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Yield gap analysis of chickpea under semi-arid conditions: A simulation study

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Abstract

Yield gap analysis provides an essential framework to prioritize research and policy efforts to reduce yield constraints. To identify options for increasing chickpea yield, the SSM-chickpea model was parameterized and evaluated. The model was applied to analyze seed yield at both potential and water limited production levels and subsequently to find the yield gap for nine different locations. Study locations are selected to represent major chickpea-growing areas of Khorasan Razavi province (located between 37° N and 33° S latitude and 61° E and 56° W longitude). The average simulated potential yield of chickpea across all study locations was 2251 kg ha^{-1}, while for the water limited yield was 1026 kg ha^{-1}, indicating 54% lower due to adverse soil moisture conditions. Average irrigated and rainfed actual yields were 64% and 79% less than simulated potential and water limited yields respectively. Maximum and minimum of simulated potential yield minus simulated water limited yield (YG_{MM}) and simulated potential yield minus irrigated actual yield (YG_{MI}) were observed in Torbat-Jam and Quchan, respectively. Generally, YG_{MI} and YG_{MM} showed an increasing trend from the north (including Neishabur, Mashhad, Quchan and Daregaz) to the south of the study province (Torbat-Jam and Gonabad). In comparison to other indices, simulated water limited yield minus rainfed actual yield (YG_{MR}) was very low because both simulated water limited and average rainfed actual yields were low in these locations. Overall, YG_{MR} was almost unaffected by the quantity of rainfall received at these locations.

Keywords: Actual yield; Benchmarking; Modelling; Potential yield.

Introduction

Chickpea is the most important legume in West Asia and North Africa especially under rainfed conditions (Silim et al., 1993). In Iran, the cultivated area of chickpea is 667760 hectares. Although Iran has globally ranked third for the cultivation area after India and Pakistan but for yield (400 kg ha^{-1}) has been ranked last among 45 producing countries (FAO, 2006). Khorasan Razavi province has the highest cultivation area and ranked as second for production amount in Iran (Anonymous, 2012).

Despite substantial progress in the mechanization of production and breeding of high-yielding cultivars, the climate is still the most important determinant of yield. Chickpea yield is limited by several factors, including the limited length of the growing season due to low and high temperatures, drought and inappropriate distribution of rainfall (Gholipoor, 2007). Chickpea yield is at low levels in major producing countries (Millan et al., 2006), indicating needs to increase crop yield via crop genetic improvement and enhanced crop management. Genetic and management constraints can be analyzed by using crop simulation model. Crop models are very useful tools to evaluate the environment constraints, genetics and management factors effects on the crop yield (Bannayan et al., 2003; Bannayan et al., 2005; Bannayan et al., 2007; Lobell et al., 2009). This study model was initially developed by Sinclair (1986) for soybean. The model was then used as a framework for other crop models such as wheat (Amir and Sinclair, 1991), barley (Wahabi and Sinclair, 2005), peanut (Hammer et al., 1995) and chickpea (Soltani et al., 1999).

Yield potential (Y_p), is the yield of a crop cultivar when grown with ample and sufficient water and nutrients along with no biotic stress (Evans, 1993; Van Ittersum and Rabbinge, 1997). When grown under conditions that can achieve Y_p, crop growth rate is determined only by solar radiation, temperature, atmospheric CO_2 and genetic traits that determine the length of growing period (called cultivar or hybrid maturity) and light interception by the crop canopy (e.g., canopy architecture). Y_p is the most relevant benchmark for irrigated systems or systems with adequate water supply to avoid water deficits. For rainfed crops, water-limited yield (Y_w), is the most relevant benchmark. For partially (supplementary) irrigated crops, both Y_p and Y_w may serve as useful benchmark. Definition of Y_w is similar to Y_p, but crop growth is also limited by water supply and hence influenced by soil type (water holding capacity and rooting depth) and field topography (runoff).

