Dryland soil water storage susceptibility to different soil tillage practices under Vetch-Wheat crop rotation

Jallil Asghari Meydani¹, Mehdi Rahmati²*, Esmaeil Karimi², Ali Asghar Aliloo³

ABSTRACT

Crop rotation and soil tillage are two practices which would result in better use of water resources. So in order to investigate the effects of different crop rotation and soil tillage practices on soil water storage, a multi-annual experiment employing two crop rotations and six tillage practices was carried out in dry-land condition of Maragheh, northwest of Iran during year 2007 till 2011. Results showed that autumn cultivation of the common vetch (CR1) compared to spring cultivation of the common vetch (CR2) left more water in the soil for the following wheat cropping in the next years and subsequently increased biological and grain yield of wheat. It was also notified that the increase of water storage in second sampling depth (15-30 cm) was significantly more than two other depths (0-15 and 30-45 cm). Results also depicted that the tillage practice applying "chisel plough + cyclo-tiller + seed drill (TP1)" compared to other practices and especially the routine tillage of the region (moldboard plow + disk harrow + manual seed broadcasting, TP5) significantly increased soil water storage. The mentioned tillage practice (TP1) markedly decreased the bulk density of soil and increased biological and grain yield of wheat, as well. Therefore, applying TP1 tillage practice beside autumn cultivation of common vetch in rotation with wheat would be a good strategy to increase soil water storage and crop yield in dry-land conditions.

INTRODUCTION

Soil water storage or available water is one of the effective factors on crop production. Therefore, rainfall reserving within top layer of the soil is one of the main issues of the dry-land crop production especially in semiarid regions (Saradon and Gianibelli 1992). Crop rotation and soil tillage practice are two main strategies which would result in better water resource management.

Several researchers have investigated crop rotation effects on soil physico-chemical and biological properties (Lal et al. 1994, Soon et al. 2007, Rahmati et al. 2011, etc.). Crop rotation would affect soil by: 1) preventing soil moisture losses, 2) improving soil formation processes, 3) increasing soil productivity, and 4) increasing air / water permeability of soil (Bahrani 1998). Contrary to physico-chemical properties of soil such as bulk density, soil water content is one of the dynamic characteristics of it which is mostly depended on the amount of rainfall during last months. Furthermore, there is an especial complexity in soil moisture relationship with several factors such as soil texture, soil structure, and etc. Regarding two last terms, crop rotation will result in unclear trend on soil water content. For example, Liebig et al. (2002) and Rahmati et al. (2011) found that crop rotation had no significant effect on soil water holding capacity or soil water content. Contrary, Roder et al. (1989) by evaluating the effects of different sexennial crop rotations including Sorghum-Soybean, Soybean – Sorghum, continues cropping of Sorghum, and continues cropping of Soybean on soil water content found that Sorghum-Soybean and Soybean-Sorghum crop rotations, respectively, had the highest and lowest soil water storages during the last year of investigation. The useful effects of the pea – wheat crop rotation on water use efficiency also was reported by Dalal et al. (1998) who evaluated eight annual pea – wheat crop rotation and continues cropping of the wheat. Peterson and Westfall (1996) also reported that soil water storage efficiency of the wheat – fallow crop rotation (the common cropping system of the central plains in United States) is lower than a quarter of the precipitation, meaning that 75% of

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the precipitation waste due to evaporation, runoff, and etc.

In addition to crop rotation, soil tillage also can affect soil physical, chemical, and biological properties and therefore will affect crop yield, as well. Soil porosity and bulk density are two important factors for water infiltration and movement into or within soil (Unger 1978, Larson et al 1983, Barzegar et al. 2004, Husnjak et al. 2002). Therefore, soil tillage plays a critical role in soil water storage by affecting pore size / distribution and bulk density (Martinez et al. 2008, So et al. 2009). However, several factors such as soil texture and structure, crop rotation, potential of the land erosion, soil moisture content, and etc. are important in appropriate tillage machinery selection. Different researchers (Zheng et al. 2011, Huang et al. 2012, Miriti et al. 2012, Berhe et al. 2013, Munkholm et al. 2013, Kurothe et al. 2014) have reported that soil tillage affects soil water storage, water use efficiency, and other soil physical properties.

Fodders and multi-annual legumes, although, are important and commonly applied in crop rotations. Effects of the different tillage practices beside crop rotations consisting fodders and legumes on soil water storages has not been evaluated yet. The current research was aimed to evaluate effects of the different tillage practices and different crop rotations of wheat with autumn or spring cultivation of the common vetch.

