Field Crops Research 119 (2010) 260–268

Contents lists available at ScienceDirect

Field Crops Research

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

# Short-term effects of tillage and residue management following cotton on grain yield and quality of wheat

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ARTICLE INFO

*Article history:*
Received 6 April 2010
Received in revised form 21 July 2010
Accepted 21 July 2010

*Keywords:*
Tillage
Residue management
Wheat
Grain quality
Yield

ABSTRACT

Grain yield and quality of winter wheat (*Triticum durum* L.) are affected by several factors, and crop management has a very important role among them. A 3-year (from 2003–04 to 2005–06) field experiment under irrigation was carried out at Diyabakir in the South East Anatolia Region of Turkey to evaluate immediate effects of tillage and residue management systems after cotton (*Gossypium hirsutum* L.) on grain yield and quality [thousand grain weight (TGW), test weight (TW), protein content (PC) and mini sedimentation (mini SDS)] of durum wheat, and correlations among these parameters. A split plot design with three replications was used, in which two residue management treatments [collecting and removing cotton stalks from plots ($S_{\mathrm{Rem}}$), and chopping and leaving of cotton stalks in plots ($S_{\mathrm{Lev}}$)] were main plots, and six tillage and/or wheat planting method combination treatments [moldboard plough + cultivator + broadcast seeding + cultivator as conventional tillage-I (CT-I), moldboard plough + cultivator + drill as conventional tillage-II (CT-II), chisel plough + cultivator + drill as vertical tillage (VT), two passes of disk harrow + drill as reduced tillage-I (RT-I), rotary tiller + drill as reduced tillage-II (RT-II), and no-till ridge planting (RP)] were sub-plots. The effect of cotton residue management on grain yield, TW, PC, mini SDS was not significant, but $S_{\mathrm{Rem}}$ (51.21 g) gave significantly higher TGW than $S_{\mathrm{Lev}}$ (50.63 g). Tillage and/or wheat planting method combination treatments had a significant effect on grain yield, TGW and TW, but did not significantly influence PC and mini SDS. Conventional tillage with broadcast seeding (CT-I) treatment produced the lowest wheat grain yield (5.395 Mg ha$^{-1}$), while there were no significant differences in grain yield among the other five tillage treatments (yields ranged from 5.671 to 5.819 Mg ha$^{-1}$). In spite of supplemental irrigations, the variability of weather conditions, particularly the amount and distribution of rainfall during the growing season, had a significant influence on wheat grain yield and quality parameters (TGW, TW, PC, mini SDS). Grain yield had a significant positive correlation with TGW, but it did not show any relationship with other grain quality parameters. In conclusion, the findings suggest that conventional tillage with broadcast seeding would be less effective in producing grain yield of wheat compared to other five tillage treatments with row planting, while management of the previous cotton stalks may not have any effect on yield and quality of wheat except TGW.

## 1. Introduction

In irrigated areas of the South East Anatolia Region of Turkey, cotton and wheat are the main arable crops. Cotton is usually grown in monoculture agriculture or in rotation with wheat. Cotton harvesting continues every year by November or December depending upon the weather conditions. Seedbed preparation is relatively hard for planting wheat following cotton because autumn rainfall results in wet soil conditions. In the region, wheat planting after cotton harvest is characterized by chopping or collecting stalks after cotton harvest, intensive tillage and broadcasting the wheat seed on leveled soil surface and then incorporating it by means of a shallow tillage operation. But, this system results in soil degradation and erosion, and in addition the production costs are very high and yield is low (Gemtos et al., 1998; Husnjak et al., 2002; Fahong et al., 2004; Hobbs et al., 2008). Besides, lateness of cotton harvesting leaves very limited time for land preparation for 'on-time' planting of wheat. Therefore, it is important to develop tillage and residue management technologies that allow more timely planting, and prevent yield reduction and soil degradation in wheat agriculture following cotton.

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doi:10.1016/j.fcr.2010.07.016

Many researchers have reported that conservation tillage protects soil from wind and water erosion and improves soil physical, chemical and biological properties, and reduces production costs (Gemtos et al., 1998; Chan and Hulugalle, 1999; Lithourgidis et al., 2006; Thomas et al., 2007; Mann et al., 2008). However, yield of wheat under conservation tillage is inconsistent, depending on soil-climatic conditions, and it is dependent on a number of interacting factors, including weed control level, residue management, cultural practices and drill performance (Dawelbeit and Babiker, 1997; Gemtos et al., 1998; Carefoot and Janzen, 1997). Under irrigation, Karlen and Gooden (1987), Hemmat and Taki (2001), Li et al. (2008) reported lower wheat yield for conservation tillage as a result of poor stands, while Hao et al. (2001), Jalota et al. (2008), Mann et al. (2008), Schillinger et al. (2010) found that conservation tillage was equal to or better than conventional tillage. Javadi et al. (2008) reported that reduced tillage using chisel plow, or disk and toothed harrows could provide an efficient alternative to conventional tillage in order to maintain high productivity in irrigated conditions. However, they stated that no-tillage did not show promising results due to lack of appropriate equipment. The adoption of conservation tillage practices is very slow due to lower crop yields in such systems, and also differences in management that farmers may not be familiar with (Cosper, 1983).

