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Crop yield and water use efficiency in semi-arid region of Turkey

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ABSTRACT

A 2-year field experiment was carried out to assess the effects of various rotational systems on crop yield, crop water use (CWU) and water use efficiency (WUE) in a semi-arid region of Central Anatolia. Five crops (winter lentil, *Lens culinaris* L.; chickpea, *Cicer arietinum* L.; sunflower, *Helianthus anuus* L.; spring lentil, *Lens culinaris* L. and winter wheat, *Triticum aestivum* L.) and fallow were rotated with winter wheat. The experimental set-up involved a rotation of alternative crops (2003–2004) and wheat (2004–2005). Similarly, wheat plots in the 2003–2004 season were then planted with alternative crops in the 2004–2005 season. This experiment took place during the last 2 years of a 21-year long field experiment. Soil moisture was measured using a soil moisture neutron probe, and then soil water storage (SWS) of the plant root zone was calculated up to the depth of 90 cm using precipitation and evapotranspiration values.

In the first year, the highest SWS throughout a depth of 90 cm from sowing was determined to be in the fallow plot (171 mm), followed by winter wheat and winter lentil with 153 and 150 mm, respectively. In the second year, high SWS values were determined for winter lentil (163 mm), fallow (156 mm) and spring lentil (151 mm). The CWU of wheat changed depending on the preceding crop; the highest CWU (254 mm) was obtained in the fallow plot in the first year and in the plot of winter lentil (290 mm) in the second year. The average over 2 years showed that fallow treatment had the highest CWU, 271 mm. The highest crop yield was recorded for wheat, with an average of 2243 kg ha^{-1} over the 2 years in fallow, followed by spring lentil (2232 kg ha^{-1}) and chickpea (1943 kg ha^{-1}). These differences were not statistically significant. The highest WUE of wheat was obtained in the preceding spring lentil treatment with 9.4 kg/(ha mm^{-1}), followed by chickpea and fallow treatments with 8.6 and 8.4 kg/(ha mm^{-1}), respectively. On the other hand, WUE in the continuous wheat plots was the lowest, with a 2.3 kg/(ha mm^{-1}) average over 2 years. According to the 2-year experimental results under the conditions in Central Anatolia, compared to fallow spring lentil was the most promising crop among the alternative crops for the two-course rotation system in terms of WUE and yield.

1. Introduction

The central part of Turkey is separated from the surrounding seas by a series of mountains that prevent rain clouds from reaching the region. As a result, about 90% of the agricultural lands do not receive adequate rainfall during the winter cereal growing season. These semi-arid dryland regions cover approximately one-third of Turkey, with 55% in Central Anatolia where annual rainfall varies from 200 to 500 mm (Tuncay et al., 2006). Because of limited rainfall for continuous cereal cropping, a cereal-fallow production system has been traditionally adopted to store soil moisture during the non-crop period for cereal grain production.

Wheat (*Triticum aestivum* L.) is the major crop in the dryland region of Central Anatolia, followed by barley (*Hordeum vulgare* L.), chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* L.) and vetch (*Vicia sativa* L.). Wheat is usually grown in a two-course rotation system consisting of wheat–fallow where the annual rainfall is less than 400 mm. Bare fallow has covered approximately 33% of the cultivated area and up to 40% in wheat–fallow and barley–fallow systems in the past (Durutan et al., 1990).

In the 1980s, due to economic difficulties, different rotation systems such as wheat–legume or continuous wheat monoculture were introduced to increase productivity, replacing the 14-month fallow. The advantages of rotations are that they have been shown

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to stabilize crop production in variable climate conditions (Lyon et al., 1995), restore or sustain soil nutrients (Marschener, 1990; Peoples and Craswell, 1992), and act as a break crop for pests and diseases (Umaerus, 1971; Peréz, 1999). Rotations also minimize the use of mineral fertilizers in the case of grain legumes such as chickpea and faba bean by providing fixed nitrogen for the following crop (Biederbeck et al., 1998). Often the yield of cereals grown in rotation with legume crops such as lentil, vetch and chickpea compared to wheat–fallow and continuous wheat monoculture has been shown to increase in Central Anatolia (Avcin and Avci, 1991; Eser et al., 1997), while the wheat yield in the wheat–legume rotation system was found to be lower compared with wheat–fallow system (Avcı et al., 1999), probably due to insufficient stored water for crop use.

There have been several attempts to study moisture storage in various rotation systems in Turkey. Eser et al. (1999) found that between 8% and 20% of the 350 mm of annual rainfall in the Anatolian Plateau is conserved in the soil for the wheat crops during a 14-month fallow period. In other words, 80–92% of the annual rainfall is wasted in order to accumulate approximately 30–70 mm of water in the soil, although in dry years this amount of conserved moisture plays an important role in the grain yield of wheat. The physical properties of soil play an important factor in fallow efficiency. Güler et al. (1981) and Yeşilsoy (1984) observed that fallow efficiency decreased with soils having low water holding capacities and infiltration rates, especially if rainfall is below 400 mm. A review by Avci (1999) showed that soil moisture differentiation among continuous wheat and various wheat rotation systems has not been studied in detail in Turkey. Some of the past studies include that of Özbek et al. (1973) who carried out a study on the differences between crop and fallow phases of the fallow–wheat rotation. Karaca et al. (1989) and Avçin and Avcı (1993) compared annual cropping systems, and the study of Halitligil et al. (1996) compared three locations in Central Anatolia (Ankara, Eskişehir and Konya). Except for the study of Halitligil et al. (1996), soil moisture measurements were seldom quantified. The present study was conducted based on the idea that instead of continuous wheat in semi-arid areas such as Central Anatolia, the application of rotation systems including legumes could be useful for increasing grain yield and water use efficiency. Additionally, an alternative to a fallow–wheat rotation system could be a legume–wheat system.

