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Ridge-furrow mulching system in semiarid Kenya: A promising solution to improve soil water availability and maize productivity

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ABSTRACT

In semiarid Kenya, field productivity of maize has been at a low integrity level due to insufficient use of rainwater use. From 2012 to 2013, an innovative ridge-furrow mulching system (RFMs) was tested using local maize (*Zea mays* L.) hybrid, *KCB* in KARI-Katumani Farm, Kenya in long and short rainy seasons. Field experiments were conducted in a randomized complete block design with four treatments: 1) RFMs with transparent polyethylene film (RFT), 2) RFMs with black polyethylene film (RFB), 3) RFMs with grass straw mulching (RFS), and 4) RFMs without mulching (CK). Soil moisture & temperature, grain yield, water use and economic benefit were determined and analyzed. The results indicated that both RFT and RFB treatments significantly increased soil water storage amount in the depth of 0–60 cm. Grain yield and water use efficiency (WUE) in both treatments were increased by 66.5–349.9% and 72.9–382% respectively, compared with those of CK over two growing seasons. In addition, grain yield and WUE in RFS treatment were only increased by from 4.2–127.1% compared with those of CK. Particularly, two types of plastic films displayed different effects on modifying topsoil temperature. Transparent film mulching significantly increased topsoil temperature by 1.3 °C ($p < 0.05$) higher than CK, to facilitate growth and grain formation in long (but cool) growing season. In contrast, black film mulching lowered soil temperature by 0.3 °C lower than CK in short (but warm) growing season, which led to better soil thermal balance. Overall, RFMs with film mulching could serve as an effective solution to increase maize productivity, and hence a promising strategy to cope with food security under climate change in semiarid Kenya.

1. Introduction

Rapidly growing human population and little adaptive capacity to climate change are two major challenges to cope with food scarcity in the bulk of African countries (Parry et al., 2005; Thornton et al., 2011). Both challenges tend to be coupled due to inefficient agricultural production (Thornton et al., 2011) and eventually lead to food shortage (Schmidhuber and Tubiello, 2007). Especially in smallholder-based eastern Africa, limited capability to adapt to climate change has led to a great vulnerability in local agricultural production in comparison with other countries in the world owing to arid environment and intricate socioeconomic factors (Morton, 2007; Müller et al., 2011; Thornton et al., 2011). Securing food supply in this area is temporarily achieved through both limited domestic production and massive importation (Rosen and Shapouri, 2008). However, over-dependence on importation would not be capable of alleviating food crisis in the long run (Wiggins and Leturque, 2010). Therefore, to improve the capacity of food self-sufficiency and climate adaptation in Eastern Africa Plateau (EAP), the high-yielding and low-input farming systems regarding extensive smallholder farmers need to be developed and adopted in order to achieve a substantial increase in crop yield (Mrabet, 2002; Siddique et al., 2012).

Kenya is mainly characterized with arid and semiarid climate type (Jayne et al., 2010), and local farming system is a representative of smallholder farming system in EAP. Maize (*Zea mays* L.) production plays a critical role in regional food security, as it is by far the primary staple food for most people living there (Akinnifesi et al., 2010; Sauer et al., 2007). Nevertheless, maize yields in this area are often less than half of the potential yields (Barron and Okwach, 2005). Insufficiency of rainwater use and soil manage-

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ment is among critical reasons. Generally, water availability is the primary limiting factor for crop growth in the tropical semi-arid environment such as the EAP (Lal, 1991). In most cases, continuous drought during critical stages of maize growth and temporal strong rainfall together with low nutrient input tend to decrease maize productivity although total rainfall amounts in the whole growing season may not be low for maize production (Barron and Okwach, 2005; Fox et al., 2005). This unmatched supply-demand relationship is frequently worsened by the surface runoff loss of plenty of rain water. In addition, various limiting factors including scarce and under-managed water resources, poor development of irrigation infrastructure coupled with unaffordable irrigation investment by farmers led to a low-level smallholder irrigation system although irrigation in the Plateau has the potential to boost agricultural productivities (Mati, 2008; You et al., 2011). Recently, several advanced farming practices have been developed by some smallholder farmers to enhance rainfall infiltration and reduce surface run-off, thereby expected to increase maize water use and precipitation use efficiency. These technologies include reduced tillage (Mrabet, 2002), in situ water harvesting such as use of micro-catchments and building terraces (Jensen et al., 2003). However, to a large extent, intense evaporation greatly restricted these current existing technologies to harvest satisfying precipitation use efficiency and maize yields.

To tackle food security in semiarid northwest China, an innovative, high-yield and low-input farming practice called ridge-furrow mulching system (RFMs) has been developed and extended in maize production in a large area, especially in Gansu province (Zhou et al., 2009). A typical configuration of RFMs contains such two technical components as ridges-furrows arrangement and various mulching materials (Gan et al., 2013). Alternating ridges and furrows serve as two functional areas for producing and collecting surface run-off (Li et al., 2007). In practice, crops are planted in the furrow in order to maximise water uptake from furrows (Ren et al., 2008). Mulching is typically applied using plastic film, crop straw, gravel-sands and rocks, etc. (Bhardwaj, 2013; Wang et al., 2011). The existences of covering materials not only greatly reduces evaporation and water erosion but also improves rainwater conservation, weeds suppression and thermal balance (Johnson and Fennimore, 2005; Liu et al., 2010a, b; Arnhold et al., 2013; Zhou et al., 2012; Zhang et al., 2013; Zhao et al., 2014). Especially, the application of RFMs with plastic film mulching in field maize production has been demonstrated to be an effective measure for improving water use efficiency, yields and economic benefits in northwest China (Gan et al., 2013). Such practice is more effective in areas where rainfall is sudden and infrequent, and soil evaporation is intense (Yao and Yin, 1999). Since 2007, RFMs with film mulching has also been widely used in many dryland crops (Jia et al., 2006; Liu et al., 2013; Wen et al., 2012; Zhao et al., 2012).

Since the RFMs is targeted to improve rainfall use efficiency, it has contributed to increased crop yield and hence greater economic benefits, than conventional dryland farming technology in semiarid northwest China. It is so far unclear whether this kind of innovative farming system RFMs can be extended to other regions with similar natural resource conditions in the world. In this study, a two-year field experiment using local maize hybrid, KCB, was conducted to test the agronomic and economic performances of RFMs and its mechanism in a semiarid site of Kenya. The objectives of this study consist of: 1) to experimentally validate the suitability and reliability of RFMs in semiarid Kenya, 2) to assess the effects of different mulching treatments on maize yields, water use efficiency and above-ground biomass, 3) to compare differentiate influence of mulching materials on soil water storage and soil temperature and 4) to evaluate economic benefit of this system regarding small household farmers in Kenya.

2. Materials and methods

2.1. Description of experimental site

A two-year field experiment was carried out at the farm of Kenya Agriculture Research Institute (KARI)-Katumani Research Centre (1°35′S, 37°14′E), southeast Kenya over two growing seasons from 2012 to 2013. The site represents a typical semiarid tropical climate at EAP, with an elevation of 1600 m, annual rainfall of 655 mm and mean annual temperature of 19.2 °C. There are two maize planting seasons following the bimodal rainfall pattern in a year. The first, known as the long rainy season, is characterized with low air temperature, in-season rainfalls of 272 mm between March and May, but peaked in April, and followed by a dry period extending to mid-October. The second is referred to as the short rainy season, with high air temperature, and rainfall amount of about 382 mm from mid-October to mid-February. Biweekly precipitation distributions and daily mean air temperature in the test years and recent 5 years are shown in Fig. 1. During the maize-growing season in test years, total precipitation was 89.9 mm and 138.3 mm in long and short season, respectively. Local soils in Katumani are sandy clay loams in texture and have been classified as chromic luvisols (Kibe et al., 1981). The depth of soil layer in the experimental site is averagely about 1.2 m. Due to low structural stability, the soils in this area are prone to slaking and erodible (Kinama et al., 2005). A brief description of soil characteristics in KARI-Katumani Farm can be found in Table 1.

2.2. Ridge-furrow mulching system (RFMs)

The schematic diagram of typical RFMs is shown in Fig. 2. One of core configuration of RFMs is alternating ridges and furrows, and each ridge-furrow unit comprises a wide-low ridge (0.6 m in width and 0.15 m in height) and a narrow-high ridge (0.4 m in width and 0.3 m in height), the naturally occurring furrows at the junction between wide-low ridge and narrow-high ridge can be used for collecting water and sowing crops. Two different sized ridges serve as the areas of producing rainwater run-off and the wide-low ridge can also be used for walking and field operation. It should be noted that the gauge of ridges are not fixed but can be modified according to local rainfall and thermal conditions. The crops are usually planted in the furrows in order to use water more effectively. The mulching materials varied from crop types, climate conditions and soil characteristics. The RFMs with plastic film has been viewed as the most efficient management practice for maize production in arid and semiarid China. Plastic film mulching helps increase soil temperature at the early stage of maize-growing season and restrain soil water evaporation. Before sowing, plastic film is laid out over the plot where two pieces of plastic films are jointed in the midline between wide and narrow ridges, and the joint is fixed stably by placing soil on the top of film. Weeds can be manually cleared through lifting film at junction of two pieces of films during the growing season. In addition, gravel-sands and rocks are usually used for some special crops such as watermelon.

2.3. Experimental design and field management

In this study, three different mulching materials were compared and four treatments were designed as: (1) ridge and furrow covered by transparent polyethylene film (0.008 mm thick and 1.2 m wide) (RFT). (2) ridge and furrow covered by black polyethylene film (0.01 mm thick and 1.2 m wide) (RFB). (3) ridge and furrow covered by grass straw (mowed from the meadow adjacent to experimental fields) (RFS). (4) bare ridge and furrow as control (CK). The size of ridges is identical among all treatments as referred to Fig. 2. Before sowing, the ridges and furrows were built up with a