academicJournals

Vol. 8(41), pp. 5069-5075, 24 October, 2013
DOI: 10.5897/AJAR2013.7740
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Tillage system and genotype effects on early vigor and water use in bread wheat in the Mediterranean region

Mohammed Karrou

ICARDA, P. O. Box 6299, Rabat-Institutes, Morocco.

Accepted 25 September, 2013

The southern part of the Mediterranean basin is among the regions that are characterized by recurrent droughts and it is threatened by the effects of climate change. To deal with these problems in wheat, improved techniques of rain water conservation and adapted varieties need to be developed. Combining zero tillage and varieties with early vigor can reduce evaporation and improve transpiration and water productivity and hence increase yields. To test this hypothesis, a field trial was conducted at ICARDA's research station at Tel Hadya, Aleppo, Syria in 2008/2009 and 2011/2012. The treatments tested were "zero tillage vs. conventional tillage" and five genotypes of bread wheat. In 2008/2009, results showed that zero tillage improved leaf area index, specific leaf area, above ground biomass production and actual evapotranspiration at the beginning of stem elongation. The values increased, respectively for these parameters, from 2.34 to 3.25, 202.9 to 226.5 cm^2 g^{-1}, 1799 to 2333 kg ha^{-1} and from 91 to 101 mm. Water productivity was improved by 15%, on average. In year 2011/2012, the effect of tillage system on all the parameters was not statistically significant. In general, all genotypes responded positively to zero tillage for these measured variables. From this study, we can conclude that zero tillage under dry conditions is a technique that can improve the early vigor of the seedlings. This enhanced early growth can ensure a good canopy cover that reduces the loss of rainwater by evaporation and increases transpiration in relatively early dry years. The non disturbance of soil by tillage reduces water loss by evaporation. However, under wet conditions due to high rainfall, the positive effect of zero tillage on soil moisture and plant growth disappears.

Key words: Wheat, zero tillage, genotype, leaf area, biomass, evapotranspiration.

INTRODUCTION

During the last decades, research and extension programs have contributed in wheat yields increases in dry areas of the Mediterranean basin. Nevertheless, severe drought and climate change that the region is facing impose the development of new strategies that will allow less rainwater loss by evaporation in rainfed areas and a better use of the scarce resource. This will allow more yield and water productivity (WP) increase and sustainability. To reach this objective there is a need for the use of improved agronomic practices and cultivars that are adapted to drought and global warming conditions.

Plant breeders and physiologists have always considered early flowering time as one of the most important traits to select adapted wheat varieties for water limited environments. With climate change, this criterion will be more emphasized in breeding programs as the length of the growing period will shrink more and

E-mail: m.karrou@cgiar.org

earlier cultivars are needed to escape terminal drought and heat stress. However, plants that flower early may achieve large harvest indices but do not produce enough biomass to set a large enough number of seeds to generate a good yield (Fischer, 1979). Plants that flower too late usually will have high seeds abortion because of heat stress and too little water left for post-flowering photosynthesis and remobilization of carbohydrates from the vegetative organs to the grains (Passioura, 2006). Consequently, ensuring an early vigor and a balance between the source (vegetative biomass production) and sink (seeds production) under early flowering constitute an important option to increase and stabilize yields in rainfed areas.

Both breeding and field management can play an important role in capturing more water and improving the efficiency of its use. So, in addition to the selection of varieties that have the characteristics described above, other technologies, such as zero tillage (ZT), allows early planting and can help the plants take advantage from the early rains and escape terminal drought and heat. Moreover, zero tillage and early vegetative cover can also reduce rainwater losses by evaporation and increase transpiration early in the season. These techniques can stimulate more early growth and hence increase the source size (vegetative biomass production) at flowering. Lopez-Castaneda (1994) showed that increases in leaf area development, or early vigor, of a cereal crop are associated with improvements in water use efficiency early in the season. Faster leaf area development can increase crop water productivity by shading the soil surface and reduce evaporation and by increasing transpiration when vapor pressure deficits are low. In addition to early growth, many scientists have shown positive effect of zero tillage on yield and water productivity of wheat (Mrabet, 2000a, b; Cantero-Martinez et al., 2007). However, zero tillage can also reduce the wheat growth rate (Kirkegaard et al., 1994) due to the increase of the soil compaction under this system (Lampurlanes and Cantero-Martinez, 2003).