The aims of this study were to evaluate the soil moisture distribution and quantify the water budgets in the soil profile, and to assess the effect of various rotational strategies in terms of crop yields, water consumptions and water use efficiencies in the semi-arid (less than 400 mm of rainfall) region of Central Anatolia.

2. Materials and methods

The effects of different dry-land crop rotations on soil–water–plant interactions and on efficient and sustainable crop productivity were determined in the experimental field of the Central Research Institute for Field Crops at Haymana (32°41′45″E, 39°37′33″N; 925 m above sea level). The soil was Typic Haplocambid (Soil Taxonomy, 1999). The A horizon is about 30 cm thick, overlying an alkaline clay B horizon rich with lime. The soil has a high clay content (>50%) in the surface soil (0–10 cm) with a bulk density of 1.04 g cm^{-3}, and contains 1.87% organic matter and followed by clay textured soil layers (10–90 cm). Bulk density was 1.04 g cm^{-3}, and organic matter ranged between 1.28% and 0.45%. Available water content was the highest at the soil surface (0–10 cm) at 11.3% and slightly decreased with depth up to 90 cm (Avcı et al., 1999).

The experiment consists of the following six crop rotation systems: winter wheat (*Triticum aestivum* L.)—fallow (traditional cropping system), continuous winter wheat, winter lentil (*Lens culinaris* L.)—winter wheat, sunflower (*Helianthus anuus* L.)—winter wheat, spring lentil (*Lens culinaris* L.)—winter wheat, and chickpea (*Cicer arietinum* L.)—winter wheat. The experimental set-up was a rotation of alternative crops (2003–2004) and wheat (2004–2005). Similarly, wheat plots in the 2003–2004 season were then planted with alternative crops in the 2004–2005 season.

The experiment started in September 2003 and was laid out in a randomized complete blocks design consisting of alternative crops and wheat blocks that are replaced every other year. Each plot was 5 m × 15 m in area and replicated 3 times, giving a total of 18 plots for a block. The plots were all instrumented with soil moisture neutron probe (SMNP) access tubes. Plots assigned to alternative crops in the 2003–2004 season were cultivated with wheat in 2004–2005. Similarly, the wheat plots of 2003–2004 season were planted with alternative crops in 2004–2005. This alternate crop management system has been practiced for the past 21 years in the same field.

Winter wheat and winter lentil were planted at the end of September; wheat was harvested in late July and winter lentil was in late June. Spring crops were planted in late March and April. The fields were plowed or disked and swept, and the wheat stubble was plowed or disked during seedbed preparation. Spring lentil was harvested in June, chickpea in early August, and sunflower in early September. Wheat–fallow rotation covers a 14-month period from the time of the wheat harvest until October of the following year. The first tillage in fallow is performed in late March or April when the soil is suitable for plowing.

The fertilizer used for wheat contained 30.57 kg phosphorus per hectare and between 70 and 100 kg of nitrogen per hectare, depending on fallow or preceding crop treatments. Alternative crops were fertilized with different amounts of nitrogen and phosphorus depending on the crop requirements.

2.1. Soil moisture measurements

SMNP aluminum access tubes were inserted to a depth of 90 cm in each plot by using a hydraulic probe, and care was exercised to minimize gap and soil disturbance during installation of the tubes. The SMNP readings were taken at 0–30, 30–60 and 60–90 cm intervals from the time of sowing until early spring in the first year but at 0–15, 15–30, 30–45, 45–60 and 60–90 cm intervals of depth from spring to harvest in the following year for more detailed soil water measurements. The SMNP (Troxler 4301, with a 10 mCi (0.37 Gbq) Am/Be neutron source) was calibrated using gravimetric soil samples and bulk density values. A coefficient of determination r^2 of 0.678 ($P < 0.01$) was obtained for the three depths with a calibration equation of $y = 15.08x + 10.7$. Soil water storage (SWS) of the plant root zone was calculated based on changes in soil moisture as measured by SMNP. Due to the shallow soil profile and the limited amount of precipitation that is unable to moisten the whole profile, soil water measurements were performed up to 90 cm of soil depth.

Grain yield, crop water use (CWU) and other crop parameters were statistically analyzed using an analysis of variance ANOVA procedure, and significant differences between treatments were determined using Duncan's Multiple Range Test.

The CWU was calculated based on the changes in SWS between sowing and harvest in the top 0–90 cm of soil depth, plus the total precipitation that fell over that period minus water left as runoff and deep drainage. CWU (mm) can be expressed mathematically as

$$\mathrm{CWU} = \mathrm{SWS}_s - \mathrm{SWS}_h + P - R$$

where SWS_s and SWS_h are soil water storage at sowing and harvest, respectively; P is growing season precipitation; and R is sum of