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Early sowing and irrigation to increase barley yields and water use efficiency in Mediterranean conditions

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ABSTRACT

In rainfed Mediterranean areas, early sowings which lead to early growth and maturity to escape terminal heat and drought usually give higher grain yield than late sowings in years when rains come early. We test the hypothesis that early sowing coupled with a small amount of irrigation to ensure earlier emergence increases grain yield significantly, while improving irrigation water productivity. Replicated field experiments were conducted for 4 years in the semi-arid central Bekaa Valley of Lebanon. Barley was sown early, and half of the plots were irrigated with 25–30 mm of water immediately after sowing (EI). Half of the plots also received irrigation around heading stage (LI). Besides yields, other agronomic data were collected throughout crop growth, and the supplemental irrigation water use efficiency (WUE_{SI}) was calculated. Our results confirm the hypothesis that in Mediterranean areas early sowing followed immediately with a small amount of irrigation increases barley grain yield significantly. Farmers in the region should seriously consider practicing this technique as it produces a higher WUE_{SI} than irrigation at the heading stage.

1. Introduction

Sowing date has a large effect on crop yields under rain-fed conditions. In West Asia and North Africa, which have a Mediterranean climate, rains come mainly in the winter months and the summer is hot and dry. Thus without irrigation in the summer only winter cropping is possible. Crops are usually sown in November or December, and harvested in May or June. Yield tends to decrease if sown later than early December, as the growing period is shortened and crops are exposed to higher risks of late season heat and water shortage in the grain filling period (Stapper and Harris, 1989; Oweis et al., 1998; Yau, 2003; Tavakkoli and Oweis, 2004). As the temperature is cool in the fall, seedling emergence can take a long time after sowing. This is especially true in the high latitude or high-elevation areas, where it is common that if seeds are sown in late November, seedlings will appear only after a month. As the seedlings are small and the winters are cold, little of the rainfall during the winters is used by the crops. Part of the rainfall is stored in the soil and the remainder infiltrates too deeply for use by the crops later in the season.

In addition to rainfall, temperature has a large effect on crop yields in Mediterranean areas (Yau and Ryan, 2009). Winter crops achieve maximum growth rates in spring. They need to flower and produce seeds before the hot, dry summer, as they are not adapted to hot conditions. Late planted crops tend not to produce large yields, even if irrigation is available. As early sowing and emergence always lead to earlier flowering and maturity, allowing an escape from terminal heat and drought, early sowing tends to produce larger grain yields (Yau, 2003).

As rains arrive late in some years, thus negating the early seedling emergence benefit of early sowing, a strategy is needed to ensure early germination after early sowing. Irrigation immediately after early sowing can ensure early germination. In the region, wheat grain yield and water productivity have been shown to be greatly increased by supplemental irrigation, which usually is applied at heading and/or after heading to reduce the water shortage stress during the grain-filling period (Oweis et al., 2000; Zhang and Oweis, 1999; Abourached et al., 2008). However, obtaining the needed large amount of water (usually >100 to <300 mm) for supplemental irrigation in this period can be difficult and costly in arid and semi-arid environments. Since the purpose of the early irrigation is to ensure early uniform germination, unlike full irrigation or supplementary irrigation later in the season, only a small amount of irrigation is needed.

The idea of applying a small amount of supplemental irrigation to initiate early emergence after early sowing emerged 3–4 decades ago. As early as in 1975, S. Ermis in the Central Anatolian Plateau of Turkey recommended two irrigations for wheat, at sowing and in April (Ilbeyi et al., 2006). In Iran, the earliest report on early irrigation after sowing probably was given by A.R. Tavakkoli in 2000

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(Tavakkoli and Oweis, 2004). Recently, three field and/or simulation studies on the technique have been reported on wheat. Early wheat establishment using 50 mm of irrigation increased grain yield over the control in two of four years in the Central Anatolian Plateau of Turkey (Ilbeyi et al., 2006). In the field study of Benli et al. (2007), also carried out in the Central Anatolian Plateau of Turkey, irrigation at sowing increased wheat yields in only one of three seasons. Nevertheless, their simulation study using weather data for 20 years showed that wheat grain yields could be improved by 15%, 19%, and 25% with only 50 mm of water at sowing at October 15, October 1, and September 15, respectively. In the simulation study of Heng et al. (2007) using data from Morocco and Jordan, 40 mm of supplemental irrigation at sowing significantly improved average wheat grain yield, particularly when 40 kg N ha^{-1} was applied.

No research on early irrigation has been conducted on barley. In addition, as inconsistent results were obtained on wheat in Turkey, and two of the three experiments of earlier research were based on simulation using long-term weather data, more field studies are needed. The objective of this study was to test the hypothesis that early sowing, followed immediately with a small amount of irrigation to ensure earlier emergence, increases barley grain yield significantly, and thus improves the irrigation water use efficiency in a Mediterranean semi-arid area.

