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Soil amendments strategies to improve water-use efficiency and productivity of maize under different irrigation conditions

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ABSTRACT

The insufficiency water for irrigation is becoming the most vital problem for corn productivity in semi-arid areas. Thus, the improvement of water-saving farming strategies is important to work out the water deficiency problem that affects maize productivity in semi-arid regions. A field research work was conducted during 2011–12 in a semi-arid area of Pakistan to clarify the interactive effects of soil amendments and irrigation levels on the maize yields, water use efficiency, evapotranspiration and total dry matter accumulations. We tested the following five soil amendments (farm yard manure at 5 t ha^{-1}; wheat crop residue at 5 t ha^{-1}; gypsum at 1 t ha^{-1}; qemyisol at 10 kg ha^{-1}; humic acid at 20 kg ha^{-1}) with two irrigation levels (350 mm and 175 mm) and traditional planting with no irrigation (CK), respectively. The results clearly indicated that soil amendment such as wheat crop residue at 5 t ha^{-1} with irrigation 350 mm could enhance the soil water availability in 0–100 cm during the key growth stages, as well as grain yields significant increased by (62%); water use efficiency (WUE) and rainfall use efficiency (RUE) were improved by (35%) and (50%) as compared with CK_1, respectively. As the amount of irrigation increased, the irrigation water use efficiency (IWUE), irrigation water productivity (IWP) decreased but the maize yields and net economic benefit tended to increase. The economic analysis also suggested that higher (45%) of net economic benefits could be obtained by using wheat crop residue at 5 t ha^{-1} as soil amendment with irrigation 350 mm as compared with CK_1 treatment. Therefore, our research work recommended that wheat crop residue at 5 t ha^{-1} with 350 mm irrigation level is a suitable treatment for efficient consumption of local rainfall and increase maize productivity in semi-arid regions because it improves the WUE, RUE and reduces ET levels, thereby enhancing the grain yield, net profit and to reduce the risk of maize productivity in semi-arid regions.

1. Introduction

The mismanagement of irrigation water thought out the world in general and Pakistan, in particular, at a farm level has caused a potential threat to the crop production because of its limited availability (Baozhen et al., 2015; Wakchaure et al., 2016). Due to water shortage or drought winter wheat yield was decrease 10–29% as compared with no water stress (Jianguo et al., 2014). Higher soil moisture depletion and highest WUE (18.9 kg mm^{-1} ha^{-1}) were recorded under limited irrigation as compared with rain-fed conditions (Giri et al., 2009; Luis et al., 2012). Corn yields losses due to water scarcity stress ranges from 20% to 85%, which indicated that water scarcity is one of the key concerns that affecting maize production in semi-arid regions (Fang et al., 2010). Water conservation within a field has been recognized one of the most important concerns throughout the world (Chris, 2011). It includes the incorporation of crop residues or farm yard manure and the recent introduction of qemisoyl, humic acid, gypsum and other organic and inorganic sources that help in improving of soil moisture retentive capacity and consequently, increase crop yield (Wallace and Nelson, 1986).

Soil amendments both synthetic and natural; greatly contribute to provide a reservoir of soil water to plants on demand in the upper layers within the soil where the root systems normally develop (Johnson and Leah, 1990). Qemisoyl served as buffers against temporary water stress

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and decrease of evaporation through limited movement of water from the sub-surface to the surface layer (De Boodt, 1990). Qemisoyl is highly cross-linked polyacrylamides with 40% of the amides hydrolyzed to carboxylic groups (Azzam, 1980). Qemisoyl did not interact directly with the soil matrices but formed aqueous gels and act as water reservoirs for the root zone of plants (Azzam, 1980; Wallace and Nelson, 1986). The roots to the plant grow through the matrix of these hydrogelled particles and draw water from them when required. Ouchi et al. (1989) and Bouranis et al. (1995) have shown that water held by qemisoyl is completely available to plants. Crop residues can improve soil physical properties, conserving soil moisture and controlling weeds (Baozhen et al., 2015). Guangshuai et al., (2016) revealed that wheat residues increased soil humus content, increased rainfall infiltration, conserve moisture, water-holding capacity, and cation exchange capacity. Wheat residues supply plant nutrients to the subsequent crops due to decomposition (Shuo et al., 2016). Huang et al., (2005) reported that wheat crop straw with 3.75- 4.5 t ha^{-1} are an effective measure to reduce evaporation and water consumption. Farm yard manure is another cheap and organic source of plant nutrient, which increased water-holding capacity of soil (Rasool et al., 2005). Therefore, the use of FYM with limited irrigation could slowly increase soil water content and crop production (Mwangi, 2010).

Gypsum used a worldwide soil amendment (Wallace and Nelson, 1986) can decrease soil crusting; develop rainfall permeation, water transmission (conductivity increased water absorption), improved N recovery from subsoil (Farina et al., 2000). Gypsum increases water infiltration as compared to the control plot as a result improves water retention in soil and enhances water-use efficiency (Yangyuoru et al., 2006). Qemisoyl and humic acid may serve as a catalyst in progress the activity of microbes in soil and enhance WUE (Philippe et al., 2011). Verlinden et al., (2009) reported that applications of humic acid at 10 and 15 kg ha^{-1} increase maize yield by 11.50 and 19.11% over control, respectively. Humic acid in combination of irrigation increases irrigation use efficiency and also shows a positive effect in enhancing microbial activity and water retention capacity of soil (Sharif et al., 2003).

