

Genotype × Tillage Interaction in a Recurrent Selection Program in Wheat

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The objective of this study was to test if the response to 10 cycles of a recurrent selection program conducted under conventional tillage and rain fed conditions was the same when contrasted, for several traits, under conventional and non-tillage practices. During two seasons (2011 and 2012) the 44 S-derived families (four/C₀ to C₁₀ populations) were evaluated under conventional and non-tillage systems in two fields next to each other. Days to anthesis, plant height, grain, and biomass yield and 1000-grain weight were determined. The grain number per m² and harvest index was also estimated. From a random sample of 10 tillers the spikelet per spike and grains per spike were measured. For each trait, a linear mixed model (regression) was fitted to the experimental data. The slopes, under conventional tillage, were significant greater than zero for grain yield, harvest index, seeds per square meter, spikelet per spike and seeds per spike. Under non-tillage the list of traits showing slopes significantly greater than zero was shorter. For most traits there was a significant difference in the intercept terms between conventional tillage and non-tillage, which is interpreted as the tillage-practice effect. The concurrent evaluation in conventional and non-tillage soil managements of ten cycles of a recurrent selection program performed under conventional tillage confirmed the occurrence of a significant genetic progress only under conventional tillage.

Keywords: *Triticum aestivum* (L.), grain yield, genetic progress, soil management

Introduction

Climate change is expected to cause losses of biodiversity, mainly in marginal environments. Strategies of adaptation to climate changes may include a re-emphasis on population breeding in the form of evolutionary plant breeding (Ceccarelli et al. 2010). Several cycles of crossing and selection are required to pyramid genes for traits of economic importance (Trethowan et al. 2010). The solution is to accumulate favourable alleles using a recurrent selection (RS) scheme, one of the most promising strategies of population improvement. With each cycle, parents that are superior are selected and intermated to produce progeny for the next round of selection. However, it can take many years and even decades to reveal substantial phenotypic changes from selection in field experiments

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(Briggs and Goldman, 2006). Moreover, crop breeding programs need to focus on developing cultivars that fit the new agronomic practices to derive greater benefits in marginal areas improving crop adaptation to conservation practices of soil moisture. In almost all published work to date the cultivars tested have been developed under conventional tillage (Trethowan et al. 2005), however breeders need to assess germplasm and breeding populations under reduced and non-tillage.

Recently, significant genotype \times tillage interaction was reported in tests involving diverse genotypes, suggesting that cultivar development should be targeted to tillage requirements (Joshi et al. 2007). However, there is evidence concerning that materials selected under non-tillage performed better in both tillage systems (Trethowan et al. 2010). In this sense, since yield increases more in higher-yielding modern varieties as water supply is increased, it is possible to generate a positive genotype by input interactions throughout a crop production practices that minimize soil degradation (Fischer 2009). The objective of this study was to test if the response to selection after 10 cycles of a recurrent selection program conducted under conventional tillage and rain fed conditions is the same when contrasted, for several traits, under conventional and non-tillage practices.

Materials and Methods

The recurrent selection program

It was carried out at the Campo Escuela de la Facultad de Ciencias Agropecuarias (Universidad Nacional de Córdoba), Córdoba (31° 29' S; 64° 00' W) in the central semiarid region of Argentina, with a characteristic Entic Haplustol soil. Sixteen commercial varieties of bread wheat (*Triticum aestivum* L.) were crossed to obtain 83 F1 hybrid combinations used as initial population (C₀) and starting point for a RS scheme with two years per cycle (evaluation and recombination). S0 progenies (full sib families) were used as selection units, grown in single row plots of 1.3 m long and 0.2 m apart, at seeding rate of 100 grains per square meter, without replications and with regular controls. The selection criteria was an index combining spike related traits, grain yield and its principal physiological (biomass and harvest index) and numerical (grain weight and number) components (Maich et al. 2006). The plant breeding program was conducted under conventional tillage without fertilization.

