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Effect of drip deficit irrigation and soil mulching on growth of common bean plant, water use efficiency and soil salinity

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ABSTRACT

The present investigation aimed at assessing the effect of two mulching materials (Rice straw mulch (RSM) and Farmyard manure mulch (FYM)), three irrigation treatments ($I_{100\%}$ = 100%, $I_{85\%}$ = 85% and $I_{70\%}$ = 70%) of crop evapotranspiration (ETc) and four mulch layer thicknesses (MLT_{0}, $_{3}$, $_{6}$ and $_{9}$ cm) on common bean yield, its components, water use efficiency and soil salinity under drip irrigation.

Results obtained showed that the maximum values of bean yield were obtained under FYM compared to RSM. The greatest values dry seed yield of bean were obtained with the no-deficit treatment ($I_{100\%}$) while the lowest ones were observed in $I_{70\%}$ treatment. The average bean yield value of MLT_9 was increased by 9.67, 25.28 and 45.80% than those of $MLT_{6,3}$ and $_{0}$, respectively.

The lowest value of soil salinity was obtained under ($I_{100\%}$), while the greatest one was obtained from ($I_{70\%}$). The highest soil salinity value was observed under MLT_0 (no mulch) compared to another treatments. The average EC value for treatment MLT_0 was increased by12.80, 18.86 and 28.75% than those of MLT_3, $_{6}$ and $_{9}$, respectively.

Under environmental conditions of the study area, the treatment ($I_{100\%}$ × FYM × MLT_9) proved to be the most suitable for producing high bean crop. Under limited irrigation water, application of ($I_{85\%}$ × FYM × MLT_9) treatment was found to be favorable to save 15% of the applied irrigation water with no reduction in bean crop.

1. Introduction

The declining availability of fresh water has become a worldwide problem, especially in arid and semi-arid regions where irrigation is necessary for crop production (Wei et al., 2016). Agricultural irrigation is vital to food production in many parts of the world and a critical tool for ensuring food security (Liang et al., 2016). More than 80% of water resources have been exploited for agricultural irrigation in Egypt (Egypt in Figures, 2015). Therefore, it is necessary to develop strategies to optimize the efficiency of water use, while maintaining the quantity and quality of the production (Nangare et al., 2016).

Dry bean (*Phaseolus vulgaris* L.) is a human food high in protein, phosphorus, zinc, iron, vitamin B1, and fiber. It is the most important legume crop worldwide for human consumption because is a source of protein (Ramirez Builes et al., 2011). According to Food and Agriculture Organization (FAO) Statistics (2013), dry bean has been globally cultivated in 29,290,861 ha and produced 23,598,102 tones with an average of 0.806 tones ha^{-1}. In Egypt, the total area devoted for the production of dry bean yield was 26768.9 ha and produced 69,486 tones with an average of 2.594 tones ha^{-1}.

The challenge of irrigated agriculture in our time is how to produce more crops from limited water supply. One way of tackling this challenge is adoption of practices that help improvement water management especially at field scale. The combine practice of deficit irrigation techniques with drip irrigation system (Topak et al., 2016 and Abd El-Mageed et al., 2016) and mulching appears to be very promising in achieving this goal (Igbadun et al., 2012). In recent years, drip irrigation system has been recommended, not only for reducing irrigation water, but also for increasing crop yield (Geerts and Raes, 2009). Drip irrigation can achieve application efficiencies as high as 95% if the system is well maintained and combined with soil moisture monitoring or other ways of assessing crop water requirement (Vickers and Cohen 2002). Drip irrigation is often used with mulch, which plays a main role in water conservation, particularly to control soil evaporation and also contributes to improving productivity (Mukherjee et al., 2012). Deficit irrigation (DI) as a water saving method is commonly applied in arid and semi-arid regions to increase water productivity (Shahrokhnia and Sepaskhah, 2016). DI, defined as the application of water below full

