Field Crops Research 173 (2015) 57–67

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Effects of tillage and time of sowing on bread wheat, chickpea, barley and lentil grown in rotation in rainfed systems in Syria

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ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form
29 December 2014
Accepted 30 December 2014

Keywords:
Zero tillage
Conventional tillage
Early sowing
Late sowing
Conservation agriculture

ABSTRACT

Cropping systems in the drylands of west Asia are characterized by grazing, burning or harvesting of stubbles, multiple cultivations and late sowing, which can limit yields and lead to soil erosion and degradation. There is a lack of information on more conservation-based technologies developed in other countries to address some of these problems, particularly manipulations of tillage and time of sowing. This long-term field experiment was conducted under rainfed conditions at ICARDA near Aleppo in northern Syria to investigate the effects of conventional tillage (CT) and zero tillage (ZT) in combination with early and late times of sowing on the performance (production and profitability) of bread wheat, chickpea, barley and lentil grown in rotation over six years (2006–07 to 2011–12). As expected, the amount and pattern of rainfall was a major driver of crop performance, varying from 222 to 453 mm among the growing seasons. The grain yield of crops was often similar under ZT and CT (≈70% of year–crop–time of sowing combinations) and with early and late sowing (≈80% of year–tillage–crop combinations), but there were also many instances when ZT yielded significantly better than CT (≈25%) and early sowing yielded better than late sowing (≈13%). Importantly, over the four years from 2008–09 to 2011–12, the improved crop management system of ZT and early sowing gave higher grain yields than the conventional farmer system of CT sown late in two (13%) of the 16 year × crop combinations, similar yields in 13 (81%) combinations and lower yields for ZT early in one (6%) combination. During this time, the average grain yield increases with ZT and early sowing when compared to CT and late sowing were a significant 332 kg ha^{-1} (18%) for wheat, 127 kg ha^{-1} (20%) for chickpea and 135 kg ha^{-1} (15%) for lentil, and a non-significant 295 kg ha^{-1} (12%) for barley. Corresponding increases in gross margins ($US) were 162, 147, 89 and 176 $ ha^{-1} for wheat, chickpea, barley and lentil, respectively. In chickpea, the most profitable treatment was ZT sown late, producing an extra 281 kg ha^{-1} and 271 $ ha^{-1} compared to CT sown late. Early sowing improved crop establishment with increased plant densities of 30%, 48% and 29% for wheat, barley and lentil respectively, while ZT increased densities by 19%, 22% and 12% for chickpea, barley and lentil, respectively, when sown early. Other yield components reflected the grain yield responses. The increased grain yields achieved in this study, in combination with lower costs and greater profits, suggest ZT plus early sowing should be evaluated and promoted more widely as an attractive cropping technology for farmers in the Middle East.

1. Introduction

The production of cereal and legume crops in West Asia, including Syria, is characterized by heavy grazing, burning or harvesting of stubbles, multiple cultivations, and delayed or late sowing. Crop production is dominated by cereals, with legumes making up a small proportion of the land cropped, and a weedy fallow is a common part of the rotation in low rainfall regions. The conventional tillage (CT) practices in this region often include three or four tillage operations with different types of ploughs and harrows (moldboard, disc, duck-foot or chisel points) before sowing, which often leads to a delay in sowing of four to six weeks after the first effective rains in autumn. Grain yields for wheat in this Mediterranean region, where a generally low and variable rainfall of about 250–350 mm falls from September–October to April–May, with almost no rain outside this period, are often less than 1.0 t ha^{-1}, well below the water-limited potential or attainable yields of

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http://dx.doi.org/10.1016/j.fcr.2014.12.014
0378-4290/

4.2–6.4 t ha^{-1} (Sadras and Angus, 2006). In contrast, wheat yields have increased steadily over the past century in other countries such as Australia with many farmers approaching attainable yields through the use of improved crop varieties and better crop management (Anderson et al., 2005; Sadras and Angus, 2006; Anderson, 2010; Passioura and Angus, 2010; Richards et al., 2014). A key component of better crop management has been zero tillage (ZT), where crops are sown early with minimal soil disturbance and retention of stubbles.

Worldwide, ZT has been adopted over 120 million hectares in the last 30 years, mainly in the USA, Brazil, Argentina, Canada and Australia (Derpsch and Friedrich, 2009; Derpsch et al., 2010). In Australia, Llewellyn et al. (2012) reported that no-tillage – defined as "seeding with low soil disturbance (points or discs) and no prior cultivation" – has been adopted by nearly 90% of Australian farmers over the same period, with most (88%) using narrow points. Whilst ZT benefits crop production, profitability and resource sustainability, and reduces demands on labor and time, it also facilitates use of other improved crop management technologies. The elimination of ploughing and the availability of effective non-residual herbicides open the way for earlier sowing, which can have a strong positive effect on crop production (Coventry et al., 1993; Hobbs et al., 2008). A key to the success of ZT in Australia is where crops are sown before or immediately after the first autumn rains using minimal soil disturbance to utilize and store rainfall, assisted by the retention of stubbles from previous crops. Early sowing usually results in rapid and vigorous crop establishment under warm autumn conditions, and if the phenology of the crop genotype is matched to the early sowing, then grain filling usually occurs earlier during cool weather in early spring, resulting in higher grain yield and water-use efficiency (Loss and Siddique, 1994; Kirkegaard et al., 2014b; Richards et al., 2014). Until recently, ZT and early sowing have been little researched by scientists and little known or used by farmers in the Middle East. Giller et al. (2011) considered that because early planting is a main advantage of alternative land preparation methods, conservation agriculture (CA) and current practice need to be compared over a range of sowing dates.