Due to the change in the soil characteristics induced by the introduction of zero tillage in crop production, the varieties developed for conventional tillage systems may not necessary have the same performance under zero tillage. Consequently, there is a need to investigate the possibilities of developing varieties adapted to the conservation tillage system. In fact, some scientists have recommended specific genotypes of wheat and barley (Yang and Baker, 1991; Tillman et al., 1991). Haul and Cholick (1989) and Ciha (1982) found that the ranking of wheat cultivars across tillage systems, including ZT, changed for grain yield. Consequently, to take a better advantage from the more available water under zero tillage in the Mediterranean region, it is important to use adapted varieties to this system.

Although many scientists have compared the performance of wheat under zero tillage and conventional tillage, published information on the combined effect of zero tillage and adapted genotype on early vigor and water use of wheat plants remains scarce.

MATERIALS AND METHODS

The experiment was conducted during 2008/09, 2010/2011 and 2011/12 cropping seasons at ICARDA's main research station, Tel Hadya, Aleppo, in northern Syria (36°01'N.36° 56'E; elevation 284 m asl). However, in year 2010/2011, the trial was discarded because the seedlings emergence was low and very heterogeneous due to unexpected attack of birds and ants on seeds. Mean annual rainfall in the area was 320 mm with considerable year to year variation ranging from 200 mm to over 500 mm. The soil at Tel Hadya, ICARDA station is generally deep, over 1 m, and fine textured (Ryan et al., 1997) and is classified as fine clay (montmorillonitic, thermic Calcixerollic Xerochrept). The relevant properties are pH 8.0, $CaCO_3$, 240 g kg^{-1}, cation exchange capacity, 52 cmol kg^{-1} at the beginning of the experiment, extractable potassium by 1 N ammonium acetate, pH 7.0 (546 mg kg^{-1}) and extractable phosphorus values (0.5 M $NaHCO_3$, <5 mg kg^{-1}) and mineral N (NO_3-N + NH_4-N) to a depth of 60 cm (12-15 mg kg^{-1}). Soil has good structure and is well drained, with a basic infiltration rate of about 11 mm/h. At field capacity and at the permanent wilting point, mean soil moisture content in the top 100 cm of the soil is about 48 and 24% by volume, respectively.

The treatments tested were 2 types of tillage (Conventional vs Zero tillage) and 5 genotypes of bread wheat. The genotypes tested were Cham 6, Cham 8, Shuha, Cham 10 and Raaid-3. The experimental design used was a split plot with tillage as the main plot and the genotype as the split plot with 3 replications. In the zero-till plot, seeds were sown directly with a drill without any previous soil cultivation. For the conventional tillage plot, the soil was plowed twice with an offset disk and this was followed by a roll-packing operation. The experiment was planted on November 17, 2008 and November 27, 2011. The seeding rate was 140 kg ha^{-1}. Phosphorus (P) and nitrogen (N) were applied at planting as Superphosphate (45%) and urea (46%) at rates of 80 kg P ha^{-1} and 60 kg N ha^{-1} respectively for P and N. At stem elongation, 30 kg N ha^{-1} were added as urea.

The parameters measured were above ground dry matter, leaf area index (Leaf area in cm^2 / ground area in cm^2) using leaf area meter LI-3000 (LI-COR, Inc, Lincoln, NE) and specific leaf area and biomass, actual evapotranspiration (ETa) and water productivity at the beginning of stem elongation. Specific leaf area is the ratio of the leaf area to leaf dry matter and water productivity was calculated as the ratio of dry matter to ETa. Soil moisture was measured using a neutron probe apparatus (Type IH-II, Didcot Instruments, Co, Ltd., Abington, UK) at 0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-105, 105-120, 120-135 and 135-150 cm. ETa was determined for each split-plot, using the soil–water balance equation: $ET = P + I - D + \Delta SW$ where P is precipitation, I is irrigation amount (mm), D is deep percolation (mm) below 1.5 m access tubes, and ΔSW is the change in soil–water storage calculated as the total soil water in the profile at sowing minus that at the beginning of stem elongation. Runoff loss was ignored as it was not observed during the period of the experiment. Also, based on the previous work at the site by Harris (1995), it was shown that the soil water deficit in the deep clay soil before the rainy season is much higher than can be replenished by annual rainfall, even in the wet years. Therefore, it was assumed that no drainage takes place below 1.5 m of the soil profile. Data were analyzed using SAS (1997).

