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Mulch covered ridges affect grain yield of maize through regulating root growth and root-bleeding sap under simulated rainfall conditions

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A R T I C L E I N F O

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A B S T R A C T

Application of various ridges covering mulch materials with ridge-furrow rainfall harvesting (RFRH) system are the principal agricultural technique for enhancing characteristics of ear and grain yield through regulating root growth distribution across the rooting zone. Therefore, at the College of Life Science in Semi-Arid Regions of China in Ningxia University, Yinchuan, and Ningxia Province， during 2014-15. The objectives of this research work were to enhance characteristics of ear and grain yield through regulating root growth and root bleeding sap flow, with following two planting models: (i) traditional flat planting (CK); (ii) ridge covered with different mulches materials (plastic film (PM), biodegradable film (BM), soil crust ridges (SC)); and two simulated rainfall levels: 320 mm and 430 mm rainfall. Finding of the current research work indicated that ridge covering mulch materials under simulated rainfall had significantly improved characteristics of ear which led to distinct effect on grain yield as compared with flat planting. The average grain yield increased by 30%, 25% and 12% for PM_{430}, BM_{430} and SC_{430} as compared to CK_{430} over 2 consecutive years, respectively. RFRH system significantly enhanced the rooting systems on the top 50 cm soil profile which was attributed to enhancing the grain yield. Root length density (RLD) and root surface area density (RSD) were significantly higher under PM_{430} (plastic film mulch with 430 mm rainfall) and BM_{430} (biodegradable film mulch with 430 mm rainfall) in the uppermost soil profile layer of 10–50 cm as compared with flat planting, but there was no significant difference in RLD and RSD among all the treatments at the deeper soil profile below 60 cm. The effect of RFRH system on root dry weight (g $plant^{-1}$) and bleeding sap of root is significantly related to the simulated rainfall levels. PM_{430} and BM_{430} significantly improved the root dry weight (g $plant^{-1}$) and rate of root bleeding sap in the different growth stages in both study years. Our results suggested that PM_{430} and BM_{430} is an effective, modern cultivation mode for maize productivity in semi-arid areas due to enhanced characteristics of ear, root spatial and temporal distribution of rooting systems across the root zones at different soil profiles, as a result in higher grain yield and reducing maize productivity risk under dry-land farming system.

1. Introduction

Inadequate and unpredictable precipitation is a major limiting factor for maize productivity in rain-fed farming system in semi-arid regions of China (Gan et al., 2008; Zhao et al., 2013; Zhang et al., 2014). Northwest region of China is mostly covered in the semi-arid area having about 56% of the nation's total cultivated land (Han et al., 2008a,b). The climatic condition in this region is mostly semi-arid with average precipitation ranges from 210 to 590 mm, with seasonal potential evapotranspiration of 700–1000 mm which is significantly exceeds from annual rainfall range (Ren et al., 2010), but decreasing trends of annual rainfall have been showed from the average mean of 46 years (1966–2012). Thus, the water deficiency issue is expected in the future (Zhang et al., 1999). The ridge furrow rainfall harvesting (RFRH) system has been used as a means of conserving soil water, improving water use efficiency (WUE), and enhancing crop productivity (Wang et al., 2011b). Simulator rainfall levels (230, 340, and 440 mm) with RFRH system lead to enhance maize yield up to 82.8%,

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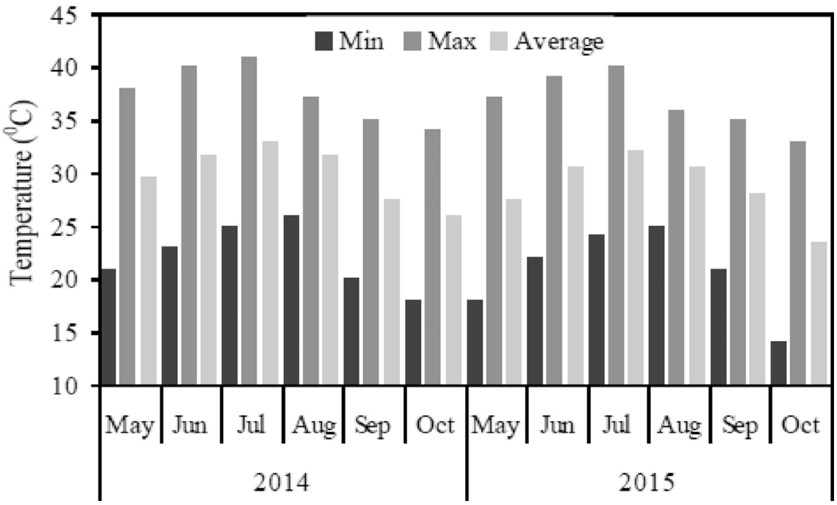

Fig. 1. Monthly minimum, maximum and average air temperature during the maize growing season in 2014 and 2015 at the experimental site.

43.4%, and 11.2%, while the WUE was improved by 77.4%, 43.1%, and 9.5%, as compared with flat planting, respectively (Ren et al., 2008).

