Effect of Tillage Systems on Wheat Productivity and Precipitation Use Efficiency Under Dry Farming System in the North East of Syria

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Abstract

The key problem of agricultural production in arid and semi-arid environments is the steady decline in the annual precipitation and soil fertility, especially under rainfed conditions. Implementing of the suitable agricultural practices help in improvement the utilization efficiency of the natural resources, and crops productivity, and as consequence the stabilization and sustainability of the agricultural production.

Conservation agriculture (CA) system is considered as one of the most important adaptive approaches mitigating the vulnerability of the agro-ecosystems to climate change, and increasing the capability of the cropping systems to adapt with drought, where it helps to improve rainwater productivity (Precipitation use efficiency). This will help increasing the productivity of the precious rainwater by converting each rain drop into dry matter “More crop per drop”, thereby increasing field crops’ yield and yield stability, which are very important prerequisites for water and food security.

Management of the frequency and type of tillage can stop soil degradation and improve soil quality, where tillage disrupts soil aggregates and enhances the oxidation of soil organic matter.

A field experiment was conducted in the North East of Syria, during three consecutive growing seasons (2007/2008 – 2008/2009 – 2009/2010), to study the effect of three different tillage systems [No tillage (NT), double disc tillage (MT) and conventional tillage (CT)] on wheat crop yield, grown in a rotation with vetch. The experiment was laid in randomized complete block design (RCBD), with three replications.

The highest grain yield was obtained with no-tillage system (5057 Kg . ha⁻¹) compared with double disk and conventional tillage (4821, 4683 Kg . ha⁻¹ respectively).

Heads density and number of kernels per head increased significantly with no-tillage (841 heads . m⁻², 48 Kernel . Head⁻¹), but tillage practices had no significant effect on thousand kernel weight. Precipitation use efficiency was significantly higher under no-till (7.6 Kg.mm⁻¹ . ha⁻¹) compared with the other tillage systems (7.4 and 7.2 Kg.mm⁻¹ . ha⁻¹ respectively).

Soil moisture content was significantly higher under no-tillage compared with minimum and conventional tillage systems, at different growth stages.

Keywords: Conservation agriculture, Water productivity, Yield components, Climate change, Wheat.

Introduction

The Mediterranean region encompasses a wide variety of agricultural systems where water is one of the main keys to productivity. Yield of Mediterranean dry land crops is usually low and widely variable due to high seasonal variability of rainfall, with 85% of annual rainfall occurring during the months of October to April. This variation in rain causes 75% of the variation in wheat yield (Kun, 1988).
The response of cereals to conservation tillage practices is variable. Higher yields are usually attributed to increased water retention or utilization by the crop, especially in arid and semi-arid regions, while lower yields are attributed to greater disease, weed spreading and nitrogen (N), immobilization (McMaster et al., 2002).

It has been found that when soil moisture limited plant growth, grain yield was always equal or greater in conservation tillage than in mouldboard ploughing, and positively correlated with earlier/greater seedling emergence and autumn growth (López-Bellido et al., 1996). Some authors found that conservation tillage might reduce yield through decreased N availability (Rao and Dao, 1996). However, residue retention by conservation tillage such as shallow or reduced tillage practices can over the long term, improve soil structure and nutrients cycling.

Tillage is responsible for most soil degradation in the Mediterranean basin (Six et al., 1999). No-tillage (NT) accompanied with suitable crop rotation causes an increase in the microbial biomass carbon (MBC) compared to conventional tillage (CT) (Dick, 1992). This could be attributed to several factors (Smith and Elliott, 1990). Plant residues lower soil temperature, and increase water content, soil aggregation and C content compared to CT systems, whereas removal of crop residues exposes soil surface to direct sun light, increasing the rate of water loss by evaporation (Roman and Agnes, 2005). The accumulation of crop residues at the soil surface provides substrates for soil microorganisms, which accounts for higher microbial biomass carbon at the surface under no-till system. Soil microorganisms mediate mineralization of soil organic matter (SOM) and nutrients (Mrabet, 2000).

Soil aggregation and aggregate dynamics are important in facilitating water infiltration, providing adequate habitat and protection for soil organisms, supplying oxygen to roots, and preventing soil erosion (Denef et al., 2001; Franzluebbers, 2002a, b). The continued existence of large pores in the soil that favor high infiltration rates and aeration depends on the stability of larger aggregates. Soil aggregation is also one of the principle processes responsible for carbon sequestration in soils (Lal et al., 1997) and in turn, structural degradation provokes soil organic matter loss (Six et al., 1999). Soil management systems that leave more plant residues on the soil surface generally allow improvements in soil aggregation and aggregate stability (Carpendo and Mielniczuk, 1990).