Data on rainfall for the two seasons are presented in Table 1. The total amounts received were 241 mm in 2008/09 and 343 mm in 2011/12. In year 2, rainfall was high and concentrated mostly between November (planting period) and January with 93 mm in

Table 1. Mean monthly precipitation, September to May at Tel Hadya, northern Syria, during 2008/2009-2011/2012).

Year	Mean monthly rainfall (mm)									
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
2008/2009	21	15	16	36	27	72	32	20	3	241
2011/2012	1.1	27	93	65	117	4	27	4	5	343
Long-term means (1980/2012)	4	20	44	56	63	54	46	30	16	333

Table 2. Effect of tillage system and genotype on leaf area index of bread wheat at stem elongation in Tel Hadya, Syria during the cropping seasons 2008/09 and 2011/12.

Season		CT(*)	ZT(*)	Mean
2008/2009$^{\alpha}$	Cham 6	3.33	4.14	3.74[a]
	Cham 8	1.69	2.85	2.27[cd]
	Shuha	1.74	2.43	2.09[de]
	Cham 10	2.26	3.22	2.74[bc]
	Raaid 3	2.69	3.61	3.15[b]
	Mean	2.34[a]	3.25[a]	
2011/2012$^{\beta}$	Cham 6	2.43	2.87	2.65[a]
	Cham 8	2.37	1.90	2.13[cd]
	Shuha	2.13	2.37	2.25[bc]
	Cham 10	1.87	2.10	1.98[cde]
	Raaid 3	2.60	2.57	2.58[ab]
	Mean	2.28[a]	2.36[a]	

(*) CT and ZT are conventional and zero tillage, respectively. $^{\alpha}$CV: 13.0; ANOVA: TS effect: not significant at α = 5%; genotype effect: highly significant with LSD = 0.55; Interaction TS x Genotype: not significant. $^{\beta}$CV: 12.2; ANOVA: TS effect: not significant at α = 5%; Genotype effect: significant with LSD = 0.46; Interaction TS x Genotype: not significant. a-e correspond to the descending ranking of means; means followed by the same letter are not significantly different.

November, 65 mm in December and 117 mm in January. In March, rainfall was 27 mm; but in February and April there was only around 4 mm. In year 1, total rainfall was less by around 100 mm and it was only 16 mm in November, 36 mm in December and 27 mm in January. However, in February and April, the quantities were 72 and 20 mm, respectively.

RESULTS AND DISCUSSION

Early vigor and rapid development of ground cover can reduce rainwater loss by evaporation and produce enough biomass necessary for supporting the onset and growth of grains. Rebetzke et al. (2004) defined greater early vigor as an increase in seedling leaf area and it is partly associated with specific leaf area. The analysis of variance of collected data showed that for all the parameters measured, the effect of the interaction Tillage x Genotype was not significant; meaning that the responses of the different genotypes to the variation of the tillage system was similar. This could be explained by the fact that the genotypes studied were selected under the conventional tillage and no one of them was developed specifically for the zero tillage system. Because of the non-significance of the interaction tillage x genotype, the effects of the two factors will be discussed separately. Also, the data will be presented by year because of the interaction tillage x year.

