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Can the dormant seeding of rainfed lentil improve productivity and water use efficiency in arid and semi-arid conditions?

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ABSTRACT

Dormant seeding (DS) has become popular in dry areas because it provides a longer growing season and optimum temperature during the early spring to grow crop. Long-term daily weather data for the period of 1984–2014, were collected for ten locations in northwestern Iran with a cold semi-arid and arid climate. The SSM-legumes model was used to investigate the effect of dormant seeding versus different fixed spring sowing dates as well as cultivars on the yield and water use efficiency (WUE) of lentil. The results showed that, the highest average grain yield across all the study locations was obtained for DS management and decreased around 49% when sowing date was delayed to 4 April. Furthermore, with a delay in sowing date, the decline in grain yield of short- cycle and long- cycle cultivars was 42% and 58%, respectively. On average, WUE for short- cycle cultivar was much higher than long-season cultivar (6.2 and 4.0 kg ha^{-1} mm^{-1}, respectively). The combination of short-cycle cultivar × DS management resulted in 30% and 29% increase in grain yield and WUE, respectively when compared with a long-cycle cultivar × DS management. This conclusion was reached because DS sowing and short-cycle cultivar increased yield and its stability due to the proper establishment and appropriate growth conditions of lentil in late winter and early spring. DS also resulted in better use of precipitation and escape from the heat and drought stresses in late spring and early summer, provided that there is no frost risk in the target regions. Overall, the results of the simulations for all the study locations suggested that sowing lentil using DS is indeed superior over the other fixed spring sowing practices because it not only shortens the frost risk to seedlings but also provides optimal conditions for the growth and use of rainfall and soil moisture as well as lentil growth.

1. Introduction

Lentil is an annual food legume that is rich in protein and micronutrients for human consumption. The straw is also valued as animal feed. The most important areas of lentil production are located in south and west Asia, northern Africa, sub-Saharan Africa, Canada, Australia, and the United States (Chen et al., 2011).

The shortage of water resources and the greater occurrence of intolerable temperatures by crops (i.e. heat and frost stresses), are primary environmental factors threatening yield of lentil around the world. These challenges for production of lentil are coinciding with global population growth that requires significant increases in food production (Borlaug and Dowswell, 2005). In the major lentil growing areas worldwide, actual grain yield is no more than one-half of the potential yield (Erskine et al., 2011), denoting a necessity to boost productivity and water use efficiency via crop genetic improvement as well as better crop management practices. For instance, matching the growth cycle of a crop to the rainfall seasons is one of the most important adaptation strategies to water shortage, particularly under rainfed conditions (Bejiga, 1991).

Amiri et al. (2016) reported that early sowing dates enabled chickpea to better exploit rainfall during the crop season and escape from terminal drought stress. Azimzadeh, (2010) also concluded that under delayed sowing of rainfed lentil in Shirvan, northeastern Iran, seasonal rainfall did not match with crop growth, which resulted in shortened pod-filling period and consequently yield loss. In Syria, grain yield was increased by sowing in December, while delaying sowing to January and February decreased grain yield by 25% (Saxena et al., 1983).

Iran is part of the WANA (West Asia and Northern Africa) region which is characterized as the area with high growth rate in population, limited arable land (mostly non-irrigated), low and highly variable

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rainfall, and limited water resources for irrigation (Saxena et al., 1996). Lentil is the most important legume crop in Iran, with 250,000 ha under cultivation (FAO, 2012). The crop is predominately grown under rainfed conditions with an average yield of about 500 kg ha^{-1} (FAO, 2012). Farmers in Iran usually sow lentil in early spring (March) and harvest around July. Under these circumstances, the crop encounters low winter rainfall, low WUE and often temperature stress and terminal drought during reproductive stages (Zyaie et al., 2012; Azimzadeh, 2010). Recently, some farmers tried a type of planting management called dormant seeding management (DS) of lentil in the area. Under DS sowing date, the seeds remained ungerminated and dormant in the soil until some criteria met. In other words, germination is done when the soil moisture and air temperature are optimized for lentil after frost and low temperatures period in winter. In this management system, it is assumed that germination would take place once the initial soil moisture in the top soil layer (200 mm) filled to the volumetric transpirable soil water (0.13, see below). While the temperature of top soil layer is above the base of 2 °C. Furthermore, the crop germination is stopped due to lower temperatures than base temperature of lentil. This method might increase grain yield, WUE and length of lentil growing season particularly when a right time is chosen to apply DS management.