The genetic progress measurement

During 2011 and 2012 the same 44 S-derived families, four for each population (C₀ to C₁₀), were evaluated under conventional and non-tillage systems in two fields, next to each other, located in the same site of the selection program. The experimental field was handled under conventional tillage during the last 30 years. Meanwhile since 2005 part of the field has been handled under non-tillage. The soil was not fertilized in both cases. Winter cereals crop rotation was used under both tillage practices. One row plots 5 m long spaced 0.20 m at a seeding rate of 250 viable seeds by square meter were used. Because of aleatorization restriction, imposed by the tillage practices, two replicates in complete

blocks where allocated within each field. At plot level, days to anthesis, plant height (cm), grain and biomass yield (g m^{-2}) and 1000-grain weight (g) were determined. The grain number per square meter and harvest index (%) was also estimated. This set of traits was the same used to build the selection criteria index. From a random sample of 10 tillers per plot the following traits were measured: spikelet per spike and grains per spike. For each trait, a linear mixed model (regression) was fitted to the experimental data. The fixed terms of the model included the tillage factor (conventional tillage – non-tillage), the number of recurrent selection cycles as a covariable, and the interaction between them. This way of specifying the fixed part of the model implies to fit two regression lines: one for each tillage practice. The random part of the model included the effects of: year, blocks within year-tillage practice, family and the random interactions among year and fixed terms of the model. A significance level of 5% was used in order to interpret results.

Results

The soil characteristics of the two experimental sites are shown in Table 1. A summary of linear regression lines fitted to each trait are shown in Figure 1. Table 2 summarizes the p-values for the hypothesis of null slopes under conventional tillage and non-tillage (first two columns). P-values for the hypothesis of non-difference between intercepts under conventional tillage and non-tillage are shown in the third column. Comparing the intercepts of all regression lines under both tillage practices (Fig. 1, Table 2, 3rd column), statistical analysis found significant difference between the intercepts of the individual regression lines for grain yield and its related traits (harvest index, seeds per square meter, weights of 1000 seeds). Regarding slopes, under conventional tillage they are significant greater than zero for: grain yield, harvest index, seeds per square meter, spikelet per spike and seeds per spike (Table 2 – 1st column). Under non-tillage the list of traits showing slopes significant greater than zero is shorter: spikelet per spike and seeds per spike.

Table 1. Soil characteristics of the two experimental sites

Characteristics	CT		NT	
	2011	2012	2011	2012
Organic matter (%)	2.65	2.57	2.52	2.57
Total organic C (g kg^{-1})	1.54	1.49	1.46	1.49
Total organic N (g kg^{-1})	0.145	0.141	0.139	0.142
C/N ratio	10.6	10.6	10.5	10.5
N – NO_3^- (mg kg^{-1})	35.8	38.8	27.70	20.9
S – SO_4^{2-} (mg kg^{-1})	18.7	20.0	13.3	6.7
P (mg kg^{-1})	81.2	87.7	83.1	99.6
pH	6.21	6.35	6.33	6.23
Electrical conductivity (mS cm^{-1})	1.40	1.20	0.90	0.70
Soil water content seeding (%)	18.9	15.3	18.80	18.9
Soil water content at harvesting (%)	8.80	10.7	10.30	14.7