2. Materials and methods

The four-year (2004–2005, 2005–2006, 2007–2008, 2008–2009) experiment was conducted on stony fields with shallow soils at the Agricultural Research and Educational Centre (33°56′N, 36°05′E, 995 m a.s.l.) in the semi-arid central Bekaa Valley, which is the food basket of Lebanon. The long-term (51 years) average annual precipitation at the site is 519 mm, 58% of which falls in December, January, and February, with essentially no rainfall from June to September. Without irrigation or rain, the soil is dry and no seed can emerge, even if sown early. Opening rains usually come in mid-to-late November, but may arrive early in late October or as late as end of December. Seeds were sown in late October, except in 2008–2009, instead of the usual mid- or late-November. In 2006–2007 and 2008–2009, unexpected heavy rain fell in late October before sowing. The experiment was not conducted in 2006–2007, but sowing was conducted in 2008–2009 after the field had dried. A day after sowing (except in 2007–2008), 25–30 mm irrigation was given to appropriate plots. Dates of sowing, early irrigation, and first rains having adequate amounts to induce seed germination are presented in Table 1.

The experiment was conducted in a randomized complete block design with 3 replicates in the first year and 4 replications in the later three years. Irrigation by sprinklers was the main factor of study. There were a maximum of 4 treatments: control (without irrigation), only early irrigation (EI), only late irrigation (LI), and both early and late irrigation (EI + LI). In 2004–2005, only two treatments, control and EI, were studied. All 4 treatments were present in 2005–2006 and 2008–2009. In 2007–2008, plants in the EI treatment were approaching maturity when plants in the LI received irrigation, thus it was decided to skip the EI + LI treatment. The LI treatment received irrigation (30 mm on 30 April in 2006; 100 mm on 15 April 2008; 60 mm on 24 April 2009) when barley was heading, which is the most common time for cereal farmers to carry out supplementary irrigation. Except for 2007–2008, a small amount of irrigation was given, as farmers usually do not irrigate barley or apply a much smaller amount of water than for wheat. The irrigation amount was raised in the dry year of 2007–2008.

Sowing was carried out by hand using a 25 cm inter-row spacing in the first year, but by a small-plot planter using a 30 cm inter-row spacing in the last 3 years. Plot size increased over the years: 2 m × 1 m in 2004–2005, 3 m × 1.8 m in 2005–2006, and 8 m × 3 m in 2007–2008 and 2008–2009. The improved barley variety, Rihane, was sown at a rate of 100 kg ha^{-1}. Nitrogen was applied twice by broadcasting: 20 kg N ha^{-1} as ammonium sulfate after sowing, and 40 kg N ha^{-1} as ammonium nitrate in early spring. Since the soils had Olsen-P > 30 mg kg^{-1}, no phosphate fertilizer was applied. No other fertilizer was applied as levels of K, Mg, Ca, and micronutrients were adequate. Weeds were controlled by hand removal in the first two years. The herbicide 2,4-D was sprayed to control broadleaf weeds in the last two years (on 27 March 2008 and 6 December 2008).

During the seasons, dates of seedling emergence, heading, and maturity were recorded when 50% of the seedlings had emerged, 50% of the plants had spikes out of the boot, and all plants turned yellow, respectively. Plant stand in percentage was scored visually after seedling emergence in all years, except 2007–2008. During the tillering stage in February and March in 2004–2005 and 2005–2006, growth vigor was scored visually on a 1–5 scale (1 good; 5 poor). Plant height from ground to the tip of the spike, excluding awns, was taken near maturity. Head number was obtained by counting a representative 1-m row of plants before maturity.

After maturity, plants were hand-harvested by cutting at ground level. Samples from 2 central 1-m rows (0.5 m^2) and 2 central 2-m rows (1.2 m^2) were collected from each plot in 2004–2005 and 2005–2006, respectively. In 2007–2008 and 2008–2009, 1 random 1-m^2 quadrate was sampled from each of the EI plots, which were uniform in height, but 6 and 4 quadrates were sampled in LI plots across the irrigation gradient in 2007–2008 and 2008–2009, respectively. After weighing, a small-plot thresher was used for threshing. Straw yield was calculated by subtracting grain yield from shoot dry matter yield. Harvest index was calculated as a fraction of grain yield over shoot dry matter yield. Thousand seed weight was measured by weighing 100 random seeds and then multiplying the weight by ten.

The analysis of variance program in the GenStat package (Version 6.1) was used to perform the statistical analysis. The option for randomized complete block design was selected to analyze individual traits for each year. For combined analysis over years, the option of general analysis of variance was used.

Supplemental irrigation water use efficiency (WUE_{SI}; Tavakkoli and Oweis, 2004) was calculated to compare the efficiency of water usage under EI vs. LI. WUE_{SI} was defined as grain yield increase over the non-irrigated control per unit of irrigation water applied. This WUE_{SI} was not the same as the productivity of total applied water (commonly abbreviated as PAW) put forward by Molden (1997) and from irrigation water productivity (IWP) used by Kulshreshtha (2006) and Sadras (2009).

3. Results

3.1. Weather and seedling emergence

Relative to the long-term average, the annual precipitation of the 4 years ranged from −151 mm in 2007–2008 to +76 mm in 2008–2009, and deficits of 55 mm and 45 mm were recorded in 2004–2005 and 2005–2006, respectively. Distribution of precipitation within season also varied among years. Rains came near the end of October in 2005–2006 and 2008–2009 (Fig. 1 and Table 1). In 2004–2005, above-average rainfall was received in November, but the spring was dry. February and March precipitation was lower than usual in 2005–2006, but rainfall in April was exceptionally high. The relatively dry 2007–2008 received little rainfall in March and no rainfall in April, but the relatively wet 2008–2009 received above-average rainfall in February and March.