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Yield gap analysis in major wheat growing areas of Khorasan province, Iran, through crop modelling

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ABSTRACT

To increase wheat productivity from current levels, the yield gap, the difference between actual and potential yield, should be analyzed. A crop model was calibrated for three winter wheat cultivars and validated for a major wheat growing area to evaluate yield gaps in Khorasan province in northeastern Iran. The validated model was used to simulate long-term yield for 14 locations under three management conditions (potential, water-limited, nitrogen-limited). The results showed that the average simulated potential yield of 7.8 Mg ha^{-1} has not yet been realized by farmers and there is a large gap between the actual and potential production levels (about 5.2 Mg ha^{-1}). The simulation showed considerable difference between cultivars for yield gap. When averaged over locations and seasons, the total yield gap obtained for Chamran wheat was 4.4 Mg ha^{-1}, for Sionz was 6 Mg ha^{-1}, and for Gascozhen was 6.1 Mg ha^{-1}. Across locations, the proportion of yield gap from water-limitation was 1.7% to 19.5% and for nitrogen- limitation was 40% to 47%. The gap caused by other limiting and reducing factors was 33–57%. The highest yield gap was observed in Ghaen for Gascozhen (7.6 Mg ha^{-1}) and the lowest was observed in Sarakhs for Chamran (3.1 Mg ha^{-1}). The results of the study suggest that the average farm yield of about 2.6 Mg ha^{-1} in irrigated fields in Khorasan province is not limited by low genetic yield potential. This indicates that farmers should emphasize more on management factors such as water availability, timing of nitrogen application, and selection of cultivars adapted for each environment to reduce yield gap.

1. Introduction

Crop productivity is greatly limited by water and nitrogen shortage in many irrigated areas of the world (Kalra et al., 2007). In the intensive cropping systems of Khorasan province in the northeast of Iran, irrigated wheat cropping accounts for about 51% of the land area under wheat production (~750,000 ha) with average yield of about 3 Mg ha^{-1} (Anonymous, 2010). But there is a large variability in irrigation water and nitrogen availability and other abiotic and biotic factors causing reduction in farmers' actual yield (i.e., yield gaps). To eliminate the yield reduction, yield gap analysis should be conducted in order to reach the actual yield to the potential one. It is also essential to understand potential yield and yield gaps in wheat production areas in order to increase grain yield to supply increasing population needs.

Recently, so many studies have been carried out regarding the yield gap concept (Bindraban et al., 2000; Naab et al., 2004; Anderson, 2010; Meng et al., 2013). Anderson (2010) reviewed the impact of environment, management and cultivar on rainfed wheat yield gap across Australia and reported that with increasing seasonal rainfall over 250 mm, the gap between average farm yield and potential grain yield increased. Their field studies in Western Australia under a range of environments (locations × seasons), levels of management (fertilizer treatments, planting dates, density) and cultivars, also showed that the main effect of environment, management and genotype accounted for about 80%, 6% and 3% of the variability in grain yield, respectively. The G × E (genotype by environment) and G × M (genotype by management) interactions were generally negligible. Meng et al. (2013) portrayed that yield gap between average farmer's yield and simulated yield potential in northwestern China was 8.6 and 6 Mg ha^{-1} for irrigated and rainfed maize, respectively and farmers achieved only 48–56% of the yield potential. In on-farm trials in peanut in Florida, USA, Gilbert et al. (2002), revealed that biotic stresses including rootknot nematode (*Meloidogyne arenaria*), and white mold (*Scleroabout tium rolfsii)* were responsible for yield gaps in approximately half of the farmers' fields.

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Using field experiments for quantifying the yield gaps and determining the yields at different production situations (i.e., potential, water and nitrogen limitation) would be time consuming and expensive and involve many years of data collection. Also, capturing all factors and their interactions affecting growth and development for a given production level, might not be possible in these field experiments (Bhatia et al., 2008). In contrast, simulation models accompanied with short-term field experiments can be used to quantify yield losses associated with biotic and abiotic stresses, and inappropriate crop management. Recently, several dynamic mechanistic crop simulation models have been developed that predict yield, growth and development of so many field crops using process-oriented approach that consider interaction of different components as well as the knowledge behind the underlying processes in crop production (Boote et al., 1996).

Since a crop model is evaluated for a given location, it can be applied for long-term simulation of crop performance under various management strategies such as sowing density, planting time, soil fertility and cultivar selection. Then, the crop models can be applied to evaluate the effects of climatic and management factors on production over a wider region and different years. Using this information, researchers can highlight the major yield-limiting factors and advice farmers more efficiently (Naab et al., 2004).

The objectives of the current study were (i) to estimate potential yields and yield gaps associated with water and nitrogen shortage in the major wheat-growing regions of Khorasan province of Iran and (ii) to evaluate yield gaps arising from use of difference wheat cultivars.