CT: Conventional tillage; NT: Non-tillage

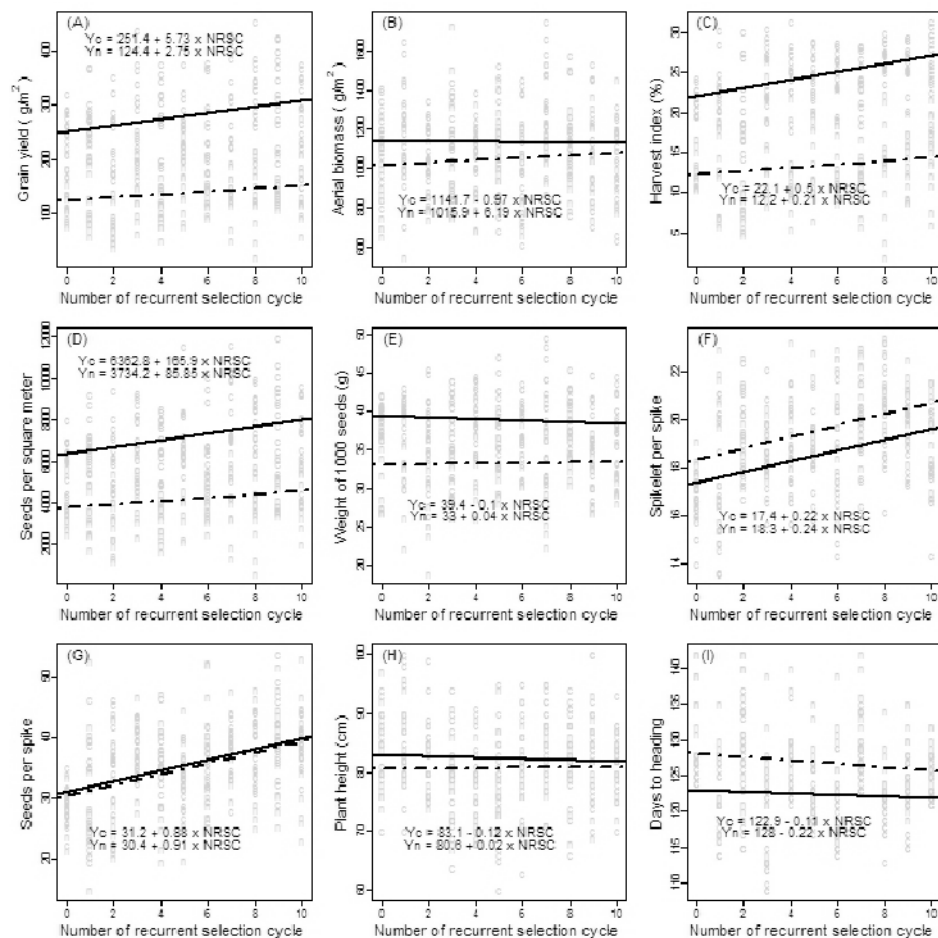


Figure 1. Regression lines on the number of recurrent selection cycles (NRSC), through conventional tillage (“c” – solid line) and non-tillage (“n” – dot dash line)

Discussion

Under conventional tillage, a significant increase of around 6 g m^{-2} per selection cycle was estimated. Thus, after 10 cycles of recurrent selection we got an overall gain of around 24%. On the other hand, under non-tillage the estimated increase per cycle was about 3 g m^{-2} , which was non-significantly different from zero (Table 2, Fig. 1(A)). We observed that the average grain yield under non-tillage was about 50% of that obtained under conventional tillage no matters the year. The observed lost of yield under non-tillage could be due to variations in water balance. Although non-tillage has a well established positive effect on water storage it may adversely affect the water uptake by plants (De Vita et al.

Table 2. Summary of p-values for the hypothesis of null slopes and for the differences between intercepts of regression lines fitted on the number of recurrent selection cycles under conventional tillage and non-tillage

Trait	CT-slope p-value	NT-slope p-value	Intercept diff. (CT-NT) p-values
Grain yield (g/m ²)	0.024934	0.380968	<0.000001
Aerial biomass (g/m ²)	0.909864	0.558102	0.249356
Harvest index (%)	0.002526	0.284250	<0.000001
Seeds per square meter	0.012174	0.297416	<0.000001
Weight of 1000 seeds (g)	0.580983	0.872697	0.000105
Spikelet per spike	0.003515	0.004733	0.162746
Seeds per spike	0.001112	0.004099	0.642826
Plant height (cm)	0.666049	0.962056	0.541768
Days to heading	0.683142	0.414454	0.006411

CT: Conventional tillage; NT: Non-tillage

P-values for the hypothesis of null slopes: first two columns. P-values for the hypothesis of non-difference between intercepts: third column

2007). Our results show that stored water at harvest was higher under non-tillage (Table 1) even when the stored water at seeding was the same (Table 1, year 2011). Álvarez et al. (2009) argued that the Entic Haplustol soils, like ours, have limited capacity to re-generate macro pores, which in turns leads to the need of periodical use of traditional tillage equipment. Consequently, non-tillage does bring with it a set of yield limiting factors, which are not relevant in conventional tillage. In the same line Mandal et al. (2010), suggest that if the genotype \times management interaction is large, cultivars selected under high input management at a research station may not perform well in low-input conditions in farmers' fields. However Trethowan et al. (2009) called into question Mandal's conclusion arguing that the number of genotypes involved on those comparisons was too small. Moreover, the majority of experiments reviewed by Carena et al. (2009) showed that there is no need to develop cultivars specific to non-tillage because the cultivars that were developed under conventional tillage systems performed relatively the same under non-tillage. In line with the above opinion, some authors consider that since the germplasm within breeding programs is continually changing and farming practices change with time, there is no need to drive parallel breeding programs (Sip et al. 2009). Our results do not support these conclusions: after 10 cycles of recurrent selection, differences between conventional and non-tillage practices on grain yield, as well as in the rate of genetic progress, were evident. Our results suggest that crop breeding programs need to focus on developing cultivars that fit the new practices as has already been noted by Higginbotham et al. (2011).