The yield gap (Y_g) is the difference between Y_p (irrigated crops) or Y_w (rainfed crops) and actual yields (Y_a). Any improvement of crop management practices requires that the potential yield and its difference with actual yield are determined and ultimately evaluated the determinants of yield gap (Lobell et al., 2009). Assessment of potential yield and yield gaps can help in identifying the yield limiting factors and helps to develop suitable strategies to improve the productivity of any crop (Naab et al., 2004). The yield gap concept has been applied in many recent studies (e.g. Bhatia et al., 2008; Lobell et al., 2009; Neumann et al., 2010; Liu et al., 2011) as an indicator for the possibility to increase crop yields in a given region.

Low level of chickpea yield has not been spatially evaluated across Khorasan Razavi province and only a few studies have been conducted (Goldani and Rezvani, 2005; Gangeali et al., 2009; Gangeali et al., 2011). In this study, yield potential and yield gap across the major chickpea-growing regions of Khorasan Razavi province was quantified by using SSM-chickpea model and evaluated actual yield and its variability within farmers' fields. This study tries to determine the potential yield capacity and chickpea yield gap.

Materials and Methods

Experiment details

For model parameterization, a field experiment was conducted in a randomized complete design with 4 replications in the research field of the Ferdowsi University of Mashhad (36. 15° N, 56. 28° E). The chickpea cultivar ILC482 was used in this experiment, since it is the most popular and predominant genotype in Khorasan Razavi province. Sowing was performed on March 15, 2012 and plant density was 33 plants per ground m^{-2}. Furthermore, the optimum irrigation and fertilization were applied.

Data collected from field experiment included plant growth and development, crop management, daily weather conditions. Plant sampling has been employed every two weeks to measure leaf area index, dry matter of different plant parts. Additional data from field experiment at Neishabur (Gangeali et al., 2011) was also collected (Table 1). In this experiment, sowing was performed on April 15 and plant density was 20 plants per ground m^{-2}. In both experiments, standard agronomic practices for weed and insect control (including chemical and non-chemical) were uniformly followed to maintain plots free from biotic stresses.

Besides the above experiments, data were obtained from a large number of field experiments involving varying seasons and management practices at diverse regions in Iran for both potential and water limited yield evaluation (Table 1).

Table 1. Data sets for independent model testing.

Region	Year	Latitude	Treatments	Reference
Mashhad				
	2003	36.15° N	Genotype, planting date, irrigation	Goldani and Rezvani (2005)*
	2005-2006	36.15° N	Genotype, irrigation	Gangeali et al. (2009)
	2006	36.15° N	Genotype	Zaferanieh et al. (2009)
	2006	36.15° N	Genotype	Nezami et al. (2009)
	2007	36.15° N	Genotype, irrigation	Parsa et al. (2009)*
Neishabur				
	2001-2002	36.16° N	Genotype, irrigation	Rezvani Moghaddam and Sadeghi Samarjan (2008)*
	2005-2006	36.16° N	Genotype	Gangeali et al. (2011)
Kermanshah				
	2001-2002	34.43° N	Irrigation, plant density	Jalilian et al. (2005)*
	2006-2007	34.43° N	Genotype, irrigation	Karimi and farneya (2009)*
	2006-2007	34.43° N	Genotype, irrigation	Farshadfar and javadi neya (2011)*
	2009	34.43° N	Irrigation	Shaban et al. (2011)*
Hamedan				
	2005-2006	34.52° N	planting date	Majnoun Hosseini and Hamzei (2011)*
	2006	34.52° N	Genotype, irrigation	Saman et al. (2010)
Ardabil				
	2006	38.15° N	Irrigation, plant density	Raey et al. (2007)
	2008	38.15° N	plant density	Khandan Bejandi et al. (2010)
Oroomeih				
	2007-2008	37.53° N	Genotype, irrigation	Taghikhani et al. (2010)
Khoram abad				
	2004-2005	33.48° N	Irrigation, plant density	Mirzaye Heydari et al. (2009)*
	2004-2005	33.48° N	Irrigation, plant density	Mousavi et al. (2009)*
Karaj				
	2006	35.55° N	Plant density	Kashfi et al. (2001)

* Water limited plots from these field experiments were also used for water limited yield evaluation.

