Field Crops Research 216 (2018) 42–52

Contents lists available at ScienceDirect

Field Crops Research

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

Genotype by tillage interaction and performance progress for bread and durum wheat genotypes on irrigated raised beds

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ARTICLE INFO

Keywords:
Conservation agriculture
Genotype × tillage interaction
Permanent beds
Wheat
Yaqui valley

ABSTRACT

Agronomic systems based on zero tillage and residue retention are becoming more important due to their potential for climate change adaptation through the reduction of soil erosion and improved water availability. Denser soil surface conditions and large amounts of crop residues, however, may be a constraint for early plant establishment, especially in irrigated production areas with high yield potential. Genotype by tillage interactions for yield are not well understood and it is unknown whether tillage should be an evaluation factor in breeding programs.

Twenty-six CIMMYT bread (*Triticum aestivum*) and durum (*Triticum turgidum*) wheat genotypes, created between 1964 and 2009, were tested for yield and agronomic performance at CIMMYT's experimental station near Ciudad Obregon, Mexico, over six years. Treatments included conventional and permanent raised beds with full and reduced irrigation. The objectives were to study breeding progress in distinct agronomic systems and to elucidate the importance of tillage and genotype by tillage interaction for yield and agronomic traits.

Breeding progress was achieved irrespective of agronomic treatment. Tillage influenced plant growth and number of grains per m^2 in both wheat types. In bread wheat, genotype by tillage interaction was significant for yield, test weight, and growth parameters. However, no cross-over effects were detected and rank changes were small. In durum wheat, genotype by tillage interaction was only significant for plant growth. The results do not indicate the need for separate breeding programs. However, the question of a need for selection under zero tillage to increase breeding progress is yet to be answered.

1. Introduction

Intensive tillage is an important component of conventional crop production systems. Physical disturbance loosens and aerates the upper soil layer creating optimal germination conditions for crops. However, intensive tillage, especially in combination with removal of crop residues, can lead to soil degradation and erosion (Montgomery, 2007).

Conservation agriculture (CA) is based on minimum soil movement, residue retention, and crop diversification. Conservation agriculture has the potential to improve soil resilience and increase sustainability of crop production (Hobbs et al., 2008). Zero tillage (ZT) is the most extreme form of minimum soil movement. When combined with crop residue retention, it improves top soil structure which in turn impacts soil flora and fauna and subsequently disease pressure (Verhulst et al., 2010). The retention of crop residue also influences the growing environment. Residue cover of the soil has positive effects on water infiltration by slowing down rain drops and preventing aggregate breakup and crust formation (Le Bissonnais, 1996). Crop residue also improves water infiltration rates by improved soil structure (Singh et al., 2016) and reducing runoff (Zhang et al., 2007). Residue cover can also lead to better soil temperature regulation. Moreover, CA can reduce production costs by reducing labor and fuel inputs necessary for conventional tillage operations. Erenstein and Laxmi (2008) summarized eleven studies from the Indo-Gangetic Plains (IGP) and found that ZT reduced tractor time and fuel use on average by 81%. Reduction of fuel input in turn leads to reduction of greenhouse gas emissions. An important advantage of ZT is the possibility of timelier sowing, since no prior tillage is needed. This reduces turnaround time significantly and is important in systems where more than one crop is grown per year. In regions with late season heat, like the IGP, timely sowing is of high importance as it allows the crop to escape extreme stress at the end of the growing cycle and can lead to higher yields (Erenstein and Laxmi,

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https://doi.org/10.1016/j.fcr.2017.11.011
Received 10 August 2017; Received in revised form 9 November 2017; Accepted 10 November 2017

2008).

Despite the many benefits of CA, different production conditions may result in challenges for crop production. Crop residues can be a constraint for crop growth as they may increase incidence of soil borne disease that survive on stubble and are carried over to the next crop (Chan et al., 1989). Large amounts of crop residues can be a physical constraint during seedling establishment (Wuest et al., 2000) Zero tillage can also increase soil surface bulk density, making it more difficult for seedlings to establish roots (Chan et al., 1989).

The differences between CA and conventional crop production systems can be expected to influence crop performance and yield. For example, Verhulst et al. (2011a) observed slower initial growth of wheat on permanent beds (PB) in the central Mexican highlands. This observation confirms earlier studies. Riley (1998) reported slower initial growth in spring barley and wheat and Vyn et al. (1991) reported slower growth of winter wheat under reduced tillage treatments. Many studies have compared yield under ZT and conventional tillage. Verhulst et al. (2011a) and Vyn et al. (1991) reported that delayed early growth under ZT was compensated for later in the season, resulting in no yield differences with conventional till (CT). In conditions with high residue loads, Rebetzke et al. (2005) observed improved emergence and biomass production of wheat genotypes with long coleoptiles than genotypes with regular length coleoptiles. Rebetzke et al. (2017) compared low and high vigor genotypes and found significantly higher yields associated with high vigor genotypes.

