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# Cultivation techniques and nutrient management strategies to improve productivity of rain-fed maize in semi-arid regions

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ABSTRACT

A field study was conducted during 2015–16 in a semi-arid area of the Loess Plateau China to clarify the interactive effects of cultivation techniques with different N and P fertilization levels on the maize growth, yield, evapotranspiration, and water use efficiency. Two planting models were tested: conventional flat planting ($M_1$), and ridge furrow (RF) rainfall harvesting planting model ($M_2$); with four N:P fertilizer rates: 0:0 kg ha$^{-1}$ ($F_0$); 100:50 kg ha$^{-1}$ ($F_1$); 200:100 kg ha$^{-1}$ ($F_2$), and 300:150 kg ha$^{-1}$ ($F_3$). The RF system increased the soil water storage (SWS), where the SWS exhibited a decreasing trend as the fertilization rate increased under both cultivation models. At 120 days after planting (DAP) the mean, SWS at the depth of 0–200 cm under the $M_1F_0$, $M_1F_3$, $M_2F_0$ and $M_2F_3$ treatments was 376.5 mm, 345.7 mm, 350.6 mm and 325.4 mm. The mean WUE over 2 years increased significantly ($P < 0.05$) with $M_2F_3$, $M_2F_2$, $M_1F_3$, $M_1F_2$, $M_2F_1$, and $M_1F_1$ by 53%, 37.7%, 34.7%, 31.9%, 21.6%, and 19.0% compared with $M_1F_0$ and $M_2F_0$ treatments. Maize responded positively to fertilizer, and $F_2$ was the economical fertilizer input rate, where the leaf area, dry matter accumulation and grain yield increased significantly with increasing fertilization rate up to the economically optimal rate (F2). Beyond the optimal rate, these quantities increased slightly as did the yields and economic returns. Agronomic efficiency steadily decreased with fertilization rate beyond the F1 level. The economic benefit was 54% greater under $M_2F_2$ treatment, which also obtained significantly higher grain yield, WUE and agronomic efficiency than that of $M_2F_0$ treatment. Thus, we recommend the $M_2F_2$ planting model for high productivity and efficient maize production in semi-arid regions.

## 1. Introduction

Maize (*Zea mays* L.) is one of the most essential forage and food cereal crops in semi-arid regions (Barbieri et al., 2012). Water and nutrient deficiency are the two main issues that limit crop productivity in semi-arid regions (Xia et al., 2012). In arid and semi-arid regions, it is hard to get better plant development due to lack of nutrients and water stress, which lead to reductions in crop productivity (Abbas et al., 2005; Nagaz et al., 2009). However, many dry-land studies have given more attention to water use efficiency compared to fertilizer use efficiency, which limits the land potential for crop production (Di Paolo and Rinaldi, 2008; Barbieri et al., 2012). Excessive fertilization may lead to imbalances in the soil nutrient levels and eventually cause environmental pollution (Adamtey et al., 2010; Barbieri et al., 2012).

In dry-land agriculture, a basic problem is balancing the fertilizer application levels when water resources are limited to improving the WUE and nutrient use efficiency (Stone et al., 2001). The soil moisture and nutrient levels are important factors that constrain agricultural productivity in rain-fed areas (Kim et al., 2008; Seghatoleslami et al., 2008). However, the ridge furrow (RF) rainfall harvesting system is a modern cultivation technique used in dry-land farming systems, which enhances the rainwater and nutrient use efficiency (Wang et al., 2011). Covering ridges with plastic film and planting in the furrows can reduce surface evaporation and supply enough rainwater at the main growth stages of maize, as well as improving the WUE (Li et al., 2005; Wang et al., 2011; Qin et al., 2014). Thus, Li et al. (2001) showed that covering ridges with plastic mulch and planting corn in the furrows increased the moisture contents at depths of 0–200 cm during at the jointing, flowering, and harvest stages by 14.8% (50.5 mm), 4.4% (13.7 mm), and 7.6% (24.7 mm), respectively, compared with conventional flat planting.