In the case of tillage systems, our data presented in Tables 2 and 3 showed that, in 2008/09, zero tillage increased the leaf area index from 2.34 to 3.25 and the specific leaf area from 202.9 to 226.5 cm^2 g^{-1}. However, in 2011/12, there was no difference between the two tillage systems. The increase, although not statistically significant, of the values of the leaf area parameters observed in the first year, supports the statement of Passioura (2006) who explained that direct sowing of seeds with a zero tillage planter enables farmers to plant early their crops when soil and air are still warm leading to good canopy cover during late autumn and winter with consequently less evaporative losses from the soil surface. However, our results do not agree with the findings of Chevalier and Ciha (1986) who demonstrated in spring wheat that the length of the second leaf on the main stem and the rate of leaf production were reduced in plants grown in no-tillage compared with conventional tillage; meaning that the no till system reduced growth early in the season.

Table 3. Effect of tillage system and genotype on specific leaf area ($cm^2\ g^{-1}$) of bread wheat at stem elongation in Tel Hadya, Syria during the cropping seasons 2008/09 and 2011/12.

Season		CT(*)	ZT(*)	Mean
2008/09$^{\alpha}$	Cham 6	216.3	243.8	230.1^{ab}
	Cham 8	200.2	217.9	209.1^{cd}
	Shuha	179.2	198.6	188.9^{e}
	Cham 10	198.6	225.5	212.1^{c}
	Raaid 3	220.3	246.6	233.4^{a}
	Mean	202.9^{a}	226.5^{a}	
2011/12$^{\beta}$	Cham 6	139.4	156.1	147.8^{ab}
	Cham 8	141.2	128.9	135.1^{bc}
	Shuha	133.7	131.6	132.7^{cd}
	Cham 10	133.1	129.4	131.3^{cde}
	Raaid 3	153.0	157.1	155.0^{a}
	Mean	140.1^{a}	140.6^{a}	

(*) CT and ZT are conventional and zero tillage, respectively. Statistical analysis:$^{\alpha}$ CV: 11.3;_ANOVA: TS effect: not significant at α = 5%; Genotype effect: highly significant with LSD = 12.3; Interaction TS x Genotype: not significant; $^{\beta}$ CV: 13.5; ANOVA: TS effect: not significant at α = 5% Genotype effect: significant with LSD = 15.8; Interaction TS x Genotype: not significant. a-e correspond to the descending ranking of means; means followed by the same letter are not significantly different.

Table 4. Effect of tillage system and genotype on above ground dry matter (kg/ha) of bread wheat at stem elongation in Tel Hadya, Syria during the cropping season 2008/09.

Season		CT(*)	ZT(*)	Mean
2008/2009$^{\alpha}$	Cham 6	2435	2745	2590^{a}
	Cham 8	1309	2118	1713de
	Shuha	1482	1953	1718^{d}
	Cham 10	1834	2424	2129^{bc}
	Raaid 3	1935	2422	2179^{b}
	Mean	1799^{b}	2333^{a}	
2011/2012$^{\beta}$	Cham 6	2982	3118	3050^{a}
	Cham 8	3087	2752	2920^{a}
	Shuha	2913	3292	3102^{a}
	Cham 10	2645	2911	2779^{a}
	Raaid 3	3045	3037	3041^{a}
	Mean	2934^{a}	3022^{a}	

(*) CT and ZT are conventional and zero tillage, respectively. Statistical analysis: $^{\alpha}$ CV: 14.1;_ANOVA: TS effect: significant at α = 5% with LSD = 53.4; Genotype effect: highly significant with LSD = 373; Interaction TS x Genotype: not significant; $^{\beta}$CV: 12.7;_ANOVA: TS effect: not significant at α = 5%; Genotype effect: not significant at α = 5%; Interaction TS x Genotype: not significant at α = 5%. a-e correspond to the descending ranking of means; means followed by the same letter are not significantly different.

Total above ground dry matter (Table 4) was, however, increased significantly from 1799 to 2333 kg ha^{-1} by the application of zero tillage in 2008/2009. In 2011/2012 season, the effect of tillage system was not significant for this parameter; but the values were higher than those obtained in 2008/09 and amounted, on average, around 3000 kg ha^{-1}. These results on plant vigor and more specifically on biomass production in 2008/2009 supported those of Kumudini et al. (2008) who showed an increase in tillering and reduction in harvest index under no-till; but contrasted those of Kirkegaard et al. (1994) who found that direct drilling and stubble retention reduced seedling growth by 15%. The non significant effect of tillage system on biomass production in 2011/2012 can be explained by the fact that during this year, rainfall was higher and stimulated more seedlings

Table 5. Effect of tillage system and genotype on actual evapotranspiration (mm) of bread wheat at stem elongation in Tel Hadya, Syria during the cropping seasons 2008/09 and 2011/12.