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crop-water requirements, is an important tool to achieve the goal of reducing irrigation water use (Fereres and Soriano 2007). DI aims to increase water use efficiency (WUE) by eliminating irrigation events that have little impact on yield. However, this application can also have other benefits related with decreasing nitrate leaching, reducing the energy used during irrigations (since most irrigation equipment is pressurized), maximizing the competitiveness of the agricultural sector (Buendía et al., 2008 and Falagán et al., 2015), reducing production costs and water consumption (Pulupol et al., 1996). Mulching can be the addition of inorganic synthetic materials, (e.g. polyethylene sheets, and gravels) or organic material (e.g. crop residues, straw, grasses, and farmyard manure) to the soil surface to provide one or several ecosystem services such as enriching or protecting the soil, preventing pest establishment or enhancing crop yield (Quintanilla-Tornel et al., 2016). The main advantages associated with mulching are: (i) less water is required for irrigation (Trenor et al., 1998), (ii) advance of harvest (Ferrer Talón et al., 2004), and (iii) the bigger size of plants (Melgarejo et al., 1998). Cover crop mulch that remains on the soil surface can be used to add soil organic matter (Dabney et al., 2001), prevent soil erosion (Saxton et al., 2000), increase soil water retention (Dabney, 1998), suppress arthropod and weed pests as well as diseases (Gonzalez-Martin et al., 2014) and prevent the evaporation and enhance the soil temperature (Liu et al., 2012). Mulching is an efficient way to reduce evaporation, improve WUE (Hartkamp et al., 2004) and maintain soil under stable temperature (Ji and Unger, 2001 and Kar and Kumar, 2007). Few studies have examined the combined effects of irrigation water applied and mulch layer thickness on grain yield and water use efficiency. Abd El-Wahed (2009) tested the effect of organic manure levels (OM_0 = 0 (control), OM_1 = 5 and OM_2 = 10 ton/ha) on barley yield. He found that the values of grain yield (GY) were grater for OM_2 treatment than those of OM_0 and OM_1. The average GY value of OM_2 treated barley plants is grater with 52.1 and 28.6% than those of OM_0 and OM_1 treated ones, respectively. Under different mulches (FYM, RSM and white transparent polyethylene mulch), the amount of salts removed from the soil significantly decreases compared with no mulch (Abd El-Mageed et al., 2016). Semida et al. (2014) found that the addition of organic materials to soil increased the water holding pores and decreased the electrical conductivity of soil (ECe). Application of mulching with different materials could significantly increase available soil water and decrease salt accumulation (Anikwe et al., 2007; Yi et al., 2010). The present investigation was planned to determine the effects of deficit irrigation, mulching materials and mulch layer thickness on common bean yield, its components, water use efficiency and soil salinity under drip irrigation system.

2. Materials and Methods

2.1. Experimental location

Two field experiments were conducted during the two growing seasons (2014 and 2015) at the private farm; Ansar Alkharigin village Ihnasiya Sdment El-Gabal Center, Beni Suef Government, Egypt. Beni Suef Government co-ordinates are latitude: 29°05′08″N, longitude: 30°56′04″E and 31 m above sea level. Some physical and chemical properties of the experimental soil are given in Tables 1 and 2. Means of value of irrigation water analysis are shown in Table 3.

2.2. Experimental design and treatments

Drip irrigation system was used in the experimental farm. The laterals were spaced at 100 cm with 16 mm diameter and inline drippers with discharge rate of 2.5 l h^{-1} were spaced at 30 cm intervals on the lateral line. The experimental layout was a split split-plot system in a randomized complete blocks design with three replications. The mulching materials were distributed in the main plots whilst, irrigation treatments were allocated in the sub-plots, while mulch layer thicknesses were allocated in sub-sub-plots. Each sub-sub-plot was 50 m long and 1 m wide (50 m^2).

Table 1
Physical properties of the experimental soil.

Soil depth, cm	Particle size distribution				Bulk density, Mg m^{-3}	FC%	WP%	AW%
	Sand, %	Silt, %	Clay, %	Soil texture class				
0–10	47.2	15.3	37.5	S C	1.46	19.79	4.69	15.10
10–20	46.3	16.8	36.9	S C	1.57	19.42	4.64	14.78
20–30	46.9	17.1	36.0	S C	1.58	18.62	4.37	14.25

SC: Sandy clay, FC: Field Capacity, WP: Wilting Point and AW: Available water.

2.2.1. Mulching materials

Two mulching materials were used in this study as follow: Rice straw mulch (RSM) and Farmyard manure mulch (FYM).

2.2.2. Irrigation treatments

Three irrigation treatments were applied as a percentage of the crop evapotranspiration (ETc) representing one of the following: $I_{100\%}$ (100% of ETc), $I_{85\%}$ (85% of ETc) and $I_{70\%}$ (70% of ETc).

2.2.3. Mulch layer thickness

Four treatments of mulch layer thicknesses (0, 3, 6 and 9 cm) were used in this study for each mulching materials. Both mulching materials were spread manually on the soil surface after sowing. Tables 4 gives further description of the studied twenty four experimental treatments.

2.3. Irrigation water applied (IWA)

The bean plants were irrigated at three days intervals by different amounts of irrigation water.

The daily ETo was computed by Eq. (1) according to Doorenbos and Pruitt (1992):

$$ETo = Kpan \times Epan \tag{1}$$

Where:

Epan = evaporation from the Class A pan (mm d^{-1}).

Kpan = the pan evaporation coefficient.

Computed ETo depended upon monthly mean weather data for a 16-year (January 1997–December 2014). The average of maximum and minimum air temperature, mean relative humidity, wind speed and class A pan evaporation are shown in Table 5.

The crop water requirements (ETc) were estimated using the crop coefficient according to equation (2).

$$ETc = ETo \times Kc \tag{2}$$

Where:

ETc = crop water requirements (mm d^{-1}).

Kc = crop coefficient.

The length of the different crop growth stages were 20, 30, 40, and 20 days for initial, crop development, mid-season and late season stages, respectively. The crop coefficients (Kc) of initial, mid and end stages were 0.40, 1.15 and 0.35 respectively according to Allen et al. (1998).

The amount of irrigation water applied (IWA) to each treatment was determined by using the Eq. (3):

$$IWA = \frac{A \times ETc \times Ii \times Kr}{Ea \times 1000} \tag{3}$$

Where:

IWA = irrigation water applied (m^3).