A study by Sayre and Hobbs (2004) showed that permanent raised beds were an excellent option and offered potential benefits in terms of higher crop yield and quality, lower production costs, improved soil structure through controlled traffic and minimum tillage, and the possibility that furrow-irrigation may be more efficient than flood irrigation. Also, the bed planting system offers opportunity for initial weed control prior to planting, facilitates access to crop for timely nutrient (especially N) application, uses lower seed rate, allows better stand establishment, and reduces crop lodging, herbicide dependence, soil erosion by irrigation water if crop residues are left on the surface in furrows and field compaction by restricting machinery traffic (Hobbs et al., 1998; Reeves et al., 1999; Sayre and Hobbs, 2004). Jin et al. (2008) stated that a permanent raised bed cropping system had the potential to make an important contribution to agricultural productivity, but ongoing research is needed on several aspects of this cropping system, including the suitability of current wheat varieties and relationships between tillage and water management practices, productivity and environmental conditions.

Under rainfed conditions, the developed technologies and practices have resulted in similar or higher crop yields from conservation tillage than those from conventionally tilled fields (Hunt et al., 1997). They also reported that no yield loss was found when no-till system was used in winter wheat agriculture after cotton. But, Ishaq et al. (2001) reported that the effect of tillage on wheat grain yield differed among years, and wheat grain yields were lower for minimum tillage than for conventional tillage, or deep tillage. They stated that wheat following cotton requires plough-based seedbed preparation to alleviate surface soil compaction and improve soil tilth. Also, Gwenzi et al. (2009) determined that tillage effects on crop yields in an irrigated wheat–cotton rotation were inconsistent throughout a 6-year period and the higher weed infestation and poor crop stand under minimum and no-tillage resulted in reduced wheat yield. They stated that minimum tillage and no-tillage were more sustainable tillage systems for semi-arid regions than conventional tillage because of limited adverse impacts on crop productivity, and improved soil structural stability. Dawelbeit and Babiker (1997) reported that the disk harrow and seed drill could be recommended for profitable wheat cultivation in irrigated Vertisols of Rahad. They determined that seed drilling and ridging after broadcasting resulted in significantly greater yields than broadcasting alone.

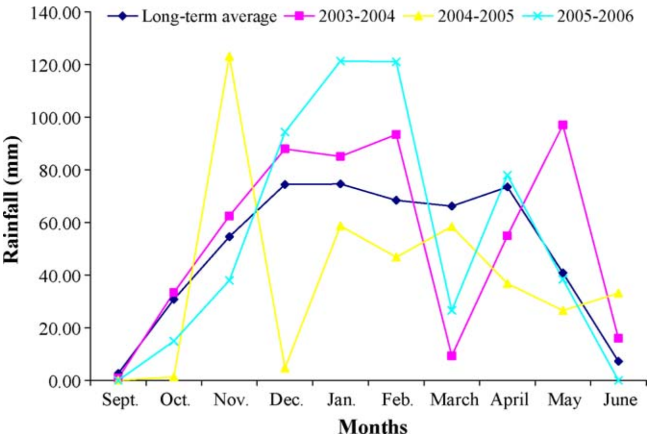

**Fig. 1.** Long-term average monthly rainfall at Diyarbakir and monthly rainfall during 3 years.

Test weight, protein content, sedimentation test of wheat are important quality parameters affecting the economic value of common wheat (*Triticum aestivum* L.). Considerable research is therefore directed toward improving these parameters in existing wheat cultivars. High test weight values are desirable because they positively influence market grade and price. Grain protein content is one of the most important measures of wheat quality, and indeed governs its final use. Temperature, sunlight and soil moisture during the grain filling stage are the environmental factors most influencing grain protein concentrations (Campbell et al., 1997; Panozzo et al., 2001; Daniel and Triboi, 2002). The complex interactions between N and water availability, yield and temperature influence grain protein concentrations (Cannell et al., 1980; Randall and Moss, 1990; Cox and Shelton, 1992; Di Fonzo et al., 2001; López-Bellido et al., 2001). Carr et al. (2003) reported that protein content, grain weight and test weight were unaffected by tillage systems, while Di Fonzo et al. (2001) and De Vita et al. (2007) found higher protein content, seed weight and test weight for no-till than for conventional tillage. In contrast, López-Bellido et al. (1998, 2001) reported higher protein content under conventional tillage than no-till. Also, in another study, protein content and sedimentation value decreased slightly without tillage when compared to a tillage based system (Pringas and Koch, 2004).

The objective of this study was to evaluate short-term effects of tillage and cotton residue management on grain yield, thousand grain weight (TGW), test weight (TW), protein content (PC) and mini sedimentation (mini SDS) of durum wheat after cotton, and correlations among these parameters in an irrigated area of South East Anatolia Region of Turkey.

## 2. Materials and methods

A 3-year field experiment was carried out from 2003–04 to 2005–06 at the South East Anatolia Research Institute research station in Diyarbakir, Turkey. The experimental station is located 37°55′36″N 40°13′49″E at 670 m above sea level. The climate of the region is characterized by a semi-arid climate (humid winters and dry summers); rainfall distribution is variable within and among years. Mean annual precipitation, based on the long-term average, is 491 mm, about 80% of which occurs from November to May. Monthly rainfall during the experimental years and the monthly average rainfall over the long-term (62 years) are shown in Fig. 1. In 2003–04, rainfall was below the long-term average in March and April, slightly above average in October and November, and above average in December, January, February and May.