Season		CT[(*)]	ZT[(*)]	Mean
2008/2009$^{\alpha}$	Cham 6	94.3	103.1	98.7^{a}
	Cham 8	84.5	97.3	90.9^{a}
	Shuha	91.1	107.9	99.5^{a}
	Cham 10	88.3	102.4	95.3^{a}
	Raaid 3	95.9	95.9	95.9^{a}
	Mean	90.8^{b}	101.3^{a}	
2011/2012$^{\beta}$	Cham 6	109.8	109.0	109.4^{a}
	Cham 8	103.8	102.6	103.2^{a}
	Shuha	102.6	98.4	100.5^{a}
	Cham 10	106.8	104.3	105.6^{a}
	Raaid 3	95.8	99.2	97.5^{a}
	Mean	103.8^{a}	102.7^{a}	

[(*)] CT and ZT are conventional and zero tillage, respectively. Statistical analysis: $^{\alpha}$CV: 9.6; ANOVA: TS effect: significant at α = 5% with LSD = 10.3; Genotype effect: not significant at α = 5%; Interaction TS x Genotype: not significant; $^{\beta}$CV 13.8; ANOVA: TS effect: not significant at α = 5%; Genotype effect: not significant at α = 5%; Interaction TS x Genotype: not significant at α = 5%. a-e correspond to the descending ranking of means; means followed by the same letter are not significantly different.

growth, but similarly under conventional tillage and zero tillage. This means that the positive effect of zero tillage on seedling growth is more apparent under relatively low early rainfall because this system allows more water storage and reduces more water loss by evaporation than the tillage practice that suffered more water stress.

The amounts of water used as evapotranspiration at stem elongation are presented in Table 5. These data showed in year 2008/09 that the difference between the tillage systems was statistically significant and zero tillage involved an increase of water use from 91 to 101 mm, representing an increase of 10%. This can be explained by more soil water availability in the zero tillage plots (Chevalier and Ciha, 1986). In year 2008/09, the increase of both ETa and dry matter under ZT was probably due to more canopy development and transpiration. In fact, Fischer (1979) showed that faster leaf area development should increase crop water use efficiency by increasing transpiration when vapor pressure deficits are low. The uptake of more water might be related to an early root growth under zero tillage conditions. Angus et al. (2001) explained that crops that are vigorous when young tend to extract more water from the subsoil, presumably because their roots grow deeper. In year 2011/2012, no significant effect of tillage system was observed. The same result was obtained by Lopez-Bellido et al. (2007a, b) who reported that under Mediterranean conditions, no-till was not more efficient than conventional tillage in terms of soil water accumulation and productivity. It seems that in our case, the early high rainfall offset the benefic effect of conservation tillage system.

Table 6 shows water productivity in the seasons 2008/2009 and 2011/2012. This tillage system improved also WP by 15%; however, the difference between zero till and conventional tillage was not statistically significant. The reasons were that in year 1, both ETa and biomass were affected positively by zero tillage; and in year 2, the effect of tillage system was not significant for both parameters (ETa and biomass).

Data analyses (Tables 2 to 6) showed that the effect of the genotype was significant for all measured variables during the 2008/09 season, except for ETa. An overall comparison between genotypes demonstrated that Cham 6 was more vigorous and that Raaid-3 and Cham 10 were ranked second and third. The values of leaf area index (LAI), specific leaf area (SLA) and biomass production in Cham 6 were 3.7, 230 $cm^2\ g^{-1}$ and 2690 kg ha^{-1}, respectively. The least performing genotype was Shuha with 2.09, 188.9 $cm^2\ g^{-1}$ and 1718 kg ha^{-1}, respectively for the parameters mentioned before. In 2011/2012, the genotype effect was significant only for the leaf area index and specific leaf area with Cham 6 and Raaid 3 being the most performing with around 2.6 for the LAI and 150 $cm^2\ g^{-1}$ for SLA in average. The genotypic variation of SLA observed in our study confirms the findings of Rebetzke et al. (2004). These authors stated that the large genotypic differences for SLA in wheat means that genotypes with higher leaf area for the same weight of leaf should have greater photosynthesis per unit ground area. Eventhough, the difference in vigor among the genotypes, they responded similarly to the tillage systems. These results do not agree with those of Watt et al. (2005) who demonstrated that vigorous wheat genotypes grow better in no-till plots.

