Anonymous, 2013). This crop is cultivated in about 500,000 ha, of which over 95 percent are grown under rainfed conditions (Sabaghpour et al., 2006). Average chickpea yield in Iran is about 400 to 600 kg ha^{-1}, which is well below the world average of 900 kg ha^{-1} (Anonymous, 2013; FAO, 2012). It seems the importance of the crop is increasing in Iran and other developing countries in the West Asia and North Africa (WANA) region with increase in population and limited access to sources of animal protein. WANA region is characterized by high population growth, low and erratic rainfall, limited arable land, and severely limited water resources. Some other countries in the region with low chickpea yield are Pakistan, Syria, Morocco, Algeria, Iraq and Eritrea (Akibode and Maredia, 2011). In addition, countries like India have become net importers of pulse grains including chickpea, which opens a potential market, and therefore much emphasis has been given on that crop now (Ali and Gupta 2012).

The main objective of this study was, therefore, to investigate chickpea water-limited potential yield and yield gap in major chickpea producing areas of Iran. Also, considering the study of Soltani et al. (2001) and of Vadez et al. (2012) that supplementary irrigation would greatly increases chickpea yield and Soltani and Sinclair (2012b) that using early maturing chickpea cultivars would increase crop yield, another objective of this research was to evaluate water- limited potential yield and gap under conditions of using one single supplementary irrigation or short-duration cultivars.

2. Methods

2.1. Locations

The assessment was conducted for five chickpea producing locations of Iran including Kermanshah, Maragheh, Bojnord, Gonbad, and Zanjan (Table 1). Kermanshah and Maragheh were selected from main chickpea growing area of Iran located in the north west of the country that is responsible for nearly 50% of total production (Sadri and Banai, 1996). Two main stations of Dryland Agricultural Research Institute (DARI) of Iran are located in Maragheh (main station for cold areas) and Kermanshah (main station for temperate areas). Other locations were selected from other chickpea growing areas spread over the country.

2.2. Yield data

For each location, actual yield data were obtained from local agricultural departments for 12 recent years, which is a recommended timeframe for yield gap analysis under water-limited conditions (van Ittersum et al., 2013; Kassie et al., 2014). As stated by van Ittersum et al. (2013) the number of years used for estimating actual yield must be a compromise between variability in yields and the necessity to avoid confounding effects of temporal yield trends due to technological or climate change. Shorter timeframe may be insufficient to capture year-to-year variability in actual yield and longer timeframe may include effects on yield from technological changes or climate change.

Potential yield under radiation-limited conditions (Y_p) and water-limited conditions (Y_w) was estimated using a chickpea model, SSM-Chickpea (Soltani and Sinclair, 2011). Y_p is defined as the yield of a crop cultivar when grown without water and nutrient limitation and biotic stress being effectively controlled. This is typically the experimental farm yield. Y_w is defined as the maximum yield that can be obtained from a crop cultivar in a specific rainfed location without any nutritional and biotic limitations (van Ittersum et al., 2013). This is also the experimental station yield where the crop does not receive any supplementary irrigation. As the grain water content of chickpea is about 12% at harvest time, simulated grain yield presented in this paper were also adjusted for this percentage of moisture content. Crop models are considered the most reliable way to estimate Y_p and Y_w as they account for variation in weather, soil, crop and management and their interactions (van Ittersum et al., 2013).

2.3. The crop model

The SSM-Chickpea model simulates phenological development, leaf development and senescence, dry matter production and partitioning, plant nitrogen balance, yield formation and soil water balance. Responses of crop processes to environmental factors of solar radiation, photoperiod, temperature, nitrogen and water availability, and genotype differences were included in the model. The model uses a daily time step and readily available weather and soil information. The model has been extensively tested using independent data from a wide range of growth and environmental conditions across Iran (Soltani et al., 2006; 2011; Amiri Deh Ahmadi et al., 2014) and some other countries (e.g. Vadez et al., 2013). In most cases, simulated grain yield were similar to observed yield with a root mean square error of less than 15% of average measured yield (Appendix A). For more detailed description of the model refer to Soltani and Sinclair (2011, 2012a). The model can also be downloaded from "https://sites.google.com/site/CropModeling".

2.4. Simulations

Weather data of the locations, including precipitation and maximum and minimum temperature, were available from Iran Meteorological Organization. Solar radiation was estimated using sunshine hours and extraterrestrial radiation (Soltani and Hoogenboom, 2003a,b; Soltani and Sinclair, 2012a).

According to the gathered local data, the following typical farmers' sowing dates were chosen for crop simulations: 1 April for Maragheh, 5 April for Zanjan, 20 April for Bojnord, 20 October for Kermanshah and 15 November for Gonbad. Simulations were performed for local cultivars which were Jam in Maragheh, Zanjan and Bojnord, Hashem in Gonbad and Beauvanij in Kermanshah.

The model was run for 12 years at each location (Table 1) to obtain Y_p and Y_w. Plant density was 33 plants m^{-2}. A soil with a volumetric water content of 0.13 cm cm^{-1}, albedo of 0.12, curve number of 79 and depth of 100 cm was used in the simulation at all the selected sites, except for Zanjan where a soil depth of 90 cm was chosen. One advantage of the model is that it uses volumetric extractable water content which is fairly constant at 0.13 cm cm^{-1} unless soil sand percentage is higher than 80% (Ritchie et al., 1999). The selected soil depth is based on a report of Dewan and Famouri (1964) which is an output of a joint project between Iran's Ministry of Agriculture and FAO. According to the report of the project, majority of dryland soils have 50–150 cm depth. The selection of soil depth of 100 cm in the study is also a reflection of chickpea effective water extraction depth which is typically 100 cm based on reports from locations in Iran and other parts of WANA region (e.g. Silim and Saxena, 1993; Soltani and Sinclair, 2011); with a soil depth of >100 cm, effective extraction depth remains 100 cm. Soil nitrogen content that the crop may uptake before activation of biological nitrogen fixation was 3 g N m^{-2}. Soil water