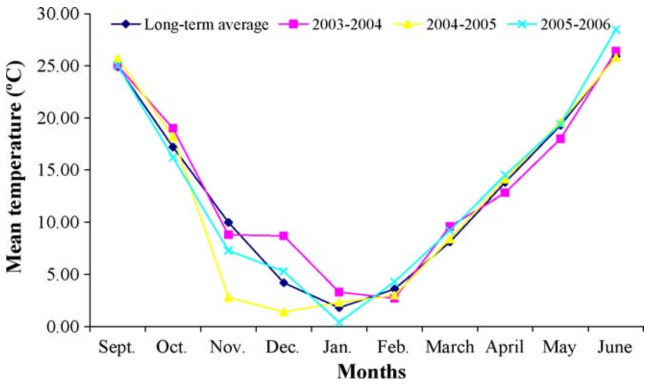

**Fig. 2.** Long-term average monthly temperature at Diyarbakir and average monthly temperature during 3 years.

In 2004–05, rainfall was below average in October, December, January, February, April and May, slightly below average in March, and above average in November. In 2005–06, rainfall was below average in October, November, March and May, and above average in December, January, February and April. Rainfall over the wheat growing period (December to early March) was slightly above the long-term average in 2003–04, lower than long-term average in 2004–05 and higher than the long-term average in 2005–06. The highest monthly rainfall was in February (followed closely by December and January) for 2003–04, in November for 2004–05, and in January and February for 2005–06. Rainfall over the reproductive period of wheat was higher in 2003–04, followed by 2005–06, and then 2004–05. Rainfall during the reproductive period was highest in May for 2003–04, in March for 2004–05, and in April for 2005–06.

Temperature records are summarized in Fig. 2. There were no large differences in temperature between the growing seasons in 2003–04, 2004–05, 2005–06 and long-term averages, particularly during the reproductive and grain filling period of wheat (March, April and May). But, June had higher mean temperature in 2005–06 than in 2003–04, 2004–05 and the long-term average. In 2004–05, while the average temperature was lower in November and December, it was higher in January than in 2003–04, 2005–06 and the long-term average. In 2003–04, the average temperature in November, December and January was higher than 2005–06.

The average monthly relative humidities during the experimental years and over the long-term (62 years) are presented in Fig. 3. Relative humidity in most months was lower in 2003–04 and 2004–05 than in 2005–06 and the long-term averages, especially during the reproductive and grain filling periods of wheat (March, April and May).

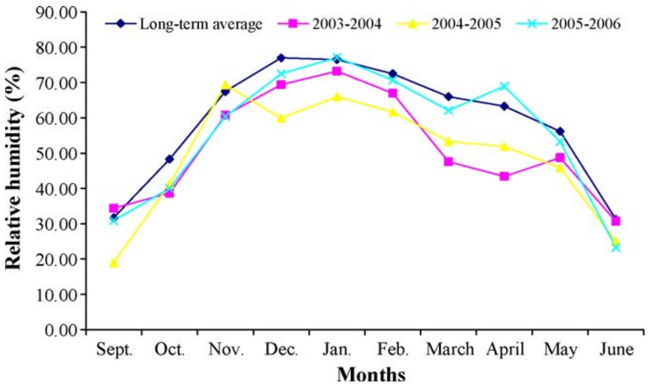

**Fig. 3.** Long-term average monthly relative humidity at Diyarbakir and average monthly relative humidity during 3 years.

**Table 1**
Details of residue management and tillage treatments.

| | |
|---|---|
| Residue management treatments | |
| $S_{\text{Rem}}$ | Collecting and removing the cotton stalks from plots |
| $S_{\text{Lev}}$ | Chopping and leaving the cotton stalks in plots |
| Tillage treatments | |
| Conventional tillage-I (CT-I) | Moldboard plough (20–25 cm) + cultivator (10–15 cm) + broadcast seeding + cultivator (4–6 cm) |
| Conventional tillage-II (CT-II) | Moldboard plough (20–25 cm) + cultivator (10–12 cm) + drill (4–6 cm) |
| Vertical tillage (VT) | Chisel plough (20–25 cm) + cultivator (10–12 cm) + drill (4–6 cm) |
| Reduced tillage-I (RT-I) | Two passes of disk harrow (10–15 cm) + drill (4–6 cm) |
| Reduced tillage-II (RT-II) | Rotary tiller (10–12 cm) + drill (4–6 cm) |
| Ridge planting (RP) | No-till ridge planting (4–6 cm) |

The soil (0–20 cm) of the experimental field was clay loam, with pH of 7.6, organic matter content of 15.3 g $kg^{-1}$, ECe of 1.92 dS $m^{-1}$, $CaCO_3$ of 95 g $kg^{-1}$ and extractable P of 40 kg P $ha^{-1}$.

Wheat was grown after cotton under irrigation. Cotton as a summer crop was planted in May and harvested in October. Wheat as a winter crop was planted in the optimum period of late October to early November and harvested in late June to early July. As is usually done in the region cotton planted after wheat was sown into residues from the wheat harvest. It involved moldboard plowing in the autumn followed by field cultivator as the secondary tillage in spring and scrubber to prepare the smooth seedbed before cotton planting in all years. The residue management and tillage treatments in the study were implemented immediately after cotton harvest in all years. Wheat was planted in all plots the same day, to avoid any differences due to sowing date although reduction of tillage in wheat agriculture following cotton resulted in a potential advantage due to timely wheat planting. A split plot design with three replications was used, in which two residue management treatments [collecting and removing cotton stalks from plots ($S_{\text{Rem}}$) and chopping and leaving of cotton stalks in plots ($S_{\text{Lev}}$)] were the main plots, and six tillage treatments [moldboard plough + cultivator + broadcast seeding + cultivator as conventional tillage-I (CT-I), moldboard plough + cultivator + drill as conventional tillage-II (CT-II), chisel plough + cultivator + drill as vertical tillage (VT), two passes of disk harrow + drill as reduced tillage-I (RT-I), rotary tiller + drill as reduced tillage-II (RT-II), no-till ridge planting (RP)] were the sub-plots. Plot size was 112 $m^2$ (20 m × 5.6 m).