Several long-term studies of maize and soybean in the USA, maize and wheat in Europe (Cannell and Hawes, 1994) and wheat in Mexico (Fischer et al., 2002) have shown that yields are often similar in ZT and cultivated systems. On the other hand, a 14-year study on soybean in Australia (So et al., 2009) showed grain yields under no-till (NT) were similar to or less than CT at the start of the experiment (1982–85), but CT was unable to sustain yields and from 1987 to 1994 yields were higher for NT (2.14 t ha^{-1}) than CT (1.67 t ha^{-1}). In a 14-year study of barley commenced in 1997 in Spain, Morell et al. (2011) found that mean yields for the 2006–09 cropping seasons were highest (2062 kg ha^{-1}) under NT, lower (1791 kg ha^{-1}) under minimum tillage (MT) and lowest (1155 kg ha^{-1}) under CT, with NT double that of CT in dry years and equal in wet years.

There have been few studies comparing ZT and CT in West Asia. In a two-year study in Lebanon, Yau et al. (2010) showed that tillage effects varied with years and crops, with grain yields under ZT compared to CT higher for safflower in 2005–06, similar with chickpea in 2005–06 and barley and safflower in 2006–07, and less with chickpea in 2006–07. In a three-year study in nearby Iran, Hemmat and Eskandari (2004) found yields were 27–31% higher under NT and MT than CT for wheat and 24–57% higher under NT than reduced, minimum and CT for chickpea. Numerous experiments in Morocco, some lasting 19 years, demonstrated superior yields (up to 146% greater) with wheat in rotation with chickpea and lentil under NT compared to CT (Mrabet et al., 2012).

Although ZT and early sowing are very compatible components for cropping systems in Mediterranean-type environments, there seem to be few studies published on the interactions between tillage and time of sowing (TOS). Given the limited awareness and use of ZT in the West Asia region, we wanted to determine if it was effective and whether, in conjunction with early sowing, it could improve the performance (productivity and profitability) of cropping. Of particular interest was whether the "improved" system of ZT with early sowing gave similar or better production and profit than the "conventional" farmer system of CT with late sowing. Our null hypothesis was that tillage and TOS have no effect on crop production or profitability.

The paper reports on results from the first six years (2006–07 to 2011–12) of a long-term experiment evaluating the effects of tillage and TOS on the production and profitability of bread wheat, chickpea, barley and lentil grown in rotation under rainfed conditions in northern Syria.

2. Materials and methods

2.1. Location

The experiment was conducted at the International Center for Agricultural Research in the Dry Areas (ICARDA), Tel Hadya, Aleppo, Syria (36.011°N 36.931°E, 285 m above sea level). The exact location of the trial, termed the B4 long-term trial, is shown in a satellite image in Sommer et al. (2014). The climate is typically Mediterranean with hot dry summers and cold wet winters, with the amount and pattern of rainfall and temperatures fluctuating widely from year to year. The average annual temperature is 17.8 °C and average annual rainfall (1980–2011) is 334 mm. The rainfed cropping season usually begins in September–November and extends to April–May. Wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* M.) are the main rainfed crops in the region.

The main soils of the region have been classified as vertisols, inceptisols, and aridisols, and are generally low in soil organic matter (SOM), nitrogen (N) and plant-available phosphorus (P), have a clay texture (60–70%), and are highly calcareous (~20% $CaCO_3$) with a pH around eight. The soil at Tel Hadya has been classified as a very fine, montmorillonitic, thermic, chromic calcixerert (Ryan et al., 1997). More details of the soils at the B4 experimental site are given in Sommer et al. (2012, 2014). The montmorillonite clay minerals expand when wet and shrink when dry and the alternate shrinking and swelling cause some moderate self-mulching. Soil water infiltration rates and saturated hydraulic conductivity are moderate to low when the soil is wet. Potentially available plant water between permanent wilting point and field capacity is between 100 and 150 mm in the upper meter of soil, with crop rooting depth to about 1.3 m.

2.2. Experimental design and management

Prior to commencement of the trial, the area had been cropped over many years with a range of cereal and legume crops under a conventional cultivation system. The aim of the trial, which commenced in 2006–07, was to evaluate the effects of tillage (CT vs ZT) and TOS (early vs late) on crop performance and profitability in a four-course rotation of wheat, chickpea, barley and lentil which was repeated four times so that each crop was present in the field each year. In the first two years (2006–07 and 2007–08) there were no TOS treatments, and the trial was a split plot design with tillage as main plots and crops as sub plots (32 in number) each measuring 24 m × 65 m (1560 m^2). In 2008–09 to 2011–12, the crop sub plots were further split into early and late time of sowing sub-sub plots (64 in number) measuring 12 m × 65 m (780 m^2). There were four replications. Tillage and TOS treatments remained on the same plots and the crops were rotated through these each year in a wheat–chickpea–barley–lentil sequence.