Annual grain legumes, grown in rotation with cereal crops, can contribute to the total pool of N in the soil and improve yields of cereals (Herridge et al., 1995). Legumes with a large harvested N index can only make a marginal contribution to the N-status of the soil, even when non-harvested residue is incorporated in the soil (Carranca et al., 1999).

No-till practices that maximize conservation of the legume residue and carry over residue from previous crops are necessary for sustainable production of legume crops on highly erodible soil landscapes (Miller et al., 2002).

Continuous conventional tillage reduced soil organic matter, independently of the rotation (Mrabet et al., 2001). The crop rotation with legumes breaks the soil pathogen cycles, and restores fertility (Halvorson et al., 2000; Fischer et al., 2002).

When maintaining a sufficient level of residues at the surface, the soil is protected against erosion and its organic carbon may significantly increase (Mrabet, 2000).

Restoration of soil organic carbon (SOC) in arable lands represents a potential sink for atmospheric CO₂.
(Lal and Kimble, 1997). Strategies for SOC restoration by adoption of recommended management practices include conversion from conventional tillage to no-till, increasing cropping intensity by eliminating summer fallows, using highly diverse rotations, introducing forage legumes and grass mixtures in the rotation cycle increasing crop production and C input into the soil (Hao et al., 2002).

In dry farming areas, the soil moisture content varies during the growth cycle. This variability is due to the annual climatic cycle and to tillage operations, which drastically alter both the total pore space and relationship between macro- and micro pores. The water content can also be affected by the amount of water consumed by the crop (transpiration). One of the main objectives of using cropping systems in semi-arid climates is to improve the efficiency of water use (Nielsen, 2002). Conservation tillage systems allow farmers to employ sustainable agricultural practices and enjoying at the same time savings in supplies (Davis and Payne, 1992).

Several experiments have demonstrated that different tillage systems applied to clayey soils help retain varying amounts of water in dry areas (Goss et al., 1978). Plants and crop in particular need relatively deep soil. The roots of wheat for instance, are known to reach depth of more than 1 m, although the greatest root density is found in the first 0.6 m (Wulfsohn et al., 1996). In intensive tillage systems that don’t make use of subsoiling ploughs, a pan develops below the worked horizon, which alters both the hydrological and mechanical properties of the soil profile. This limits the depth of the root system (Josa-March et al., 2002). For this reason, the water content in this ploughing layer is of particular importance when growing cereals, as most root development occurs above this depth.

Farmers in the east and northeast region of Syria grow wheat which is rotated with legumes, such as vetch, lentil, and chickpea. Conventional tillage with mouldboard ploughing is commonly used in this region, but conservation tillage (minimum and no-tillage) has not yet been introduced. Crop response to tillage systems is diverse due to the complex interactions between tillage-induced soil edaphic, crop requirements, and weather.

The objective of this research work is to evaluate the impact of different tillage systems on wheat yield and yield components under rainfed conditions, and to assess the role of no-till in the improvement of precipitation use efficiency and soil moisture content.

Materials and Methods

A field experiment was conducted to determine the effects of three tillage systems on crop yield and yield components in durum wheat (Triticum durum var. turgidum) (Variety Acsad1105), alternated with vetch (Vicia sativa L.) as a crop rotation during three growing seasons (2007 - 2010) on a clay-loam soil in the North East region, Syria (Amooda region, which belongs to Al-Khamishli city), in a farmer’s field. The ten year average precipitation, temperature and relative humidity values for the experimental sites were 510 mm, 17 °C, and 75% respectively, the annual rainfall and the top soil’s water content were monitored weekly using two permanent sets of TDR probes of 0.20 m in length, which were vertically installed in each plot.