Details of cotton residue management and tillage treatments used are given in Table 1. Ridge planting was carried out with a planter modified for planting two rows of seed on the top of ridge. The space between ridges was 70 cm. The space between each row on the ridges was 15 cm. No tillage was practiced on the top of ridges except loosening of the soil by the seeding process. A winged shovel was mounted on the planter to reshape the sides/shoulders of ridges. The other treatments were planted with a planter with a row spacing of 12.5 cm. Firat-93, a winter wheat cultivar widely used in the region, was planted at a seeding rate of 100 kg $ha^{-1}$ for ridge planting treatment and 200 kg $ha^{-1}$ for the other treatments. In the ridge planting system, the lower seed rate was used to provide the amount of seed in a row and to keep plants to plants distance within a row similar to other planting/seeding systems/treatments.

A compound fertilizer (20–20–0; % N–$P_2O_5$–$K_2O$) to supply 80 kg N plus 80 kg $P_2O_5$ $ha^{-1}$ was applied as basal fertilizer at planting, and 80 kg N $ha^{-1}$ as ammonium nitrate (33% N) was applied at the first node stage for each crop. No weed control was applied, because the weed population was low. Irrigation for ridge planting was applied to the corrugations between rows, and uniformly applied over surface for the other treatments at flowering stage in 2003–04, flowering and grain filling stage in 2004–05, grain filling stage in 2005–06 growing season, with 75 mm at each irrigation. For a given irrigation, all plots received the same amount of water.

Grain yield was measured by harvesting the full length of each plot (20 m), using Hege-125 plot combine harvester (Hege Equipment, Inc., Colwick, KS, U.S.A.) with a 1.2 m wide header comb. Each plot sample was weighed and three sub-samples were dried to determine moisture content. Grain yields were converted to 12% moisture content. Grain yield, TGW and TW were measured in all 3 years, but PC and mini SDS were determined in 2 years (2004–05 and 2005–06). Thousand grain weight was determined by weighing four sets of 100 grains per each plot sample, using a digital electronic scale with 0.01 g precision. Test weight (weight per unit volume) was obtained with a Schopper chondrometer. The grains were ground with a laboratory grinding mill prior to PC and mini SDS test analysis. The milled grain was analysed for protein content with near-infrared spectroscopy. Mini SDS was determined according to Pena et al. (1990).

The data for all variables were subjected to analysis of variance (ANOVA) using SAS, and mean comparison was made using Fisher's unprotected LSD at $P \leq 0.05$ (SAS Institute Inc., 2002). All data were tested for normality to determine if transformation was necessary. Homogeneity of variance tests was done before combining across years in the combined ANOVA. Simple correlation coefficients between the characters examined were calculated using correlation analysis.

## 3. Results

### 3.1. Grain yield

Combined ANOVA across years indicated that cotton residue management (M) had no significant effect on grain yield of wheat, while tillage system (T) and year (Y) influenced it significantly (Table 2). No interaction effects between M, T and Y were significant.

Comparisons between years indicated that grain yield was significantly lower in 2003–04 than the other 2 years, and there were no significant differences in yield between 2004–05 and 2005–06 (Table 3).

Among tillage and/or wheat planting method combination treatments, CT-I produced the lowest grain yield of wheat. However, there were no significant differences among the other tillage treatments (Table 4).

### 3.2. Thousand grain weight

The ANOVA showed that TGW was significantly affected by cotton residue management, tillage system and year (Table 2). No interaction effects between M, T and Y were significant.

TGW was lowest in 2003–04, and it was slightly but significantly higher in 2005–06 than 2004–05 (Table 3). The variability of climatic conditions among 2003–04 and other 2 years may have significantly affected the TGW, as suggested for grain yield.

The $S_{\mathrm{Rem}}$ treatment resulted in higher TGW than the $S_{\mathrm{Lev}}$ treatment. While the highest TGW was found in the RP tillage treatment, RT-II had the lowest TWG (Table 5). The higher TGW in the RP treatment contributed to increased grain yield.

### 3.3. Test weight

The combined ANOVA over years showed that tillage system and year significantly influenced TW, but it was not significantly influenced by cotton residue management (Table 2). Tillage × year interaction had significant effect on TW, but other interaction effects were not significant.

The TW was significantly higher in 2004–05 than other 2 years, particularly 2005–06 which had higher rainfall (Table 3). The CT-I and RP had the lowest TW and there was no significant difference among the other tillage treatments (Table 6).

There was a significant Y × T interaction for TW (Table 2). This indicates that the effect of tillage system on TW changed according to years. Although there was no significant difference among tillage treatments in 2003–04 and 2004–05, the highest TW was observed in RT-I in 2005–06 (Table 7).

### 3.4. Protein content

The ANOVA over 2 years indicated that grain PC was not significantly affected by either, but it differed significantly between years (Table 2). No interaction effects between M, T and Y were significant.

Protein content was higher in 2004–05 which had lower rainfall and relative humidity during grain filling stage than in 2005–06 (Table 3 and Figs. 1 and 3). The lower rainfall and relative humidity during May (the period when protein accumulation takes place in the grain) may have significantly increased PC in 2004–05. The cotton residue management and tillage systems had no influence on PC. Among tillage systems, PC varied from 12.40 to 12.79% (Table 8).

### 3.5. Mini sedimentation volume

The combined analysis over 2 years indicated that cotton residue management and tillage systems had no significant influence on mini SDS, but it was significantly affected by year (Table 2). Tillage × year interaction was significant, but all other interactions were not significant.

The mini SDS was significantly higher in 2004–05 than in 2005–06 which had higher rainfall (Table 3). Mini SDS was highest (9.12 mL) in the VT and lowest (7.66 mL) in the RT-I. But, there was no significant difference among tillage treatments (Table 9). There was a significant Y × T interaction for mini SDS (Table 2). This interaction indicates that the effect of tillage systems on mini SDS changed in 2004–05 and 2005–06 (Table 10). Although there was no significant difference among tillage treatments in 2004–05, the highest mini SDS was observed in CT-II in 2005–06.

### 3.6. Correlations between parameters evaluated

The correlation coefficients among grain yield, TGW, TW, PC and mini SDS are presented in Table 11. Grain yield showed a significant and positive correlation with TGW, but it was not related with other quality parameters such as TW, PC and mini SDS. The TW exhibited a significant positive correlation with PC and mini SDS, and the PC was significantly correlated with mini SDS.

## 4. Discussion

The climatic conditions, especially rainfall patterns, were variable during experimental years. Grain yield was significantly lower in 2003–04 than the other 2 years, and there were no significant differences in yield between 2004–05 and 2005–06. The similar grain yields in 2004–05 and 2005–06 were because sufficient water was available in the soil profile due to irrigation applied at the grain filling stage. But, no irrigation was applied at that stage in 2003–2004

**Table 2**
Significance of analysis of variance (ANOVA) for grain yield, thousand grain weight (TGW), test weight (TW), protein content (PC) and mini sedimentation (mini SDS) of durum wheat as affected by year, residue management and tillage system.

| Source of variation | df[a] | Yield (Mg ha$^{-1}$) | TGW (g) | TW (kg hL$^{-1}$) | df | PC (%) | Mini SDS (mL) |
|---|---|---|---|---|---|---|---|
| Year (Y) | 2 | **[c] | ** | ** | 1 | ** | * |
| Residue management (M) | 1 | ns[d] | *[b] | ns | 1 | ns | ns |
| Tillage (T) | 5 | ** | ** | ** | 5 | ns | ns |
| M × Y | 2 | ns | ns | ns | 1 | ns | ns |
| T × Y | 10 | ns | ns | * | 5 | ns | * |
| M × T | 10 | ns | ns | ns | 5 | ns | ns |
| M × T × Y | 10 | ns | ns | ns | 5 | ns | ns |

[a] df, degree of freedom; [b] *, significant at the 0.05 probability; [c] **, significant at the 0.01 probability; [d] ns, not significant.

**Table 3**
Effect of years on grain yield, thousand grain weight (TGW), test weight (TW), protein content (PC), mini sedimentation (mini SDS) of durum wheat.

| Years | Yield (Mg ha$^{-1}$) | TGW (g) | TW (kg hL$^{-1}$) | PC (%) | Mini SDS (mL) |
|---|---|---|---|---|---|
| 2003–04 | 5.074 b[a] | 49.22 c | 82.69 b | | |
| 2004–05 | 5.953 a | 51.40 b | 83.72 a | 13.17 a | 10.16 a |
| 2005–06 | 6.057 a | 52.11 a | 82.49 b | 12.07 b | 7.09 b |

[a] Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.

**Table 4**
Effect of residue management and tillage treatments on grain yield of durum wheat.

| Tillage | Grain yield (Mg ha$^{-1}$) | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | Residue management | | | | | | | | |
| | 2003–04 | | 2004–05 | | 2005–06 | | Mean | | |
| | $S_{\text{Rem}}$[a] | $S_{\text{Lev}}$[b] | $S_{\text{Rem}}$ | $S_{\text{Lev}}$ | $S_{\text{Rem}}$ | $S_{\text{Lev}}$ | $S_{\text{Rem}}$ | $S_{\text{Lev}}$ | |
| CT-I[c] | 4.991 | 4.920 | 5.695 | 5.609 | 5.552 | 5.607 | 5.623 | 5.608 | 5.395 b[d] |
| CT-II[e] | 5.185 | 4.879 | 5.972 | 6.230 | 6.128 | 6.118 | 6.050 | 6.174 | 5.752 a |
| VT[f] | 5.136 | 5.289 | 5.916 | 6.074 | 6.236 | 6.269 | 6.074 | 6.172 | 5.819 a |
| RT-I[g] | 5.201 | 5.132 | 6.057 | 5.755 | 6.218 | 6.124 | 6.137 | 5.940 | 5.748 a |
| RT-II[h] | 5.193 | 4.817 | 6.125 | 5.935 | 6.044 | 5.911 | 6.085 | 5.923 | 5.671 a |
| RP[i] | 5.103 | 5.046 | 5.886 | 6.205 | 6.138 | 5.911 | 6.012 | 6.059 | 5.715 a |
| Mean | 5.135 | 5.014 | 5.942 | 5.968 | 6.052 | 5.990 | 5.997 | 5.979 | |

[a] $S_{\text{Rem}}$, collecting and removing the cotton stalks from plots.
[b] $S_{\text{Lev}}$, chopping and retaining the cotton stalks in plots.
[c] CT-I, conventional tillage-I.
[d] Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.
[e] CT-II, conventional tillage-II.
[f] VT, vertical tillage.
[g] RT-I, reduced tillage-I.
[h] RT-II, reduced tillage-II.
[i] RP, ridge planting.

**Table 5**
Effect of residue management and tillage treatments on thousand grain weight (TGW) of durum wheat.

| Tillage | TGW (g) | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | Residue management | | | | | | | | |
| | 2003–04 | | 2004–05 | | 2005–06 | | Mean | | |
| | $S_{\text{Rem}}$[a] | $S_{\text{Lev}}$[b] | $S_{\text{Rem}}$ | $S_{\text{Lev}}$ | $S_{\text{Rem}}$ | $S_{\text{Lev}}$ | $S_{\text{Rem}}$ | $S_{\text{Lev}}$ | |
| CT-I[c] | 48.66 | 48.00 | 51.11 | 49.88 | 52.25 | 51.23 | 51.68 | 50.56 | 50.19 bc[d] |
| CT-II[e] | 49.33 | 49.33 | 52.08 | 51.21 | 53.23 | 52.56 | 52.66 | 51.89 | 51.29 ab |
| VT[f] | 50.33 | 49.66 | 51.99 | 52.33 | 52.31 | 50.20 | 52.15 | 51.26 | 51.14 abc |
| RT-I[g] | 48.66 | 48.33 | 51.19 | 50.77 | 52.64 | 51.83 | 51.91 | 51.30 | 50.57 bc |
| RT-II[h] | 48.66 | 49.00 | 50.33 | 49.88 | 51.98 | 51.81 | 51.15 | 50.85 | 50.28 c |
| RP[i] | 51.00 | 49.66 | 52.99 | 52.99 | 53.15 | 52.73 | 53.07 | 52.86 | 52.09 a |
| Mean | 49.44 | 49.00 | 51.61 | 51.18 | 52.59 | 51.73 | 52.10 a | 51.45 b | |

[a] $S_{\text{Rem}}$, collecting and removing the cotton stalks from plots.
[b] $S_{\text{Lev}}$, chopping and retaining the cotton stalks in plots.
[c] CT-I, conventional tillage-I.
[d] Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.
[e] CT-II, conventional tillage-II.
[f] VT, vertical tillage.
[g] RT-I, reduced tillage-I.
[h] RT-II, reduced tillage-II.
[i] RP, ridge planting.

**Table 6**
Effect of residue management and tillage treatments on test weight (TW) of durum wheat.

| Tillage | TW ($kg\ hL^{-1}$) | | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | Residue management | | | | | | | | |
| | 2003–04 | | 2004–05 | | 2005–06 | | Mean | | |
| | $S_{Rem}$[a] | $S_{Lev}$[b] | $S_{Rem}$ | $S_{Lev}$ | $S_{Rem}$ | $S_{Lev}$ | $S_{Rem}$ | $S_{Lev}$ | |
| CT-I[c] | 82.33 | 82.00 | 83.33 | 83.33 | 82.16 | 81.90 | 82.75 | 82.61 | 82.56 c[d] |
| CT-II[e] | 83.00 | 82.33 | 83.33 | 83.66 | 82.63 | 82.90 | 82.98 | 83.28 | 82.97 ab |
| VT[f] | 83.33 | 83.00 | 84.66 | 84.00 | 82.50 | 82.30 | 83.58 | 83.15 | 83.24 a |
| RT-I[g] | 82.33 | 82.33 | 83.33 | 83.00 | 83.10 | 83.00 | 83.21 | 83.00 | 82.96 ab |
| RT-II[h] | 82.66 | 83.00 | 84.00 | 83.66 | 82.56 | 82.70 | 83.28 | 83.18 | 83.10 ab |
| RP[i] | 83.00 | 83.00 | 84.00 | 84.33 | 82.46 | 81.73 | 83.23 | 83.03 | 82.75 bc |
| Mean | 82.77 | 82.61 | 83.77 | 83.66 | 82.57 | 82.42 | 83.72 | 82.49 | |

[a] $S_{Rem}$, collecting and removing the cotton stalks from plots.
[b] $S_{Lev}$, Chopping and retaining the cotton stalks in plots.
[c] CT-I, conventional tillage-I.
[d] Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.
[e] CT-II, conventional tillage-II.
[f] VT, vertical tillage.
[g] RT-I, reduced tillage-I.
[h] RT-II, reduced tillage-II.
[i] RP, ridge planting.

because of adequate rainfall in May. Also, the lower grain yield in 2003–04 than in the other 2 years was most likely due to lower rainfall and relative humidity during reproductive period in March.

The CT-I (broadcast seeding under conventional tillage) treatment produced the lowest grain yield of wheat because broadcasting of seed in the CT-I treatment no doubt resulted in poor soil-seed contact and lack of uniformity. Weak contact between soil and seed may lead to less nutrients being taken up. Earlier, Dawelbeit and Babiker (1997) reported that seed broadcasting resulted in significantly lower yields than seed drilling and ridging after broadcasting. Likewise, Mann et al. (2008) reported that sowing of wheat in lines rather than by broadcasting gave healthy and vigorous crop leading to high grain yield. However, there were no significant differences among other treatments, perhaps because soil water content was similar among treatments due to irrigation. Carr et al. (2003) reported that differences in grain yield did not occur because soil water was unaffected by tillage. In spite of one-half seeding rate (100 $kg\ ha^{-1}$ for RP vs. 200 $kg\ ha^{-1}$ for all other tillage treatments), the no-till ridge planting (RP), new production technique in wheat production, produced grain yields similar to the CT-II, VT, RT-I and RT-II treatments, and higher than in the CT-I treatment. Our results support the view of Hobbs et al. (1998), Reeves et al. (1999), Sayre and Hobbs (2004), and Govaerts et al. (2005) who stated that permanent raised beds can be an excellent option for wheat and offer potential benefits in terms of both productivity and costs. This suggests that no-till ridge planting may be considered a good agronomic practice because of its relatively lower production costs (due to savings in time and machinery use for tillage, and seed), but it also suggests the need for further research to verify the influence of relatively higher seeding rate in RP on grain yield and quality of wheat under irrigation in this agroecological region.