Earlier studies of soil amendments have focused mainly on the soil physical and chemical properties, microorganism activity, enzyme activity, soil temperature and photosynthetic characteristics (Ren et al., 2008; Baozhen et al., 2015). However, improving dry-lands maize production needed to clarify the interactive effect of soil amendments with irrigation is unknown. Thus, the present study investigated to find out the most suitable soil amendment in combination with irrigation levels effect on the soil water storage (SWS), WUE, evapotranspiration (ET), irrigation use efficiency, net economic profit, and maize yields in the semi-arid regions of Pakistan.

2. Materials and methods

2.1. Site description

This research work was carried out during 2011–12 at New Developmental Farm of The University of Agriculture, Peshawar Pakistan. The trial site was located at a longitude of 71° 30′E and latitude of 34° 00′N, at an elevation of 510 m above sea level. The climatic conditions of the study station were illustrated as a semi-arid area with a warm temperate climate and an annual mean evaporation rate of 1844 mm. The annual mean rainfall = 460 mm $year^{-1}$, where over 60% of the precipitation occurred in July–September. The amounts of precipitation during June-September were 335 mm in 2011 and 362 mm in 2012. The monthly rainfall distributions during the two year of maize growing seasons are shown in Fig. 1. In the 2012 growing season, the rainfall was well distributed with 52 mm in June, 100 mm in July, 120 mm in August, and 90 mm in September, while in 2011; the levels were 61, 73, 143 and 58 mm in the same months, respectively (Fig. 1). The field experimental was conducted on a flat field. According to the FAO/UNESCO Soil Classification (FAO/UNESCO, 1993), the soil at the experimental site was a Calcic Cambisol (sand 14%, silt 26%, and clay 60%) with relatively low fertility. Selected physics-chemical properties of the experimental site are shown in Table 1.

2.2. Experimental design and field management

The research work was carried out with a randomized complete block design having three replications. The width and length of each plot were 5.6 m × 4.0 m, and they were cultivated by conventional tillage. Each plot was consisted of 8 rows having 70 cm row-to-row distance. A 1.2 m-wide isolation belt was placed between each plot to prevent water leakage. The field experiment included five soil amendments treatments: (i) FYM: farm yard manure at 5 t ha^{-1}; (ii) CR: wheat crop residue at 5 t ha^{-1}; (iii) GYP: gypsum at 1 t ha^{-1}; (iv) QEM: qemyisol at 10 kg ha^{-1}; (v) HA: humic acid at 20 kg ha^{-1}) with two irrigation (350 mm and 175 mm) levels with a precise water meter and traditional planting with no irrigation (CK), respectively. The partition of irrigation at each growth stage of maize is listed in Table 2. The irrigation volumes of 350 and 175 mm were measured according to the irrigation area. All the farm yard manure and wheat crop residue were applied before planting, while gypsum, qemyisol and humic acid were applied at the time of planting, respectively. Nitrogen was applied at 120 kg ha^{-1} at the same time. In all experimental treatments, P and K fertilizers were applied at 90 and 40 kg ha^{-1}. Maize genotype, (Azam) was planted at a rate of 66,666 plants ha^{-1} seeds were sown on June 10 for the 2011 planting year and June 9 for 2012 with the seed rate of 30 kg ha^{-1} and weed was controlled by hand and hoe during each growing season.

2.3. Sampling and measurements

2.3.1. Soil water content

Before sowing of maize crop, soil moisture content was determined at 20 cm increments, to depths of 100 cm at 0, 30, 60, 90,120, and 140 days after planting. The soil moisture content was measured in the 0–100 cm depth using the soil auger method with a 54 mm-diameter steel core-sampling tube, which was driven by hand to a depth of 100 cm, where samples were taken from the middle of rows at each 20-cm interval from 0 to 100 cm. The soil cores were weighed wet, dried in a fan-assisted oven at 105 °C for 48 h, and weighed again to determine the soil moisture content (Ferraro and Ghersa, 2007).

$$\text{Soil moisture content} = [(\text{wet soil weight- dried soil weight})/ \text{dried soil weight}] \times 100\% \quad (1)$$

The evapotranspiration (ET) rate was determined on a seasonal basis, which was calculated using the soil water balance equation as follows (Ren et al., 2008):

$$ET = P + I + C + (\Delta W) - D - R \quad (2)$$

Where ET is the crop water consumption (mm) in the sampling interval from 0 to 100 cm; P is precipitation (mm); I (mm) is the irrigation; C is the upward flow through the root zone; ΔW is the change in the SWS for the soil profile (0–200 cm depth) between sowing and harvesting; D is the downward drainage out of the root zone; R is the surface runoff. In the research, the ground water table remains at the depth of about 80 m below the surface, so the upward flow from the root was insignificant. Runoff was never observed as the experimental field was flat, and the drainage was assumed to be no significant over 100 cm depth.

The WUE, IWUE and IWP were calculated as:

$$WUE = GY/ET \quad (3)$$

$$IWUE = GY/I \quad (4)$$

$$IWP = (GY_1 - GY_2)/I \quad (5)$$

Where WUE is the water-use efficiency as kg mm^{-1} ha^{-1}, GY is the maize

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