Crop model

The chickpea model of Soltani and Sinclair (2011) was used in this study. The model simulates phenological development, leaf area development and senescence, biomass partitioning, plant nitrogen balance, yield formation and soil water balance. In this model, responses of crop processes to environmental factors of solar radiation, photoperiod, temperature and water availability were included. The model needs readily available weather and soil information and operates on daily time steps (Soltani and Sinclair, 2011). Recently, it has been tested and used in Tabriz (38° 5′ N, 46° 17′ E) in north west Iran and Gonbad (37° 15′ N, 55° 10′ E) in north east Iran (Soltani and Sinclair, 2012) and India (Vadez et al., 2012).

Model parameterization and evaluation

The model parameterization was conducted in three steps. First, some of crop parameters were modified based on the observed data from field experiments. These parameters were estimated by model iterations until a close match between simulated and observed data was obtained. Second, the same modified parameters were used to simulate chickpea growth with the observed daily weather data. The simulations started from the sowing date and ended at maturity. Finally, the simulated results of LAI, aboveground biomass and grain yield were examined by the root mean square error (RMSE). RMSE was calculated as 1 (Wallach and Goffinet, 1987):

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n}} \qquad (1)$$

Where O_i is the observed data, P_i is the simulated data and n is the total number of observations.

Simulation of potential and water limited yield

The study was performed at nine regions in Khorasan Razavi province located in the northeast of Iran, lying between 37° N and 33° S latitude and 61° E and 56° W longitude, under two water conditions i.e. potential and water limited. Depending on the availability of weather data, the simulations were carried out for 18 to 21 years. For each year, simulations were separately performed. The standard conditions of simulations are presented in Table 2.

Table 2. Geographical details, period of weather data used of regions selected for simulation of potential yields of chickpea in Razavi Khorasan province.

Region	Latitude	Longitude	Period	No. of year	Sowing date	Plant density (plants m^{-2})	Cultivar
Daregaz	37.26°	59.6°	1995-2012	18	19 February	33	ILC482
Quchan	37.40°	58.30°	1995-2012	18	4 April	33	ILC482
Gonabad	34.21°	58.41°	1995-2012	18	19 February	33	ILC482
Kashmar	35.23°	58.48°	1995-2012	18	19 February	33	ILC482
Mashhad	36.15°	56.28°	1993-2012	21	19 February	33	ILC482
Neishabur	36.16°	58.48°	1993-2012	21	16 March	33	ILC482
Torbat-Jam	35.15°	60.35°	1995-2012	18	19 February	33	ILC482
Torbat Heidareye	35.16°	59.13°	1995-2012	18	16 March	33	ILC482
Sabzevar	36.12°	57.39°	1995-2012	18	19 February	33	ILC482

Table 3. Parameters of ILC482 genotype obtained in parameterization.

Crop parameters	Description	Coefficient for ILC482
PTDVER1	Biological day between plant emergence and flower appearance (day).	23
PTDR1R3	Biological day between first flower and first pod (day).	9
PTDR3R5	Biological day between first pod and initiate seed filling (day).	3
PS	Photoperiod sensitivity coefficient.	0.00730
MXNOD	Maximum stem node number (node d^{-1}).	0.61
GNC	Grain nitrogen concentration (mg g^{-1}).	0.009
PDHI	Maximum increase of harvest index rate per day at linear stage of its increase.	0.004

Actual yields

The region yields represent the average yield of the crop in diverse farmers' fields and are the product of climate of the region and management practices adopted by the different farmers. Irrigated and rainfed actual yields were based on statistical data at region level for the period 2002-2012, which were collected from the Agricultural Jihad of the Khorasan Razavi province (Anonymous, 2012). These yields were averaged out for calculating the actual yield for each region for which simulations were carried out.

Yield gaps

Yield gaps were defined as:

YG_{MM}= Simulated potential yield - simulated water limited yield

YG_{MI}= Simulated potential yield - irrigated actual yield

YG_{MR}= Simulated water limited yield - rainfed actual yield

Results and Discussion

Model parameterization and evaluation

In this study, minor changes have been made on some parameters of the model and these parameters are presented in Table 3. Evaluation of the model for crop growth in terms of leaf area index and total above ground biomass indicated that the model predicted the growth characteristics reasonably well (Figure 1). The RMSE values for LAI were 0.31 and 0.34 at Mashhad and Neishabur respectively. The RMSE values for crop biomass were 635 and 692 kg ha^{-1} at these locations respectively.