2. Materials and methods

2.1. Study area and weather data

The study was carried out at 14 locations in Khorasan province, which is located in northeastern Iran. Historical weather data for 1987 to 2009 were obtained from the Iran Meteorological Organization for the 14 locations. The weather data included daily sunshine hours (h), daily maximum and minimum temperatures (°C), and daily rainfall (mm). Daily solar radiation was estimated using the Goudriaan (1993) method. The geographical details of study locations and soil properties are presented in Table 1.

2.2. APSIM-Wheat model

The Agricultural Production Systems sIMulator (APSIM) crop model ver. 7.2 (Wang et al., 2002; Keating et al., 2003) was applied to evaluate yield gaps in the major winter wheat growing area of Khorasan province, Iran. This model simulates the impacts of weather, genotype, soil properties, and management factors on crop growth and development, soil water and nitrogen balance on a daily basis and finally predicts yield. The model requires input data, including local weather and soil conditions, cultivar-specific parameters, and crop management information. SOILWAT module was used to determine soil water balance under water-limited conditions. The model has been described in detail by Keating et al. (2003) and used for the prediction of wheat (Heng et al., 2006; Sadras et al., 2003), sugarcane (Cheeroo-Nayamuth et al., 2000), and in climate change studies (Luo et al., 2009).

The needed soil parameters for the model included lower limit (LL) and drained upper limit (DUL) of soil water content ($cm^3\ cm^{-3}$), and saturated (SAT) water content ($cm^3\ cm^{-3}$). These parameters were estimated based on soil texture and bulk density using the Soil Parameters Estimate Program (SOILPAR, Donatelli et al., 1996). Soil texture and bulk density were obtained from a previous study (Tatari, 2008) and from information obtained from questionnaires collected at the field level. The questionnaires were sent to extension agents at all sites to obtain information on the main wheat producing villages. The management and environmental information that was requested included the different growing seasons, crop area, planting dates, local soil characteristics, amount of nitrogen applied, irrigation practices, actual yield obtained by each farmer, plant density and information on weed, pest and disease infestation that limit the productivity of irrigated wheat. In total 600 farms received and responded to the questionnaires.

2.3. Model evaluation

Model evaluation consisted of model calibration and validation. For model calibration, a field experiment was conducted in a randomized complete block design with four replications in the experimental fields of Ferdowsi University in Mashhad, Iran (36°16′N, 59°38′E and elevation of 999 m). The experimental factors included three cultivars (Chamran, Sionz, Gascozhen) and four levels of nitrogen (N) application (0, 55, 110, 172 kg N ha^{-1}). The cultivars selected are the most popular and predominate in the study area. Planting was done on October 8, 2007 and all blocks were well-irrigated to avoid water stress. Half of the nitrogen fertilizer (as urea) was applied at the time of planting and other half at anthesis for all treatments. The plant population of 350 m^{-2} was maintained with row-spacing of 25 cm. Crop phenology as duration to anthesis and physiological maturity were monitored and biomass accumulation, leaf area, and grain yield were measured. To maintain plots free from biotic stresses (weeds and insect pests), local agronomic practices were followed.

Table 1
Geographical details, soil properties, management inputs and period of weather data used for simulation in study locations.

Location	Latitude	Longitude	Altitude (m)	Number of irrigation[a]	Nitrogen fertilization at sowing[b] (kg N ha^{-1})	Simulation period	PAWC[c] (mm)
Birjand	32°52′	59°12′	1491	6	200	1996–1987	150
Bojnord	37°28′	57°28′	1091	6	185	1996–1987	150
Ferdows	34°01′	58°10′	1293	7	165	1996–1987	150
Ghaen	33°43′	59°10′	1432	5	250	1996–1987	150
Ghoochan	37°04′	58°30′	1287	6	261	2009–1987	84
Golmakan	36°32′	59°17′	1176	7	278	1996–1987	96
Gonabad	34°21′	58°41′	1056	9	247	2009–1987	102
Kashmar	35°20′	28 °58′	1110	6	210	2009–1987	120
Mashhad	36°16′	59°38′	999	5	252	2009–1990	150
Nishabour	36°16′	58°48′	1213	6	277	2009–1991	84
Sabzevar	36°12′	57°39′	972	6	185	2009–1987	102
Sarakhs	36°32′	61°10′	235	6	176	2009–1987	84
TorbatHeydariyeh	35°16′	59°13′	1450	9	280	2009–1987	150
TorbatJam	35°15′	60°35′	950	9	300	2009–1992	150

[a] Number of irrigation per crop season, 50 mm each.
[b] Average amount of nitrogen applied by farmers at each location at sowing.
[c] Plant available water holding capacity of each soil.