The tillage treatments consisted of no-tillage (NT), double disc tillage (MT): two passes of diskng; and conventional tillage (CT): mouldboard ploughing followed by two passes of tandem disk. All disc operations were performed to a depth of 8 - 10 cm.
All the tillage treatments were fixed and repeated on the same plot during the experiment period. Wheat was drilled at a rate of 200 kg ha\(^{-1}\) on 15 November. The distance between rows was 17 cm, and 10 cm between plants within the same row. The length of the raw was 10 m, where each plot (replicate) contained 40 rows), for the no-till treatment, while the same seeding rate was conventionally planted for the other tillage treatments. Vetch was drilled at a seeding rate of 120 kg ha\(^{-1}\) on 13 November. The distance between rows was 20 cm, and 10 cm between plants within the same row. The length of the raw was 10 m, where each plot (replicate) contained 40 rows), for the no-till treatment, while the same seeding rate was conventionally planted for the other tillage treatments. The planting was done by using a direct driller (Funkhouser), which is imported from Brazil.

Fertilizer applications were based on the recommended regional guidelines, and based on the soil analysis. Only a small amount of residues was left on the soil surface for the no-till treatment. In both tillage systems, crop residues were incorporated into the topsoil following the traditional practice in the area (in July or August). The crop residues remaining on the soil surface covered less than 30% of the soil surface.

**Investigated traits**

1. **Number of spikes per square meter**: Three random square meters from each plot/replicate, from each tillage treatment were harvested, and the total number of spikes was counted, and then divided by three to get the number of spike per m\(^2\).

2. **Number of kernels per spike**: The fertile spikes were completely threshed, and the number of the grains was recorded by using an electric grain counter, then the resulting value was divided by the number of the spikes.

3. **1000-kernel weight (gm)**: The 1000-kenel weight was computed based on the following equation:

\[
(\text{Grain weight} - (\text{weight of impurities} + \text{weight of broken seeds})/ \text{Total number of grains}) \times 1000
\]

4. **Grain yield (Kg . ha\(^{-1}\))**: The average weight of grains per square meter was converted from gm. m\(^{-2}\) into Kg . ha\(^{-1}\).

5. **Precipitation Use Efficiency (Kg . mm\(^{-1}\). ha\(^{-1}\))**: Precipitation Use Efficiency (PUE) is defined as the ratio of grain weight to the total amount of water utilized by plant per land unit area. This trait is highly correlated with economic yield under dry farming system. It is calculated from the following formula:

\[
PUE = \frac{\text{Grain weight per hectare}}{(\text{annual precipitation} - \text{water lost by evaporation})}
\]

6. **Soil moisture content**: A compound soil sample was taken randomly from each plot, by means of a 4'\(^{\prime}\) post hole auger, number of samples collected from each plot were representative of the plot area (5 samples). Ten gram of the air dry soil sample transferred to a weighed silica dish and put in an air oven at 105 °C and dried for 16 hours. The soil sample then cooled in a desiccator and weighed. The loss in the weight represents the soil moisture content (Chopra and Anwar, 1991).

**Experimental design and statistical analysis**

The experiment was laid in a randomized complete block design (RCBD), and each treatment was repeated three times (replicates). The data were compiled, tabulated and statistically analyzed using M-Stat-C to compute the least significant difference (LSD) at 0.05 level of significance among the investigated tillage treatments.
Results and Discussion

Effect of tillage system on wheat grain yield

It has been found that the amount of wheat grain yield and response to the tillage systems varied depending on the amount and distribution of precipitation in each growing season. We have taken the average grain yield because the main purpose of the study was to compare the different tillage systems rather than the impact of the variation in the environmental factors. In general, grain yield was significantly higher (5057 Kg . ha\(^{-1}\)) in the no-tillage treatment compared to the double disc and conventional tillage treatments (4821 and 4683 Kg . ha\(^{-1}\) respectively). The grain yield ranking from the highest to the lowest was NT > MT > CT, indicating that grain production increased as tillage intensity decreased (Table 1). The lower grain yield with CT compared to the other two treatments might have been partly due to the greater water loss, due to exposure of the wet sub-soil layers to direct sunlight as a consequence of soil inversion, or due to lower root development.

Bradford and Peterson (2002) related wheat yield increase to improved physical, and moisture conditions. Campbell and Janzen (1995) related increased yields of wheat under NT to a reduction of soil moisture loss and increase of organic carbon at the surface horizons. Frequently, the literature shows that soils under a no-tillage system are more humid because of the accumulation of crop residues on the soils surface (Smith and Elliott, 1990) and that crop yield values are greater for no-tillage than for CT (Unger, 1990; Sakine, 2005). Rieger et al., (2008) showed that the wheat grain yield decreased by 3% under no-till compared to conventional and minimum tillage treatments, this was mainly attributed to fewer ears per unit land area and a significantly lower thousand-kernel weight.