Despite the importance of early growth described above, the increase of early vigor needs to be handled

Table 6. Effect of tillage system and genotype on water productivity (kg ha^{-1} mm^{-1}) of bread wheat at stem elongation in Tel Hadya, Syria during the cropping season 2008/09.

Season		CT(*)	ZT(*)	Mean
$2008/2009^{\alpha}$	Cham 6	26.0	26.7	26.3^{a}
	Cham 8	15.5	21.7	18.6^{d}
	Shuha	16.3	18.2	17.3^{de}
	Cham 10	20.7	23.7	22.2^{bc}
	Raaid 3	19.9	25.3	22.6^{ab}
	Mean	19.7^{a}	23.1^{a}	
2011/2012	Cham 6	27.2	28.6	27.9^{c}
	Cham 8	29.7	26.8	28.3^{c}
	Shuha	28.4	33.5	30.9^{ab}
	Cham 10	24.8	27.9	26.3^{c}
	Raaid 3	31.8	3.06	31.2^{a}
	Mean	28.4^{a}	29.5^{a}	

(*) CT and ZT are conventional and zero tillage, respectively. Statistical analysis: $^{\alpha}$ CV: 14.1; ANOVA: TS effect: not significant at α = 5%; Genotype effect: highly significant with LSD = 3.8; Interaction TS x Genotype: not significant at α = 5%; $^{\beta}$CV: 14.3; ANOVA: TS effect: Not significant at α = 5%; Genotype effect: significant with LSD = 2.0; Interaction TS x Genotype: Not significant at α = 5%. a-e correspond to the descending ranking of means; means followed by the same letter are not significantly different.
a-e correspond to the descending ranking of means; means followed by the same letter are not significantly different.

carefully because it can have a positive or a negative effect on grain yield depending on soil moisture conditions along the whole growing season. In fact, a production of an amount of dry matter high enough to support the development of the sink (grains) (Fischer, 1979) is necessary to ensure high yields during moderate and non severe water stress conditions; however, excessive early vegetative growth due to wet soil and high nitrogen availability may deplete more rapidly soil moisture and result in too little available water during grain filling (Passioura, 2006). Consequently, a balance between the source and sink development and use of available water is an important strategy to increase and sustain yields in rainfed areas.

In the case of the actual evapotranspiration, data showed that all the genotypes responded slightly but positively to zero tillage except Raaid-3 where the values were the same for the two tillage systems. However, for water productivity, more response to zero tillage, although not statistically significant, was observed in the case of Cham 8 in year 2008/2009 and Shuha and Raaid-3 in year 2011/2012. As described earlier for growth parameters (LAI and dry matter), it can be noticed that Cham 6, then Raaid-3 and Cham 10 had also, in average, higher WP than the other genotypes.

Conclusion

From this study, we can conclude that zero tillage under dry conditions is a technique that can improve the early vigor of the seedlings. This enhanced early growth can ensure a good canopy cover that reduces the loss of rainwater by evaporation and increases transpiration in relatively early dry years. The non disturbance of soil by tillage reduces water loss by evaporation. However, under wet conditions due to high rainfall, the positive effect of zero tillage on soil moisture and plant growth disappears. The interaction “Tillage x Genotype” was not significant for all parameters measured; consequently, it was not possible to identify genotypes suitable to zero tillage. Consequently, further studies, for a longer period, with more diversified genotypes are needed to select varieties adapted to conservation tillage. It might be rewarding to initiate research on breeding for no-till conditions which not only develop specific varieties, but also include in them required traits of resistance to biotic stresses that are often associated with this system.

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