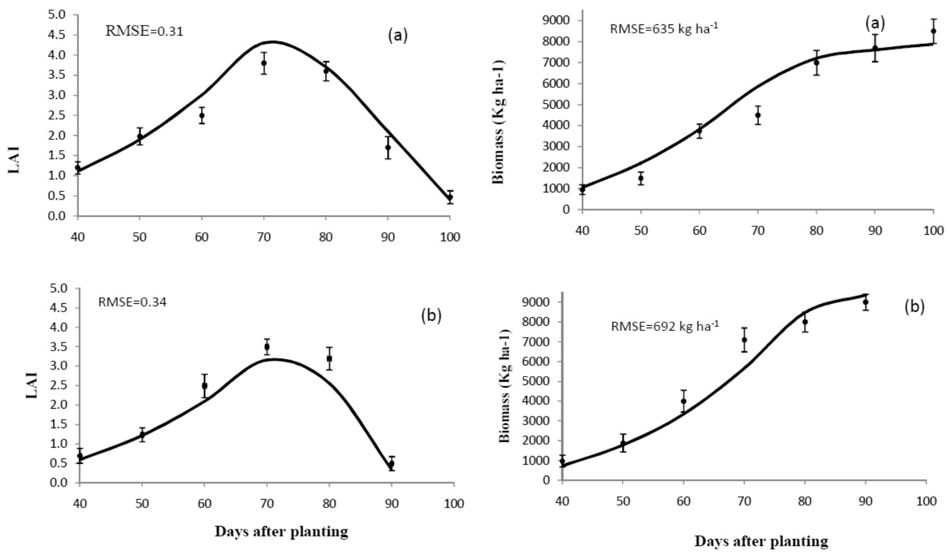

Figure 1. Comparison of simulated (lines) and observed (data points) values of leaf area index (LAI) and above ground biomass of chickpea in Mashhad (a) and Neishabur (b). (Vertical bars show the standard error of means).

For potential yield evaluation, plots from 19 field experiments that grown with ample water and nutrients and biotic stress factors were effectively controlled at diverse locations were also selected (Table 1). The RMSE and R^2 value for grain yield were 127 kg ha^{-1} and 0.92 respectively and indicates a close agreement between the simulated and observed value of grain yield for these diverse experiments (Figure 2). In addition, for water limited level evaluation, plots from 10 field experiments that only water was limited were also selected (Table 1). The RMSE and R^2 value for grain yield were 110 kg ha^{-1} and 0.74 respectively (Figure 3).

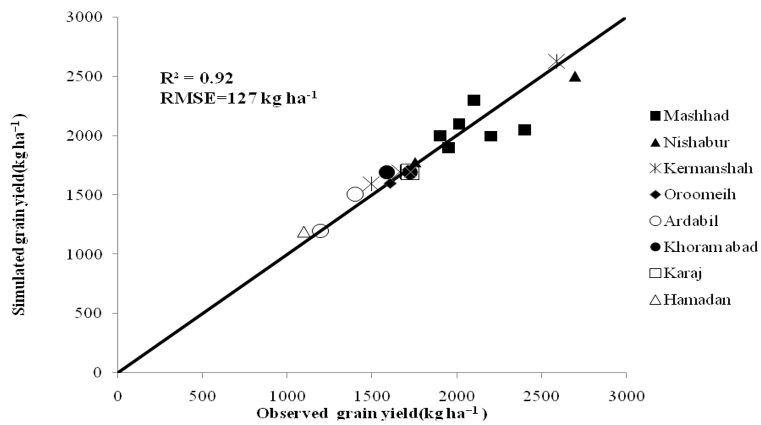

Figure 2. Simulated versus measured potential yield. Solid line is 1:1 line. Data obtained from different experiments are indicated with different symbols.