RFRH technique with different ridge covering mulch materials is one of the most efficient and technical applications for the efficient use of rainfall, especially light intensity rainfall (Chakraborty et al., 2008). This technique can be improving conserving soil water, WUE, and enhancing sustainable root growth and development up to 60 cm soil depth (Wang et al., 2011a). The RFRH system with mulches has become popular to a great extent. Plastic film mulching is one of the most effective practices which collect rainwater effectively and thereby reduce evaporation, enhance soil water infiltration, improving root growth, grain yield and reduce farmer expenditure (Gan et al., 2008). However, plastic film mulching leads to be a key environmental problem in soil. There are few research studies suggesting that application of biodegradable mulch, straw mulch, gravel-sand mulch and soil crust ridges with RFRH system could be a convenient solution.

In order to deal with water scarcity problems, many agronomists have recommended that water-saving agriculture techniques should be implemented. Maize is very susceptible crop to water stress at their main growth stages, such as tasseling, silking and seed filling stages as a result significantly effected root growth and grain yield (Jama and Ottman, 1993; Cakir, 2004). RFRH technique with different ridge covered mulching materials increase grain yield and improved characteristics of ear significantly in rain-fed farming system (Lynch, 2007; Zhang et al., 2009). However, a few research articles have been illustrated root growth distribution across the rooting zone and its relationship with soil water accessibility to maize crop under RFRH farming systems. Understanding root morphology is very important to get maximum crop production in rain-fed farming, as roots are the most important organ for water and nutrient uptake, play a key role in the plant-soil ecosystem (Fageria, 2004; Qin et al., 2006). Therefore, study of crop rooting systems and their relation with soil water get more attention in the recent years; water increases the availability of nutrients, while nutrients improved root growth (Sarolia and Bhardwaj, 2012). The root growth distribution across the rooting zone of a crop is an essential determinant and its function to supply water and nutrient uptake to maize crop (Fageria, 2004; Spedding et al., 2004). Root diameter, Root length density, root weight density, root surface area density and rate of root bleeding sap are the key root morphological characteristics, which directly influence the function of the whole root system across the root zone (Lynch, 2011).

Water stress reduces uptake and accumulation of nitrogen and phosphorus in roots and restricts root growth (Morita et al., 2000). Various ridge covering mulch materials with simulated rainfall conditions produce greater root length or root diameter which can enhance the capacity of water extraction and nutrient uptake to the crop than those with shorter root length or root diameter, as a result reduce water stress in crops (Dong et al., 1995; Hodge et al., 2009). Simulated rainfall regimes can affect soil moisture, which will significantly influence the depth and density of root penetration system, as result significantly increase the root length density, enhance root biomass and promotion of photosynthetic production, which eventually improved characteristics of ear and grain yield (Li et al., 2010). The root length density is an essential factor for the evaluation of RFRH system with rainfall simulator on root growth and characteristics of ear (Amato and Ritchie, 2002). Rate of root bleeding-sap is a sign of the root pressure, plant growing potential and root activity (Doussan et al., 2006). However, there were very few research studies on simulated rainfall (SR) technique and ridge covering mulch materials in a rain-fed farming system. Therefore an experiment was designed and conducted under field condition. The aims of this research work was to determine the application of ridge-covering mulch materials with simulated rainfall regimes effect on characteristics of ear and grain yield of maize through regulating root growth distribution across the rooting zone and root bleeding sap in rain-fed farming system.

2. Materials and methods

2.1. Experimental site description

The field experimental study was performed during crop season (2014-15) at the College of Life Science in Semi-Arid Regions of China in Ningxia University, Yinchuan, and Ningxia Province. The site is located with latitude of 34°20' N, longitude of 108°24′ E, and an elevation of 466.7 m above sea level. The climatic conditions of research sites were semi-arid, warm temperate with annual mean air temperature 12.9 °C, mean annual maximum and minimum air temperatures were 42 °C and −17.4 °C, respectively. Monthly air temperature during the two experimental maize growing seasons, and the 40-year monthly averages (1973–2013) are shown in (Fig. 1). The total yearly sunshine duration was 2196 h and the frost free period was 220 days. The annual mean rainfall (average value of 1966–2012) was 550 mm. The rate of occasion distribution of rainfall events below the average for the reference period of 1966–2012 were about once 4 years (320 mm < rain rainfall < 430 mm) and 4 years (rainfall ≥ 430 mm), respectively during summer season. The rainfall amount during the months of April-October in 2014 was 313 mm and in 2015 was 330 mm. Mean soil bulk density of 1.37 g cm^{-3}, total nitrogen (N) 0.7 g kg^{-1}, total phosphorus (P) 0.6 g kg^{-1}, total potassium (K) 7.9 g kg^{-1}, available (N) 41.3 mg kg^{-1}, available (P) 8.56 mg kg^{-1}, and available (K) 100 mg kg^{-1}, respectively. The average field water holding capacity (FWHC) and permanent wilting point (PWP) of the root zone soil profile