Planting maize in furrows and using plastic film as mulch improved crop growth and improved the accessibility for nutrient uptake (Ren et al., 2010). Excessive fertilization may lead to the increased depletion

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of SWS reservoirs by crops due to dry soil layers, thereby reducing the availability of water (Kim et al., 2008). Earlier studies have shown that the efficient use of precipitation and nutrients can significantly improve the nutrient use efficiency, sustain the maize productivity, and facilitate sustainable dry-land farming systems (Di Paolo and Rinaldi, 2008). In semi-arid regions, the soil fertility status and financial profits can be achieved by enhancing the rainwater use efficiency with the RF cultivation technique, as a result improving the supply of soil water, nutrient uptake and maize productivity (Singh et al., 2010). Li et al. (2004) and Tiquia et al. (2002) showed that RF system can increase the deep soil water contents and reduce severe water stress at main growth stages to maximize production. Drought is one of the most important ongoing problems that affects dry-land agriculture, but the insufficient fertilizers and unnecessary losses of inadequate light rain also lead to reduced maize production during non-drought periods in semi-arid regions. Therefore, combining the RF cultivation technique with different fertilizer levels in semi-arid areas is slowly gaining attention (Ogola et al., 2002). For improving crop yields extremely low or high fertilization levels are not beneficial, while biomass accumulation, leaf area plant$^{-1}$ photosynthesis efficiency, and yields can increase by the optimized supply of water and nutrients (Teixeira et al., 2014).

Earlier research work of RF planting technique had mostly focused on the efficiency of ridge catchments, the optimum ridge-furrow ratios, soil temperature, WUE, and photosynthetic characteristics (Ren et al., 2010). However, increasing dry-lands crop production needs to consider the interaction between the rainwater harvesting and nutrients management strategies. However, the response of the crop yield to combined RF planting technique with different N:P fertilizer levels is unknown. Therefore, we investigated the combined effects of RF system with different N:P fertilizer levels on soil water storage, grain yield, WUE, nutrient use efficiency and economic returns. We expect that this practice could support a complete rainwater harvesting system and provide a reference for fertilizer application to maize planting under the RF system in a semiarid region of China.

## 2. Materials and methods

### 2.1. Site description

This research work was conducted during 2015 and 2016 in Zhongwei city, Ningxia Province, with latitude of 36°78 ' N, longitude of 106°02' E, and an elevation of 1365 m above sea level. The climatic conditions at the research station were warming temperate with an annual mean evaporation rate of 1753 mm yr$^{-1}$. The average mean annual temperature = 6.9 °C, total duration of sunshine hours = 2236 h yr$^{-1}$, the frost-free period was 141 days, and the average annual mean rainfall = 585 mm yr$^{-1}$, where over 60% of the rainfall occurred during July–September. The amounts of rainfall during May–September were 289 mm in 2015 and 323 mm in 2016. The monthly rainfall distributions during the two experimental maize growing seasons and the 40-year monthly averages (1973–2013) are shown in (Fig. 1). Chemical properties of the trial site are presented in Table 1.