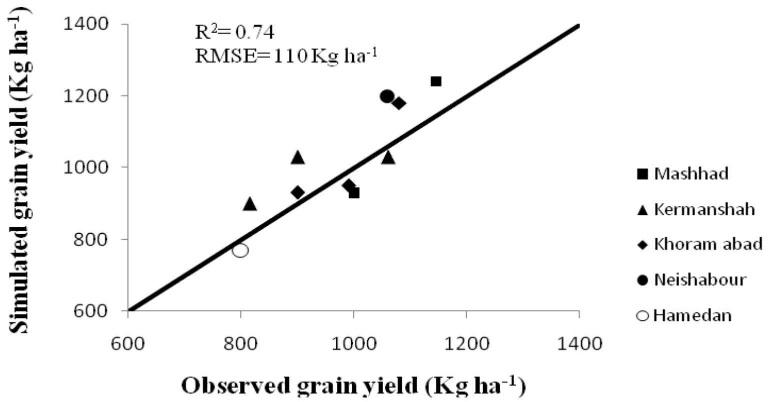

Figure 3. Simulated versus measured water limited yield. Solid line is 1:1 line. Data obtained from different experiments are indicated with different symbols.

Actual yields

The irrigated actual yields (region average yields) varied from 617 kg ha^{-1} in Gonabad to 1016 kg ha^{-1} in Neishabur with an average value of 799 kg ha^{-1} as compared to simulated potential (2251 kg ha^{-1}) and water limited yield (1012 kg ha^{-1}) (Table 5). Furthermore, the rainfed actual yields varied from 270 kg ha^{-1} in Neishabur to 162 kg ha^{-1} in Torbat-Heydareye. The average of rainfed actual yields was 230 kg ha^{-1}. Rainfed actual yields were very low due to drought and low rainfall (Table 5). Since more than 90% of the cultivated area of chickpea in Iran is rainfed, one of the most important factors in reducing yield is drought stress occurrence at different growth stages (Ganjeali et al., 2009). Recent studies (Parsa et al., 2012; Gangali and Nezami, 2008; Ganjeali et al., 2009) have shown that fall and winter sowing produced more yield because the plant used the rainfall more efficiently. Therefore, in arid and semi-arid areas, due to the lack of adequate and poor distribution of rainfall in the spring, it is necessary to change sowing date from spring to fall or winter.

Simulated potential yield

Simulated potential yields are governed only by two major climatic variables including solar radiation and temperature. The average values of climatic variables during growth and development of chickpea are presented in Table 4. Averaged across the historical series of weather data, solar radiation and temperature during chickpea growth ranged from 20.0 to 23.0 MJ m^{-2} d^{-1} and 15.0 °C to 21.1 °C, respectively, depending on the location. In this study, the mean potential yields of selected locations showed a significant positive association (R^2=0.63, P<0.01) with mean crop season solar radiation and temperature (R^2=0.51, P<0.05) (Figures 4 and 5). Bhatia et al. (2008) also showed that the variability of potential yield of soybean was affected by the variability of solar radiation in India. With respect to the potential yields of the location, one or two supplementary irrigation at critical stages of growth can increase yield. Parsa et al. (2012) have indicated that supplementary irrigation at flowering stage increased grain yield up to 62% compared to rainfed conditions.

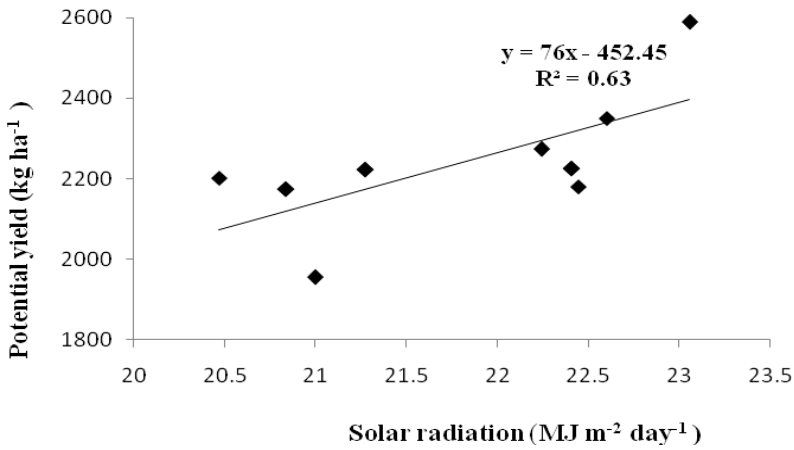

Figure 4. Association of long-term mean simulated potential yield with mean crop season solar radiation among selected regions across Razavi Khorasan.