Crop simulation models have been used to investigate the effects of the best management practices on crop productivity in the past two decades. For instance, Rasam and Soltani (2007) analyzed the effect of a sowing date on chickpea yield using the CYRUS chickpea model and concluded that earlier sowing dates led to greater leaf area index and higher dry matter production. They also found that early sown crops flowered and matured earlier and escaped terminal drought stress. Using the SSM-Legumes model, Ghanem et al. (2015) showed that delaying sowing alone or in combination with long-phenology cultivars can result in a higher probability of crop yield increase in lentil producing areas of East Africa as it coincides with the end of the rainy season (September) and would therefore offer a potential of growing lentil in this area.

Apart from farmers' experiences regarding DS management over the last decade, only a few scientific reports have been conducted on this issue (Mostafaie, 2016 and 2017). Therefore questions still remain about why and how much the DS management over a long-term period along with changing cultivars can increase lentil productivity and exploit better rainfall over growing season in the arid and semi-arid conditions of Iran. The main objective of this study was to examine the change in an agricultural management practice (i.e. DS versus different spring sowing dates) as well as cultivars to increase water-limited potential yield of lentil at ten locations in northwestern Iran.

2. Materials and methods

2.1. Study area and weather data

Ten locations in northwestern Iran were studied (Table 1). Rainfed actual grain yields and cultivation area (Fig. 1) data reported for each location for the period 2004–2014 were collected from local agricultural departments (Anonymous, 2015). The yields are the average yield of lentil in diverse farmers' fields. Long-term daily weather data for the period of 1984–2014, including sunshine hours per day (sunrise to sunset), precipitation, and maximum and minimum temperatures were collected for each location from its climatological station. As the daily solar radiation ($MJm^{-2}\ d^{-1}$) is required for running crop simulation models and normally not measured in many weather stations, it was estimated using Angstromequation as follows (Prescott, 1940):

$$Rs = \left(a\ + b\,\frac{n}{N}\right)Ra \tag{1}$$

where Rs is the global solar radiation at the ground surface ($MJm^{-2}\ d^{-1}$), n is the actual duration of sunlight (h), N is day length (h), Ra is extraterrestrial radiation ($MJm^{-2}\ d^{-1}$) and a and b are Angstrom coefficients. Parameters a and b for the different study locations were 0.317 and 0.386, respectively (Moini et al., 2011).

2.2. Crop model description

The SSM-legumes model was used in this study (Soltani and Sinclair, 2012b). The robustness of this model has been examined using different experiments over a wide range of circumstances for different legume species including soybean (Sinclair et al., 2010), chickpea (Vadez et al., 2013; Amiri et al., 2016 and Amiri, 2016), bean (Marrou et al., 2014) and lentil (Ghanem et al., 2015). The SSM-Legumes model calculates leaf area index as a function of temperature and limitations due to insufficient nitrogen and soil water (Table 2). The leaf area index of the crop is used to calculate intercepted solar radiation, which in turn is used to calculate crop growth as a function of radiation use efficiency (Sinclair et al., 2014). Radiation use efficiency, like leaf development, is decreased under limiting soil water supply (Soltani and Sinclair, 2012b). The transpiration rate is computed as a function of crop growth multiplied by the atmospheric vapor pressure deficit, divided by a mechanically-based transpiration coefficient (Soltani and Sinclair, 2012b).

Estimation of the soil water balance in the lentil model is according to the original SSM-Legumes (Soltani and Sinclair, 2012b). That is, the whole soil volume occupied by roots is considered as a single reservoir for estimating the storage of crop available soil water. Soil water condition, estimated as the amount of transpirable soil water (ATSW), was computed daily using the water balance equation. The volume of soil used in the calculation was increased daily as root development increased depth of extraction (Soltani and Sinclair, 2012b).

The duration of each development phase of the plants was determined by the biological days needed for completion of the phenological phase (Soltani and Sinclair, 2012b). The biological days are the total number of days needed to complete a development phase when plants are grown under optimum photoperiod and temperature situations (biological days multiplied by optimum temperature is equivalent

Table 1
Geographical characteristics of the selected locations.

Locations	Location code	Latitude	Longitude	Elevation (masl)	Annual mean tempetature (°C)	Cumulative percipitation (mm)
Aligoudarz	1	33. 37 N	49. 67 E	2022	14	430
Ardabil	2	38. 15 N	48. 17 E	1332	9	303
Kangavar	3	44. 50 N	47. 96 E	1457	13	437
Kermanshah	4	34. 21 N	47. 90 E	1400	14	456
Khoramabad	5	33. 29 N	48. 22 E	1147	17	509
Mianeh	6	37. 27 N	47. 42 E	1110	11	628
Oroomieh	7	37. 40 N	45. 30 E	1328	10	555
Parsabad	8	39. 39 N	47. 55 E	31.9	15	271
Tabriz	9	38. 50 N	46. 17 E	1361	12	310
Takab	10	36. 24 N	47. 6 E	1817	10	352

masl: meter above sea level.