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Mean grain yield (Kg. ha(^{-1}))</th>
<th>Mean heads/square meter</th>
<th>Mean kernel per head</th>
<th>1000-kernel weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tillage (NT)</td>
<td>5057 (^a)</td>
<td>841 (^a)</td>
<td>48 (^a)</td>
<td>38.9 (^a)</td>
</tr>
<tr>
<td>Double disk (MT)</td>
<td>4821 (^b)</td>
<td>800 (^a)</td>
<td>48 (^a)</td>
<td>35.8 (^a)</td>
</tr>
<tr>
<td>Conventional tillage (CT)</td>
<td>4683 (^c)</td>
<td>795 (^b)</td>
<td>37 (^b)</td>
<td>37.8 (^a)</td>
</tr>
<tr>
<td>L.S.D (_{0.05})</td>
<td>128</td>
<td>50</td>
<td>8.59</td>
<td>N.S</td>
</tr>
</tbody>
</table>

Several authors described a higher bulk density in soils under conservation tillage system (Moreno et al., 2000; Pelegrin et al., 1990; Hill et al., 1985) during the complete agricultural cycle. Increased bulk density is associated with soil compaction and changes in total porosity and pore geometry (Horton et al., 1989). Soils under conservation tillage systems appear to have a large properties of small pores (<15 \(\mu\)m radii) in relation to CT (Hill et al., 1985). This will increase the water retention capacity of the soil at any matric potential, and reduces the water availability for plants, and plants are consequently submitted to higher stress conditions under NT than these under CT and MT treatments.

Effect of tillage system on yield components

There was significant effect of tillage on head density (Table 1) and kernels per head when averaged across years. But tillage system did not significantly affect 1000-kernel weight (Table 1). Head density was significantly higher in the no tillage treatment (481 spikes . m\(^{-2}\)) than in the other treatments (800 and 795 spikes . m\(^{-2}\) respectively). This large number of heads under no-tillage might be attributed to better
seedling establishment, increased tiller production, and tiller survival. Lower yields following disc and conventional tillage were mainly due to fewer heads m\(^{-2}\) (Table 1).

**Effect of tillage system on precipitation use efficiency**

There was also an effect of tillage on wheat precipitation use efficiency. No tillage treatment reached a significantly higher precipitation use efficiency (PUE) level (8.6 Kg mm\(^{-1}\) ha\(^{-1}\)) than MT and CT (7.4 and 7.2 Kg mm\(^{-1}\) ha\(^{-1}\) respectively), as averaged across years, because of better water usage in the pre-anthesis period for semi-arid conditions, where plant usually suffer of drought and heat terminal stresses (Table 2).

Table 2. Mean precipitation use efficiency (PUE) of wheat under three tillage systems.

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>PUE (Kg mm(^{-1}) ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tillage (NT)</td>
<td>8.6 (^a)</td>
</tr>
<tr>
<td>Double disk (MT)</td>
<td>7.4 (^b)</td>
</tr>
<tr>
<td>Conventional tillage (CT)</td>
<td>7.2 (^b)</td>
</tr>
<tr>
<td>L.S.D (_{0.05})</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Tillage system and soil water content**

The results showed that the amount of water in the top 0.2 m of the soil decreased significantly from one tillage system to another in the following sequences: NT > MT > CT (Fig. 1). These results indicate that the water content in the soil is associated with crop residue management. Crop residues reduce runoff, increase water infiltration and reduce soil evaporation. But in dry land farming these effects may be reduced or may even disappear if the crops don’t produce enough residues, or if the residues are not left on the soil surface for weed control.

The superior effect of no-till in comparison to conventional tillage system was due to lower water evaporation from soil, which is often combined with enhanced soil water availability for plants in the rhizosphere (De Vita et al., 2007).

![Figure 1. Monthly precipitation and top soil water content under three different tillage systems.](image)

In general, increased yield and yield components under conservation tillage system compared to reduced and conventional tillage systems is highly attributable to improving the soil moisture content via reducing the rate of water loss by evaporation and thereby increasing the amount of water at the plant available tension, which will play a pivotal role in increasing precipitation use efficiency (Rainwater productivity) and reducing the resilience of the cultivated crops to terminal drought and heat stresses, indicating the relevance of conservation agriculture as a promising more productive, profitable and sustainable farming system.

**References**


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