Herrera et al. (2013) summarized results from 14 studies on bread wheat and observed mixed results. In four studies there was no yield difference between ZT and CT, in six studies yield was higher under CT and in four higher under ZT. Pittelkow et al. (2015) conducted an extensive meta-analysis on crop yields in ZT and CT. Their analysis included 678 studies, representing 50 crops and 63 countries. Across all crops and environments, yields were reduced in ZT by 5.1%. However, results varied widely between crop species and agro-ecological environments. For example ZT reduced yield of root crops on average by 21.4%. In contrast, oilseed, cotton, and legume crops in ZT did not have lower yield. In wheat, yield reduction was relatively low at 2.6%. Zero tillage systems across all tested crops performed best under rainfed conditions in dry environments, where yields matched or exceeded those under CT for all crop categories. Under these conditions wheat yields were increased on average by about 2% relative to CT. These observations indicate an influence of genetic and morphological characteristics as well as environment and management factors on crop performance in ZT. It is clear that the question of ZT effects on yield does not have a simple answer. Tillage interacts with other management and environmental factors, and genotypes add their effects as well. Whether crops should be bred to adapt to the cropping system, or conservation agriculture, needs to be determined.

Herrera et al. (2013) pointed out that although area under CA is increasing, these conditions are not represented in the selection conditions of most breeding programs. However, if targeted breeding programs were to be developed for different tillage practices, it would need to be assured that relevant genotype by tillage interaction (G × T) exists, especially for grain yield performance.

Genotype by tillage interactions have been studied by various researchers (e.g.: Ciha 1982; Hall and Cholick 1989; Cox 1991; Cox and Shelton 1992; Hwu and Allan 1992). Trethowan et al. (2012) studied a diverse set of bread wheat cultivars and found highly significant G × T for grain yield and quality parameters. Moreover, they developed a mapping population and were able to map quantitative trait loci associated with variation for yield in ZT. In the review by Herrera et al. (2013), G × T effects on yield were significant in eight cases and in six they were not. One important concern mentioned by the authors was that almost all genotypes were selected under CT. Therefore, it is possible that adaptation to ZT and G × T is limited.

In our study, CIMMYT durum wheat (*Triticum turgidum*) and bread (common) wheat (*Triticum aestivum*) genotypes, developed between 1964 and 2009, were grown over six consecutive years in four agronomic environments, including conventionally tilled (CB) and permanent raised beds (PB), each with full (FI) and reduced irrigation (RI). The objectives were (1) to study breeding progress in CIMMYT-derived wheat genotypes in four distinct agronomic treatments and (2) to shed further light on the importance of tillage and G × T interaction for yield and agronomic traits.

2. Materials and methods

2.1. Plant material

The bread and durum wheat genotypes used were developed by CIMMYT breeding programs. Thirteen durum wheat genotypes created between 1970 and 2009 and thirteen bread wheat genotypes developed between 1964 and 2006 were screened for growth and agronomic traits. The wheat materials included a basic set of historically important CIMMYT varieties and the best materials that were available from the CIMMYT breeding programs when the study initiated. All genotypes were selected under CT conditions. In earlier years flat planting was used, while bed systems were established in the early 1990's. A full list of genotypes is provided in Table S1.

2.2. Experimental set-up

The experiments were conducted during the winter growing seasons (November to May) 2009/10 to 2014/15 at CIMMYT's experimental station near Ciudad Obregon, Sonora, in northwestern Mexico (lat. 27.33 N, long. 109.09 W, 38 masl). The station is characterized by an arid climate with highly variable rainfall. Mean annual precipitation is 308 mm (1993–2015). During the growing seasons used in the study, average rainfall was 55 mm with large differences between years, ranging from 5 to 122 mm. Annual reference evaporation is approximately 1800–2000 mm (Verhulst et al., 2011a,b,c,d). Long-term mean annual temperature is 23.5° C (1993–2015) with monthly mean temperatures ranging from 16° C in January to 31° C in July/August. According to the World Reference Base the soil is classified as a Hyposodic Vertisol (Calcaric, Chromic) (Verhulst et al., 2009).

Agronomic performance of bread and durum wheat genotypes was determined in four distinct agronomic systems, each corresponding to a different environment and all involved sowing on raised beds: 1) conventionally tilled beds with full irrigation (CB-FI), 2) conventionally tilled beds with reduced irrigation (CB-RI), 3) permanent beds with full irrigation (PB-FI), and 4) permanent beds with reduced irrigation (PB-RI). Permanent beds and conventionally tilled treatments were located in adjacent blocks. Permanent beds were reshaped when necessary, but the top of the beds were not tilled. Prior to experiment initiation, the PB area had been under ZT for three years. In autumn 2005 the entire experimental area was tilled (one pass with a chisel plough to 50 cm and a moldboard plough to 40 cm and two passes with a disc plough to 20 cm). In subsequent years beds were reshaped without tillage prior to planting in PB environments. In CB environments soil was tilled after harvest and before sowing with a disk plough to 20 cm. New beds were formed before planting. The trial was irrigated during the summer fallow period to germinate weeds and volunteers. These were controlled with glyphosate under PB and tillage under CB (Verhulst et al., 2011a).

Bread and durum wheat genotypes were tested with three replicates together in the same randomized complete block design. Each plot was 8 m^2, consisting of two 80 cm wide and 5 m long beds sown with two rows of wheat with 26 cm distance between rows and at a sowing density of 250 seeds m^{-2}. In all agronomic systems a seeding irrigation was applied. Full irrigation treatments received three or four additional irrigations (approximately 520 mm water per season), to avoid moisture stress; RI treatments received one additional irrigation at around heading (approximately 240 mm per season). Irrigation was