**MATERIALS AND METHODS**

This research was carried out in dry-land agricultural research institute (DARI) of Maragheh, northwest of Iran during year 2007 till 2011. The current research was aimed to evaluate the interactive effects of the different tillage practices and crop rotations on soil water storage. Climatological characteristics and the result of the pre-sampling analysis of the study area are reported by Table 1 and 2.

<table>
<thead>
<tr>
<th>Seasonal year</th>
<th>Temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Annual evaporation (mm)</th>
<th>Annual precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; year</td>
<td>2008-2009</td>
<td>5.8</td>
<td>39.8</td>
<td>1059.8</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; year</td>
<td>2009-2010</td>
<td>6.6</td>
<td>48.5</td>
<td>1052.0</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; year</td>
<td>2010-2011</td>
<td>5.9</td>
<td>43.7</td>
<td>1108.6</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>6.1</td>
<td>44.0</td>
<td>1073.5</td>
</tr>
</tbody>
</table>

Table 2: Soil physic-chemical properties of the study area, measured at depth 0-20 cm

<table>
<thead>
<tr>
<th>EC (dS/m)</th>
<th>pH</th>
<th>OC (%)</th>
<th>P (mg/Kg)</th>
<th>K (mg/Kg)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.42</td>
<td>7.65</td>
<td>0.66</td>
<td>7.4</td>
<td>535</td>
<td>8</td>
<td>44</td>
<td>48</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Table 3 reports results of combined analysis of the soil moisture ($\theta_m$) which were measured during 2nd to 4th year of the investigation in order to evaluate effects of the applied crop rotations and tillage practices on soil water storage.

Table 3: Results of the combined analysis of the soil moisture which were measured during different years of the investigation (years 2, 3, and 4)

<table>
<thead>
<tr>
<th>Source of the variation</th>
<th>df</th>
<th>0-15 cm Mean of squares</th>
<th>15-30 cm Mean of squares</th>
<th>30-45 cm Mean of squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2</td>
<td>150.91**</td>
<td>165.87**</td>
<td>94.11**</td>
</tr>
<tr>
<td>Replication (Year)</td>
<td>6</td>
<td>21.97**</td>
<td>13.58**</td>
<td>20.14**</td>
</tr>
<tr>
<td>Crop rotation (CR)</td>
<td>1</td>
<td>107.52**</td>
<td>117.19**</td>
<td>0.62**</td>
</tr>
<tr>
<td>Tillage practice (TP)</td>
<td>5</td>
<td>90.44**</td>
<td>131.25**</td>
<td>143.01**</td>
</tr>
<tr>
<td>CR × TP</td>
<td>5</td>
<td>0.015*</td>
<td>0.188*</td>
<td>0.494*</td>
</tr>
<tr>
<td>CR × Year</td>
<td>2</td>
<td>0.0005**</td>
<td>0.007**</td>
<td>0.022**</td>
</tr>
<tr>
<td>TP × Year</td>
<td>10</td>
<td>0.538**</td>
<td>0.715**</td>
<td>1.287**</td>
</tr>
<tr>
<td>CR × TP × Year</td>
<td>10</td>
<td>0.015**</td>
<td>0.007**</td>
<td>0.025**</td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>0.880</td>
<td>0.990</td>
<td>1.221</td>
</tr>
</tbody>
</table>

Statistical analysis (Table 3) showed the significant differences ($P<0.01$) for $\theta_m$ of three sampling depths (0-15, 15-30, 30-45 cm) among years, crop rotations, and tillage practices (except $\theta_m$ of the second depth, 15-30 cm, among crop rotations), whereas no significant differences was observed among the interactions of the year, crop rotation, and tillage practice.

Figure 1 illustrates means comparison of the measured $\theta_m$ of the three sampling depths (0-15, 15-30, 30-45 cm) among different crop rotations. Figure 2 reveals that the CR1 crop rotation resulted in higher storage of the moisture within 0-30 cm depths than CR2 crop rotation (with average $\theta_m$ of 25.7% vs. 23.7%). It seems that soil water depletion by spring cultivation of the common vetch is higher than autumn ones due to their short growth season which will result in higher water demands to accelerate their growth rate. Autumn planting of crops results in higher water use efficiency due to the occurrence of the root growth during autumn season which plays a critical role in water absorption in early growth in spring (Morison et al. 2008). Several researchers have also documented the beneficial effects of the crop rotation on soil moisture storage and water use efficiency (Benson 1985, Roder et al. 1989, Pala et al. 2007, Miriti et al. 2012). For example, Pala et al. (2007) reported that Chickpea and Medic depleted more water from the soil than lentil, watermelon, and vetch. So wheat cropping after Chickpea and medic was solely depended on current seasonal rainfall. Contrary, lentil, watermelon, and vetch left some residual soil moisture for the following wheat crop.