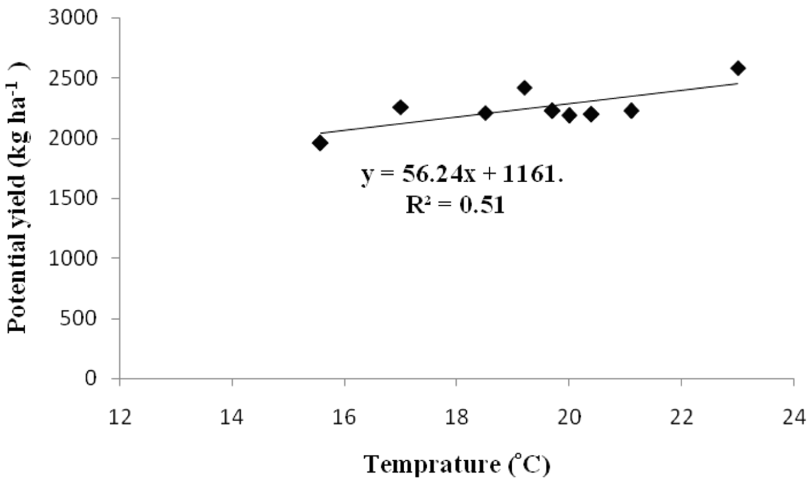

Figure 5. Association of long-term mean simulated potential yield with mean crop season temperature among selected regions across Razavi Khorasan.

Linear regression between potential yield and year in any of the regions was not significant meaning less seasonal variability in potential yields due to water and nutrients at potential condition and no biotic stress. Other studies also have indicated that variability in potential yields across years would not be very high (Aggarwal et al., 1994; Bhatia et al., 2008).

Averaged across regions and seasons, simulated potential yield was 2251 kg ha^{-1} with a coefficient of variation of 7%. Among regions, mean simulated potential yield ranged from 1956 kg ha^{-1} in Quchan to 2584 kg ha^{-1} in Torbat-Jam. Mean solar radiation in these regions was 20.9 and 23.0 MJ m^{-2} d^{-1}, respectively (Tables 4 and 5). Furthermore, the minimum potential yield was 1116 kg ha^{-1} in Quchan in 2012 and the maximum potential yield was 3159 kg ha^{-1} in Torbat-Jam in 1994. Mean solar radiation and temperatures were 21.2 MJ m^{-2} day^{-1} and 15 °C in Quchan and 23.3 MJ m^{-2} day^{-1} and 18 °C in Torbat-Jam.

Table 4. Average of solar radiation, temperature and rainfall during growth period of chickpea at selected regions in Razavi Khorasan province.

Region	Solar radiation (MJ m^{-2} day^{-1})	Temperature (°C)	Rainfall (mm)
Daregaz	20.8	20.1	96
Quchan	20.9	15.57	124
Gonabad	22.2	20.4	36
Kashmar	22.4	19.7	60
Mashhad	20.4	18.5	92
Neishabur	22.6	19.2	82
Sabzevar	21.2	21.1	54
Torbat Heydarie	22.7	15.0	82
Torbat-Jam	23.0	17.7	60

Table 5. Average of simulated potential and water limited yield, actual yields and yield gaps at selected locations in Razavi Khorasan province.

location	Potential (A)	CV	Water limited yield (B)	CV	Irrigated actual yield (C)	Rainfed actual yield (D)	YG_{MI} (A-C)	YG_{MM} (A-B)	YG_{MR} (B-D)
Daregaz	2186	8	900	33	840	265	1346	1286	635
Quchan	1956	22	1300	28	900	265	1055	656	1035
Gonabad	2197	17	850	35	617	-	1580	1347	-
Kashmar	2225	12	1153	32	702	172	1522	1072	981
Mashhad	2213	16	1251	34	885	245	1327	962	1006
Neishabur	2421	17	952	24	1016	270	1404	1469	682
Sabzevar	2224	10	967	30	751	236	1472	1257	731
Torbat Heydarie	2257	15	977	36	850	162	1407	1280	815
Torbat-Jam	2584	11	880	36	630	226	1954	1704	654
Average	2251	14	1026	32	799	230	1452	1226	817
CV	7		15		15	16	15	23	18