Cotton residue management and tillage treatments significantly affected the TGW of wheat. The $S_{Lev}$ treatment resulted in lower TGW than the $S_{Rem}$. This may have resulted from poor soil-seed contact due to cotton residue in the $S_{Lev}$, because poor soil-seed contact can lead to less nutrients being taken up, resulting in reduced grain weight. It is also possible that lower TGW is in part due to decreased N mineralization associated with cotton residue (Camara et al., 2003). While the highest TGW was found in the RP tillage treatment, RT-II had the lowest TGW. The fact that the RP treatment had the higher TGW might have resulted from less competition among plants for nutrition and water because plant density

**Table 7**
Effect of year × tillage interaction on test weight (TW) of durum wheat.

| Tillage | TW ($kg\ hL^{-1}$) | | |
|---|---|---|---|
| | Year | | |
| | 2003–04 | 2004–05 | 2005–06 |
| CT-I[a] | 82.16 a[b] | 83.50 a | 82.03 c |
| CT-II[c] | 82.66 a | 83.50 a | 82.76 ab |
| VT[d] | 83.16 a | 84.16 a | 82.40 bc |
| RT-I[e] | 82.33 a | 83.50 a | 83.05 a |
| RT-II[f] | 82.83 a | 83.83 a | 82.63 abc |
| RP[g] | 83.00 a | 83.16 a | 82.10 c |

[a] CT-I, conventional tillage-I.
[b] Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.
[c] CT-II, conventional tillage-II.
[d] VT, vertical tillage.
[e] RT-I, reduced tillage-I.
[f] RT-II, reduced tillage-II.
[g] RP, ridge planting.

**Table 8**
Effect of residue management and tillage treatments on protein content (PC) of durum wheat.

| Tillage | PC (%) | | | | | | Mean |
|---|---|---|---|---|---|---|---|
| | Residue management | | | | | | |
| | 2004–05 | | 2005–06 | | Mean | | |
| | $S_{Rem}$[a] | $S_{Lev}$[b] | $S_{Rem}$ | $S_{Lev}$ | $S_{Rem}$ | $S_{Lev}$ | |
| CT-I[c] | 13.40 | 13.16 | 12.16 | 11.99 | 12.78 | 12.57 | 12.40 |
| CT-II[d] | 13.03 | 13.13 | 12.15 | 11.87 | 12.59 | 12.50 | 12.79 |
| VT[e] | 13.33 | 13.26 | 11.55 | 12.21 | 12.44 | 12.73 | 12.73 |
| RT-I[f] | 12.80 | 12.90 | 12.30 | 11.63 | 12.55 | 12.68 | 12.68 |
| RT-II[g] | 13.40 | 13.10 | 12.56 | 12.12 | 12.98 | 12.61 | 12.54 |
| RP[h] | 13.00 | 13.60 | 12.28 | 12.04 | 12.64 | 12.61 | 12.59 |
| Mean | 13.16 | 13.19 | 12.16 | 11.98 | 12.66 | 12.58 | |

[a] $S_{Rem}$, collecting and removing the cotton stalks from plots.
[b] $S_{Lev}$, chopping and retaining the cotton stalks in plots.
[c] CT-I, conventional tillage-I.
[d] CT-II, conventional tillage-II.
[e] VT, vertical tillage.
[f] RT-I, reduced tillage-I.
[g] RT-II, reduced tillage-II.
[h] RP, ridge planting.

**Table 9**
Effect of residue management and tillage treatments on mini sedimentation (mini SDS) of durum wheat.

| Tillage | Mini SDS (mL) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Residue management | | | | | | |
| | 2004–05 | | 2005–06 | | Mean | | Mean |
| | $S_{Rem}$[a] | $S_{Lev}$[b] | $S_{Rem}$ | $S_{Lev}$ | $S_{Rem}$ | $S_{Lev}$ | |
| CT-I[c] | 11.33 | 10.33 | 6.83 | 6.83 | 9.08 | 8.58 | 8.83 |
| CT-II[d] | 7.53 | 10.00 | 8.50 | 7.33 | 8.02 | 8.66 | 8.34 |
| VT[e] | 13.00 | 8.16 | 8.00 | 7.33 | 10.50 | 7.75 | 9.12 |
| RT-I[f] | 10.33 | 8.66 | 5.50 | 6.16 | 7.91 | 7.41 | 7.66 |
| RT-II[g] | 10.00 | 11.83 | 6.66 | 6.50 | 8.33 | 9.16 | 8.75 |
| RP[h] | 9.66 | 11.16 | 7.16 | 8.33 | 8.41 | 9.75 | 9.08 |
| Mean | 10.31 | 10.02 | 7.11 | 7.08 | 8.71 | 8.55 | |

[a] $S_{Rem}$, collecting and removing the cotton stalks from plots.
[b] $S_{Lev}$, chopping and leaving the cotton stalks in plots.
[c] CT-I, conventional tillage-I.
[d] CT-II, conventional tillage-II.
[e] VT, vertical tillage.
[f] RT-I, reduced tillage-I.
[g] RT-II, reduced tillage-II.
[h] RP, ridge planting.

**Table 10**
Effect of year × tillage interaction on mini sedimentation (mini SDS) of durum wheat.

| Tillage | Mini SDS (mL)<br>Year | |
|---|---|---|
| | 2004–05 | 2005–06 |
| CT-I[a] | 10.83 a[b] | 6.83 abc |
| CT-II[c] | 8.76 a | 7.91 a |
| VT[d] | 10.58 a | 7.66 ab |
| RT-I[e] | 9.50 a | 5.83 c |
| RT-II[f] | 10.91 a | 6.58 bc |
| RP[g] | 10.41 a | 7.75 ab |

[a] CT-I, conventional tillage-I.
[b] Values within a column for each trial followed by the same or no letter(s) are not significantly different at the 5% level of the LSD test.
[c] CT-II, conventional tillage-II.
[d] VT, vertical tillage.
[e] RT-I, reduced tillage-I.
[f] RT-II, reduced tillage-II.
[g] RP, ridge planting.

was significantly lower. The higher TGW in the RP treatment contributed to increasing grain yield. Carr et al. (2003) reported that grain weight was not affected by tillage systems, whereas De Vita et al. (2007) and Di Fonzo et al. (2001) reported higher grain weight for no-till than for conventional tillage. The variability of climatic conditions among 2003–04 and the other 2 years may have significantly affected the TGW, as suggested for grain yield. Royo et al. (2000) reported that water deficit from anthesis to maturity reduces the duration and rate of grain filling, and hence reduces mean grain weight.