Figure 2 also shows that neither autumn nor spring planting of the common vetch affected $\theta_m$ of the third sampling depth (30 – 45 cm). It may be due to lack of root activity of the common vetch within this sampling depth due to its superficial (20 cm) root system.
to 30) roots. So it seems that the soil moisture variations within 30 to 45 cm depths were free of the crop rotations effects.

Figure 3 illustrates means comparison of the measured soil moisture within the three sampling depths (0-15, 15-30, 30-45 cm) among different tillage practices. Results showed that first tillage practice (TP1) stored the highest amount of the moisture within all three sampling depths and second tillage practice (TP2) was in second place. Contrary, the 5th tillage practice (TP5) was the worst one regarding soil water storage within all three sampling depths. In line with our results, Larson et al. (1983) also reported that different tillage instruments affected soil water storage especially in surface layers which is one of the key factors for plants germination and establishment in initial growth stages. Berhe et al. (2013) also have evaluated the effect of tillage depth and type on water use efficiency. They reported that, although, the type of tillage did not affect irrigation water use efficiency, increasing tillage depth significantly increased irrigation water use efficiency.

Generally, Figure 3 depicts that tillage practices affected soil moisture of the three sampling depths similarly. So it can be assumed that a proper tillage application could result in higher storage of the water within all mentioned depths.

It is mainly concerned that crop rotations and soil tillage practices affect soil water storage by affecting pore size and distribution (Martinez et al. 2008, So et al. 2009). Several investigators have also reported the useful effects of crop rotation and soil tillage on soil structural properties (Barber 1972, Dick and Van Doren 1985, Griffith et al. 1988, Huang et al. 2012, Munkholm et al. 2013, 

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Bulk density ($D_b$) as a proxy criteria of pore size and distribution was determined and analyzed at the end of the current research. Table 4 reports the results of the analysis of variance for $D_b$ of the three sampling depths (0-15, 15-30, and 30-45 cm) depicting that there were significant (P<0.01) differences among crop rotations and tillage practices. There were, however, no significant differences among the interaction of the crop rotations and tillage practices. The means comparison of the $D_b$ of the three sampling depths among crop rotations and tillage practices are reported by Figures 4 and 5. Figure 4 reveals that $D_b$ of the CR1 crop rotation ($D_b$=1.287 gr/cm$^3$) was significantly lower than one of the CR2 ($D_b$=1.686 gr/cm$^3$). The means comparison of the $D_b$ among tillage practices (Figure 5) also showed that the first and second tillage practices (TP1 and TP2) had the lowest $D_b$ (1.370 and 1.414 gr/cm$^3$, respectively) and fifth tillage practice (TP5) had the highest $D_b$ (1.592 gr/cm$^3$). Figure 5 also reveals that $D_b$ trend within first sampling depth (0-15 cm) is clearer than those of the two other depths especially the third one (30-45 cm) which may be due to soil plowing in superficial depths.

The results of $D_b$ was in line with the results of the moisture storage. This agreement shows that CR1 crop rotation not only affected soil water storage, but also improved soil structure quality which will multiply effects on soil water storage. This was similar for proper soil tillage practice, as well.

As mentioned before, soil water storage is one of the effective factors on crop production. So in order to examine if any improvement in soil water storage have resulted in better production or not, the crop yield of wheat among different applied crop rotations and tillage practices were analyzed. Results (Table 5) showed that there were significant differences (P<0.01) of biological and grain yields of wheat among years, crop rotations, and tillage practices. The biological and grain yields of the wheat in the third year of the investigation were significantly higher than second and fourth years. It seems to be due to high rainfall amount of mentioned year (Table 1). Considering high storage of soil moisture and soil structure improvement (based on bulk density analysis) in CR1 crop rotation, an increase in wheat biological and grain yields was expected which is clearly illustrated by Figure 7. The same trend was also obtained by first tillage practice (TP1) showing high biological and grain yields of wheat (Figure 8).

**CONCLUSION**

Results of the current research revealed that crops yields are highly depend on soil available water. Autumn planting of the common vetch stored more water in soil which was applicable by next crop.
(wheat). Contrary, the spring planting of the common vetch depleted more water from soil. On the other hand, results depicted that the common soil tillage practice of the region (TP5: "moldboard plow + disk harrow + manual seed broadcasting") resulted in more soil moisture depletion which will lead to lower crop production. Contrary, first and second tillage practices (TP1: "chisel plough + cyclo-tiller + seed drill", TP2: "semi-moldboard plow + cyclo-tiller + seed drill") resulted in better water use efficiency which was shown by biological and grain yields increases. Generally, the current research properly showed that appropriate crop rotation and tillage practice employment would result in higher crop production.

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