Simulated water limited yield

Under water limited conditions, the average simulated yield of chickpea was 1026 kg ha^{-1} with a coefficient of variation of 15% (Table 5). Overall, the average water limited yields was very low because the average rainfall in these regions was 76 mm. Among these regions, the water limited of the crop ranged from 1300 kg ha^{-1} (Quchan) to 850 kg ha^{-1} (Gonabad). The average rainfall was 124 mm and 36 mm in Quchan and Gonabad respectively (Table 4). As productivity at this level was primarily governed by the water availability (rainfall), both the spatial and temporal variability in simulated water limited yield was of very high magnitude as compared to simulated potential yield (Table 5). Such large variation in simulated water limited yield explain the degree of fluctuations in chickpea yield under rainfed conditions in Khorasan Razavi province.

In Iran, chickpea grown in locations that are primarily related to annual rainfall between 300 mm to 500 mm. These locations also have inappropriate rainfall distribution rather than deficient rainfall (Gangeali and Nezami, 2008). Furthermore, recent studies (Karimi and Farneya, 2009; Parsa et al., 2012; Nezami et al., 2009) have indicated that at least 50 percent of the cultivated area of chickpea have sufficient rainfall, but rainfall distribution is not appropriate. This can be an important factor in reducing the chickpea yield. In contrast to simulated potential yield, no significant association was observed between mean simulated water limited yield and mean crop solar radiation of these locations. This indicated that at this production level the variability in potential yield across the locations was largely governed by the availability of water.

Yield gaps

The simulation of potential yield in major chickpea-growing region of Khorasan province clearly indicated high yield potential of chickpea which is not presently realized by the farmers. The average irrigated actual yields across regions was about 1452 kg ha^{-1} which was less than the average simulated potential yields, indicating a 64% reduction of actual yield as compared to potential one (Table 5). The average rainfed actual yield was about 817 kg ha^{-1} less than the average simulated water limited yields indicating a 79% reduction in rainfed actual yield as compared to water limited yields.

YG_{MI} (simulated potential yield minus irrigated actual yield) ranged from 1055 (Quchan) to 1954 kg ha^{-1} (Torbat-Jam) (Table 5). Torbat-Jam had the highest potential and the lowest actual irrigated yield among study locations

(Table 5), which lead to its largest yield gap. In contrast, the lower yield gap in Quchan was due to its lower potential yield (1956 kg ha^{-1}) and relatively higher actual yield (900 kg ha^{-1}). When the YG_{MI} was plotted against the mean crop season rainfall of these regions, a significant ($P<0.05$) negative relationship (R^2=0.56) (Figure 6) was observed, so that by increasing each 1 mm of rainfall, the yield gap was reduced about 6 kg ha^{-1}.

Lobell et al. (2009) evaluated causes of yield gaps in rice, wheat and maize in major global crop locations and mentioned that crop yields hardly exceeded 80% of their yield potential. Caldiz et al. (2002) by evaluating the potato yield production systems in Argentina reported that along with increasing of potential yield at a region, yield gap has also increased.

YG_{MM} (simulated potential yield minus simulated water limited yield) ranged from 656 (Quchan) to 1704 kg ha^{-1} (Torbat-Jam) (Table 5). The lowest potential yield and the highest water limited yield were in Quchan (Table 5). Generally, YG_{MI} and YG_{MM} showed an increasing trend from the north (including Neishabur, Mashhad, Quchan and Daregaz regions) to the south of this province (Torbat-Jam and Gonabad). Because potential yield had increasing trend from north to south of the province. In the present study, the YG_{MM} showed a significant negative association (R^2=0.43, $P<0.05$) with mean crop season rainfall (Figure 6), as by increasing each 1 mm of rainfall, the yield gap was reduced about 7 kg ha^{-1}.