Wheat's harvest index have shown a progressive increase throughout the twentieth century. Moreover, the largest contribution to the increased yield potential of modern wheat varieties came from the increase in harvest index (Zhang et al. 2012; Bustos et al. 2013). Our results under conventional tillage (Fig. 1(C)) are coincident with those of other authors (Green et al. 2012; Lopes et al. 2012; Matus et al. 2012; Xiao et al. 2012; Sanchez-García et al. 2013), where a significant genetic progress was achieved during the

wheat plant breeding. In other words, the variation in harvest index was strongly associated with the recurrent selection cycles attained.

Retrospective studies associate increases in yield with null (Acreche et al. 2008) or significant increases (Rodrigues et al. 2007; Reynolds et al. 2009; Xiao et al. 2012) in total biomass production. Our results did not show a significant trend in biomass production as dependent on the number of recurrent selection cycles (Fig. 1(B), Table 2). Similarly to Royo et al. (2007) conclusions, increases in grain yield were due to changes in photosynthates partitioning within the plant.

Guarda et al. (2004) and Shearman et al. (2005) results showed that number of grains per unit land area contributed to the genetic gain of grain yield. Regarding the association between grain number and its weight, Morgounov et al. (2010) showed that the number of grains per unit area and the thousand-kernel weight were linearly correlated with grain yield. However, several authors observed that the number of grains had increased over time without alteration of the weight of the grains (Rodrigues et al. 2007; Acreche et al. 2008). Similar results were obtained in this study under conventional tillage. In coincidence with grain yield and harvest index, the cycle \times tillage interaction significantly reduced the genetic gain under non-tillage for the grain number yield component.

Some studies (Morgounov et al. 2010; Tian et al. 2011; Zheng et al. 2011) reported higher grain weights closely correlated with yield improvement. In contrast, Rodrigues et al. (2007), Zhou et al. (2007) and Acreche et al. (2008) observed no significant change on the kernel weight in the modern wheat cultivars with respect to the older ones. The 1000-grains weight did not show a trend in this study (Fig. 1(E), Table 2, 1st and 2nd columns), indicating that the total amount of available assimilates was directed to support the grains number (Table 2, Fig. 1(D)).

Contrary to what has been reported by Tian et al. (2011), but coincidentally with Acreche et al. (2008) results, the present study indicated a significant genetic improvement for spikelet number (Fig. 1(F)).

The number of seeds per spike has been related to yield stability under contrasting environments, to the additive nature of its heritability and to the genetic progress of yield (Acreche et al. 2008; Mladenov et al. 2011; Tian et al. 2011). Regarding the tillage \times genotype interactions for this yield component, it was always reported as non-significant (Kumudini et al. 2008). No differences in the rate of genetic progress between the two systems evaluated in the present study warrant a shift in focus to traits that previously received little attention as selection criteria (Table 2, Fig. 1(G)). Indeed, higher number of grain per spike may be needed under continuous changes of mechanization or growing conditions and sowing regimes.

Heading date can be considered an important adaptive trait. Initiating reproduction too early or too late in the life of an individual could have negative effects on its ability to produce progeny. Some studies showed a significant decrease in days to heading (Guarda et al. 2004; Lopes et al. 2012). Our results are consistent with other publications (Underdahl et al. 2008; Graybosch and Peterson 2010; Mladenov et al. 2011; Mustătea and Saulescu 2011) where increased grain yield was achieved without extending the crop-

ping season (Fig. 1(I)). According to Morgounov et al. (2010) conclusions, our germ-plasm tend to belong to mostly suitable medium maturity group.

A general tendency of reduction in the wheat plant height was found by several authors as a result of breeding programs (Zhou et al. 2007; Xiao et al. 2012). However, an increased partitioning through additional reduction in plant height is not likely, as comparative studies indicate that optimal plant heights have already been achieved (Mustătea and Saulescu 2011; Zheng et al. 2011; Lopes et al. 2012). According to the crop plant ideotype concept advanced by Reynolds et al. (1994), shorter plants are better adapted to irrigated, high input environments, while taller plants are considered to have better yield stability under adverse conditions. Because of plant height remained constant along the cycles of recurrent selection evaluated (Fig. 2(H)), it is possible to argue that genotypes that are not too tall or too short are desirable for growing under rain fed environments with terminal drought stress.

Consistently with the fact that most of the selection process was conducted under conventional tillage, the genetic progress was only expressed in the context of conventional tillage. These results have direct implication on our current breeding program, which have been redirected to meet sustainable agricultural practices such as non-tillage.

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