Test weight sometimes increases as tillage is reduced, possibly because soil water and N are conserved (López-Bellido et al., 1998). Previous research has shown higher TW for no-till than for conventional tillage (López-Bellido et al., 1998; Di Fonzo et al., 2001; De Vita et al., 2007). Other researchers (Cox and Shelton, 1992; López-Bellido et al., 2001; Carr et al., 2003) reported no influence of tillage systems on TW. In our study, the CT-I and RP had the lowest TW and there were no significant difference among other tillage treatments. The climatic conditions significantly affected the TW. The lower rainfall in 2004–05 during grain filling stage resulted in increased TW. Similarly, Czarnecki and Evans (1986) and Rharrabti et al. (2003) reported that higher rainfall during the grain filling stage caused a significant reduction in TW, affecting density and shape characteristics of grain.

**Table 11**
Correlation coefficients among grain yield, thousand grain weight (TGW), test weight (TW), protein concent (PC) and mini sedimentation (mini SDS) parameters.

| | Grain yield | TGW | TW | PC | Mini SDS |
|---|---|---|---|---|---|
| TGW | 0.2476*[a] | | | | |
| TW | 0.2004ns[b] | 0.0741ns | | | |
| PC | −0.1177ns | −0.0987ns | 0.5490***[c] | | |
| Mini SDS | −0.0218ns | −0.1271ns | 0.5670*** | 0.5133*** | |

[a] *, significant at the 0.05 probability; [b] ns, not significant; [c] ***, significant at the 0.001 probability.

Cotton residue management and tillage treatments had no significant influence on seed PC, possibly because of their minimal effect on plant-available soil N and water content. Likewise, Carr et al. (2003) reported that tillage systems had no effect on grain protein content because soil N was unaffected by tillage systems. Documented studies about effect of tillage on grain protein content show inconsistent results. While López-Bellido et al. (1998, 2001) reported that conventional tillage had higher PC than no-till, Di Fonzo et al. (2001) and De Vita et al. (2007), determined higher PC for no-till than for conventional tillage. But, Campbell et al. (1977) and Carr et al. (2003) found no effect of tillage system on PC. These inconsistent results were due mainly to growing and crop management conditions (Rieger et al., 2008). In our study, the fact that wheat was irrigated during grain filling may have resulted in reduced water stress and unchanged PC in treatments. In our study, climatic conditions significantly influenced PC. Annual rainfall was 389.40 mm in 2004–05 and 538.50 mm in 2005–06 growing season. The rainfall and relative humidity during April and May (flowering and grain filling stage) was lower in 2004–05 than in 2005–06. The PC increased with the lower rainfall and relative humidity during the grain filling period when protein accumulation takes place in the grain. López-Bellido et al. (1998) reported that water stress increased PC while grain yield was reduced. Also, Lloveras et al. (2001) and Abad et al. (2004) reported that grain quality of irrigated wheat can be greatly affected by the variability of the Mediterranean climate.

The mini SDS values described as gluten quality were not affected by residue management and tillage treatments. The fact that wheat was irrigated during grain filling stage may have resulted in unchanged mini SDS in treatments possibly due to their small effect on plant-available soil N and water content. Climatic conditions significantly influenced mini SDS. The mini SDS increased with the lower rainfall and relative humidity during the grain filling period when protein accumulation takes place in the grain.

There was no significant correlation between grain yield and PC. This could be attributed to unaffected grain yield because enough water was available in the soil profile due to irrigation at grain filling. The significant and positive correlation between TW and PC was due mainly to growing conditions, which simultaneously enhanced these two parameters. Likewise, the significantly positive correlations were found between PC and mini SDS volume, confirming the results of several authors (Fowler and De La Roche, 1975; Autran and Galterio, 1989; Galterio et al., 1993; Novaro et al., 1997; Porceddu et al., 1998; Bechere et al., 2002). Thus, it appears that increasing PC could lead to an increase in gluten strength and quality under the conditions of our study.

## 5. Conclusions

The effect of cotton residue management on grain yield, TW, PC, mini SDS was not significant, but $S_{Rem}$ (51.21 g) gave significantly higher TGW than $S_{Lev}$ (50.63 g). Tillage and/or wheat planting method combination treatments had a significant effect on grain yield, TGW and TW, but did not significantly influence PC and mini SDS. Conventional tillage with the broadcast seeding (CT-I) treatment produced the lowest grain yield (5.395 Mg ha$^{-1}$), while there were no significant differences among other tillage treatments (yields ranged from 5.671 to 5.819 Mg ha$^{-1}$) when wheat was planted in rows. Grain yield had a significant positive correlation with TGW, but it did not show any relationship with other grain quality parameters. Even under irrigated conditions, the variability of weather conditions, particularly the amount and distribution of rainfall during the growing season had a significant influence on wheat grain yield and quality parameters (TGW, TW, PC, mini SDS), in spite of supplemental irrigations. Grain yield and TGW were lowest in 2003–04. The TW was higher in 2004–05 than the other 2 years which were similar. The PC and mini SDS were higher in 2004–05 which had lower rainfall than in 2005–06. Overall, conventional tillage with broadcast seeding was least effective in producing grain yield of wheat, and yields were similar among the other tillage treatments. Cotton residue management had no effect on wheat production and quality except TGW.

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