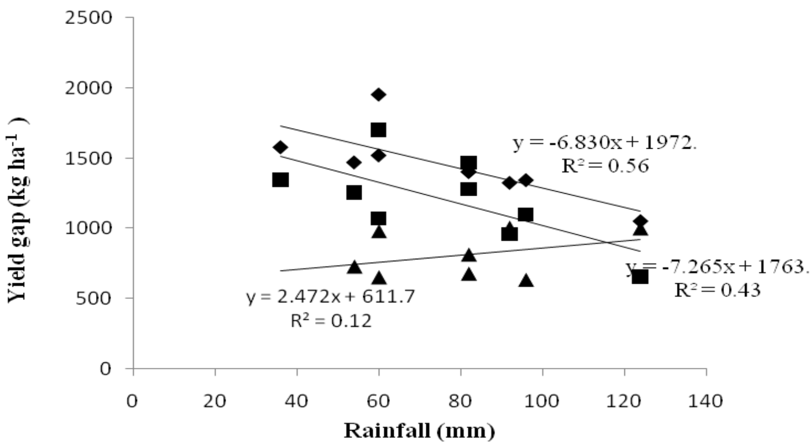

Figure 6. Association of long-term mean yield gap between simulated potential and irrigated actual yield (♦), mean yield gap between simulated potential and water limited yield (■) and yield gap between simulated water limited and rainfed actual yield (▲) with mean crop season rainfall among selected regions across Razavi Khorasan province.

YG_{MR} (simulated water limited yield- rainfed actual yield) varied from 635 (Daregaz) to 1035 kg ha^{-1}(Quchan). YG_{MR} was very low in comparison to other yield gaps (Table 5) because both simulated water limited and average rainfed actual yields were low in these regions. Furthermore, YG_{MR} was unaffected by the amount of rainfall received at these regions (Figure 6). So, farmers must choose a suitable sowing date to adjust plant phenological stages with optimum climatic conditions to achieve high yields. Recent studies (Zaferanieh et al., 2009; Nezami et al., 2009; Gangeali et al., 2009) have shown that winter sowing in comparison to spring sowing increased yield up to 100%. This achievement is due to the adaptation of chickpea phenology with desirable temperature and moisture regimes and also prolonging vegetative growth before flowering stage. Bhatia et al. (2008) analyzed potential and yield gap of soybean (Glycine max L. Merr.) by using CROPGRO model in 21 locations of India and showed that the average potential yield was 3020 kg ha^{-1}, while the percentage of yield gap was 70% and concluded that farmers only harvest 30% of potential yield. Meng et al. (2013) quantified the yield potentials and gaps in four maize agro-ecological regions of China. They indicated YGM (Modeled yield potential-Average farmers' yield) was 8.6 and 6.0 Mg ha^{-1} for irrigated and rainfed maize, respectively. The average farmers' yield was 48-56% of the yield potential.

Conclusion

The results suggested that Khorasan Razavi province with low actual chickpea yields have a large yield gaps and high potential to increase current yields. The model simulations showed that the average potential yield of chickpea for the regions was 2251 kg ha^{-1}, while the water limited yield was 1026 kg ha^{-1} indicating a 54% reduction in yield due to adverse soil moisture conditions. The average irrigated and rainfed actual yield were also 64% and 79% less than simulated potential and water limited yields respectively. Across all study locations the potential yields were less variable than water limited and actual yields and correlated with solar radiation during the season (R^2=0.63, $P<0.05$). Generally, YG_{MI} and YG_{MM} showed an increasing trend from the north (including Neishabur, Mashhad, Quchan and Daregaz regions) to the south of this province (Torbat-Jam and Gonabad). In comparison to other yield gaps, the quantity of YG_{MR} were very low because both simulated water limited and average rainfed actual yields were low in these regions. Furthermore, YG_{MR} was almost unaffected by the amount of rainfall received at these locations. Such study results will enable policy makers that adjust their policies in each region to manage and reduce yield gaps. Furthermore, the obtained pattern of yield gap analysis of the Khorasan Razavi province will also be applicable to other provinces and provide more accurate planning based on the spatial and temporal fluctuations of yield in future.

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