### 2.2. Field management and experimental design

The field research was carried out with a completely randomized block design using three replicates. The length and width of each plot were 5.0 m × 3.6 m, and they were cultivated by conventional tillage. The field experiment included eight treatments: (i) flat planting with N:P at 0:0 kg ha$^{-1}$ ($M_1F_0$); (ii) flat planting with N:P at 100:50 kg ha$^{-1}$ ($M_1F_1$); (iii) flat planting with N:P at 200:100 kg ha$^{-1}$ ($M_1F_2$); (iv) flat planting with N:P at 300:150 kg ha$^{-1}$ ($M_1F_3$); (v) plastic film and furrow planting with N:P at 0:0 kg ha$^{-1}$ ($M_2F_0$); (vi) plastic film and furrow planting with N:P at 100:50 kg ha$^{-1}$ ($M_2F_1$); (vii) plastic film and furrow planting with N:P rate at 200:100 kg ha$^{-1}$ ($M_2F_2$); and (viii) plastic film and furrow planting with N:P at 300:150 kg ha$^{-1}$ ($M_2F_3$). Ridge and furrow widths were 60 cm and ridge height was 15 cm in the RFRH system. Ridges were covered with plastic film (0.025 mm thickness), and furrows were left bare (Fig. 2). The fertilizer comprised urea (N 46%) with diammonium phosphate ($P_2O_5$ 46.0%, N 18.0%). Both nitrogen and phosphorus were applied at the time of sowing by spreading it evenly over the plot (across the whole plot for conventional cultivation technique, and into the furrows with the RF system).

Maize (Xianyou 335) was sown on April 29, 2015 and on April 24, 2016 with an inter-row distance of 30 cm, using a hole-sowing machine with a seeding depth of 4–5 cm. The maize was harvested on September 18 "2015" and on September 26 "2016". After harvesting the maize crop, the plastic film was removed before the subsequent sowing operation. Irrigation water was not supplied during the two study years, and weeds were removed by hand in each maize growing period.

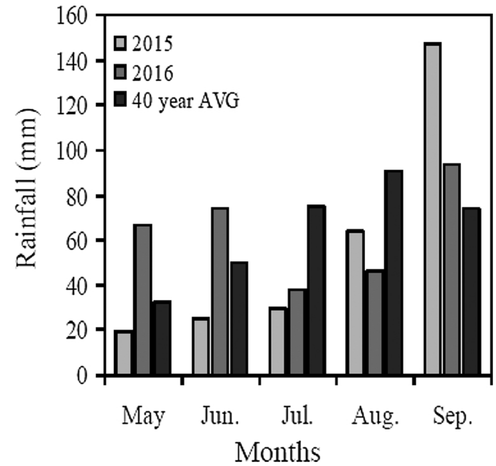


**Fig. 1.** Monthly rainfall distribution during the maize-growing seasons in 2015 and 2016 at the experimental site.

**Table 1**
Properties of experimental site of the soil layers (0–60 cm depth) at the Dryland Agricultural Experiment Station, Ningxia.

| Year | Soil layer (cm) | Organic matter (g kg$^{-1}$) | Total N (g kg$^{-1}$) | Available N (mg kg$^{-1}$) | Available P (mg kg$^{-1}$) | Available K (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|
| 2015 | 0–20 | 12.30 | 0.85 | 33.87 | 8.76 | 139.30 |
| | 20–40 | 13.90 | 0.85 | 27.37 | 3.77 | 110.00 |
| | 40–60 | 12.83 | 0.81 | 22.66 | 3.25 | 85.30 |
| 2016 | 0–20 | 14.86 | 0.98 | 63.24 | 23.68 | 136.47 |
| | 20–40 | 13.41 | 0.92 | 51.72 | 5.09 | 103.71 |
| | 40–60 | 14.21 | 0.93 | 46.47 | 4.41 | 90.11 |

### 2.3. Sampling and measurements

#### 2.3.1. Soil water contents

Soil sampling was performed before sowing the maize, at the seedling, jointing, and heading stages, as well as after the filling period and harvest. The soil auger was driven by hand to a depth of 200 cm with samples taken at each 10 cm in the range 0–20 cm and at 20-cm intervals from 20 to 200 cm. For the ridge furrow rainfall harvesting planting model, the soil sampled was taken from the middle of a furrow, side of the furrow and the middle ridge, where the soil water content was calculated as the mean value of the three different positions. For the traditional flat planting model, the soil was sampled from between the rows. The soil cores were wet weighed, dried in the oven at 100 °C for 50 h, and weighed once more to obtain the moisture content (Ferraro and Ghersa, 2007).

The evapotranspiration (ET) was calculatedon a seasonal basis, by using the soil water balance equation as follows: