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Recent progress and prospects in the development of ridge tillage cultivation technology in China

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ABSTRACT

The trace of high and low ridge in the Sanyangzhuang village site showed that adopting ridge tillage cultivation technology (RT) in China has a long history of more than 2000 years. In this paper, we reviewed recent advances of the development and application of RT in China. The better yields from crops grown on ridges/furrow compared with those on flat land were attributed mainly to the improvement of soil moisture conditions, better air permeability and effective supply of soil nutrition. However, most studies of RT are mainly concentrated in upland crop. It has not been reported on RT's higher water use efficiency (WUE) and the capacity of drainage & impounding during the rice production process. New systems of ridge tillage & terrace cultivation model (RTT) for irrigated rice are described here. Further research is needed to optimize management strategies and to strengthen basic research for RTT to obtain environmental and economic benefits and to evaluate practicability and effectiveness of RTT in the paddy field.

1. Introduction

The trace of high and low ridge in the Sanyangzhuang village site indicated that adopting ridge tillage in China has a long history of more than 2000 years (Liu and Zhang, 2008; Han, 2010). The ridge tillage was originally applied for planting Chinese millet (*Setaria italic*) in the region of Yellow river, The function of this method is to easy-drainage during the rainy season and to convenient-irrigation in the dry season (Han, 2010), and the crop was able to be selected for planting in the furrow or on the ridge based on the seasonal distribution of rainfall, which can ensure stable yields despite drought or excessive rain (Han, 2010). This method has been extensively used for multiple crops cultivation including maize (*Zea mays* L., Ren et al., 2008a,b; Wang et al., 2011; Ma et al., 2011a; Wu et al., 2012), wheat (*Triticeae dumort* L., Wang et al., 2007; Chen et al., 2010; Ma et al., 2011b; Li et al., 2011), rape (*Brassica rapa* L.), potato (*Solanum tuberosum* L., Qin et al., 2011), soybean (*Glycine max* L., Yang and Zhao, 1995; Liu et al., 2011a), tobacco (*Nicotiana tabacum* L.), peanut (*Arachis hypogaca* L.), and rice (*Oryza sativa* L., Gao et al., 2004; Zhang et al., 2005; Liang et al., 2010).

With the increasing of global climate changes, extreme climate events such as uneven seasonal distribution of rainfall, heavy rain event and storm event may become more frequent (Mearns et al., 1984; Karl and Easterling, 1999; Easterling et al., 2000). The ability of natural precipitation accumulation under agricultural facilities and cultivation measures and its water utilization efficiency was challenged and to be one of the restraining factors in the agricultural production. The data of Table 1 showed us that linear trend in total and heavy precipitation above various thresholds (threshold used to define heavy rain was 50 mm/24 h in Northeastern China and 100 mm/24 h in Southeastern China) for different regions in China. The number of days annually exceeding 100 mm (4 in.) of precipitation has been increasing in the southern China, and the number of days annually exceeding 50 mm (2 in.) of precipitation has been decreasing in the northern China. Since the changes of heavy rain or storm event and the increase of lighter (<5 mm) daily rainfall totals, the diverse approaches for natural precipitation harvesting, storage and conversation has been developed for efficient water utilization on crop production in China (Cheng, 2006). For example, in northern of China, the application of ridge tillage cultivation technology (RT), plastic film or straw mulching on the soils can largely reduce the evaporation of soil water, decline the degree of water deficit and increase water

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Table 1
Regions/seasons/periods where the linear trends of the number of days with heavy precipitation are amplified relative to changes in mean precipitation totals and frequency. Usually the season with maximum precipitation totals has been selected (Sun and Groisman, 2000).

Country	Period	Threshold used to define heavy rain (mm)	Season	Average number of days with heavy rain	Linear trend % per 10 year
Northeastern China	1951–97	50	JJA	1.0	−3.1
Southeastern China	1951–97	100	JJA	0.5	1.3

reserve in the soil (Hu and Jiang, 1998; Chen, 2002), finally leading to an increase of crop yield (Fan et al., 1999; Zhai et al., 2004; Wang et al., 2004a,b). And in the southern of China, the accumulation of natural precipitation was mainly dependent on reservoirs and hilly pond. However, the capacity of natural precipitation storage and efficient water utilization for paddy field remains not to be developed.

In this review, we summarized the recent progress on practice of RT in China, and mainly focused on the effects of RT application on water utilization efficient (WUE), soil property, crop yield, and crop growth characteristics including root, nutrition utilization and balance, and photosynthesis. Based on the water requirement characteristic rice and the high temperature and rainy climate in southern China, we proposed a new technology-Water-Saving ridge Tillage & Terrace Cultivation Technology. This technology will show us a new approach to achieve the goals of high yielding, more efficient and ecological on crop production by reducing water consumption and enhance WUE, similarly to the classic farming technology of China such as rice-fish complex ecosystem and rice-duck complex ecosystem. Finally, we discussed the unresolved issues that remain to be addressed in further research for this new technology.

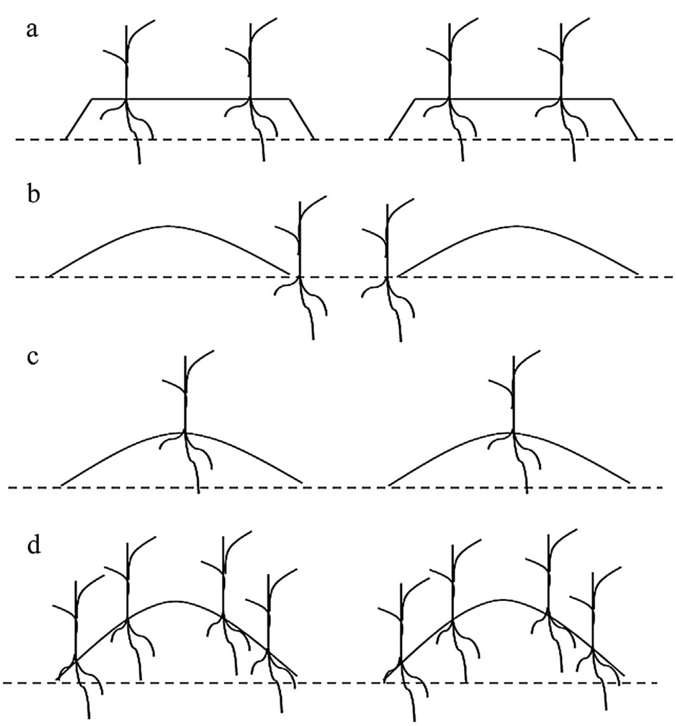

Fig. 1. Four basic forms in the ridge tillage technology, a–d were bed (wide ridge) cultivation model, ridge and furrow planting of rainfall harvesting model, ridge mulching and planting of warming and water conservation model and ridge tillage & terrace cultivation technology, respectively.

2. Progress in research of RT

2.1. The form of ridge tillage

Four basic forms have been developed with the needs of crop practical production and the conditions of local climate. Bed (wide ridge) cultivation model, as shown in Fig. 1a, was suitable for dry farming or paddy-upland rotation in region with the frequent rainfall and high groundwater level. Its advantage was the convenient for drainage, increase soil water evaporation and soil temperature due to the reduction of soil water content in the surface, improve air capacity of soils.

Ridge and furrow planting of rainfall harvesting model (Fig. 1b) was mainly applied in the arid & semi-arid region with rare rainfall and rainfall pattern based mainly on light rain or heavy rain. And that combines with the use of plastic film mulching on the ridge and straw mulching or not in the furrow, natural precipitation harvesting in the furrow. These measurements are helpful to largely increase the amount of water leakage, effectively inhibit invalid evaporation of soil moisture, and significantly improve crop water use efficiency.

Ridge mulching & planting of warming and water conservation model (Fig. 1c) was usually used for the areas where low temperature often happens in the early stage of crop growth and a higher soil moisture requires to elevate. The applying of plastic film mulching and planting in the ridge can enhance soil temperature, and inhibit invalid evaporation of soil moisture, then to promote fast growing and stringing of seedlings, improve solar energy utilization efficiency, consequently, achieve the goal of crop high and stable yield.

Ridge tillage & terrace cultivation model (RTT, Fig. 1d) is newly developed by Huang et al. (2010), which is based on the condition of often and concentrated rainfall in southern China, and frequent water storage and drainage during the rice production process. The novel model is that water storage in the furrow, rice planting with a terrace type in the ridge with moistening irrigation. The model could achieve dual objectives of water storage and drainage, and eventually achieve water-saving and high efficient rice production.

2.2. Yield

Previous studies indicated that crops production with RT often achieved higher yield than those on flat land (Table 2), when the RT models are reasonably applied based on local precipitation and the trait of crop growth & development. For examples, using the rainwater-harvested furrow/ridge system, grain yield of spring maize and summer maize increase by 11.2–82.8%, 3.3–75.4%, respectively (Ren et al., 2008a,b), Li et al. (2011) reported that under furrow–ridge mulching cultivation conditions, grain yield of winter wheat increase by 16–44%. Compared with flat tillage cultivation technology (FT), grain yield of potato, summer soybean and soybean in the RT increase by 75–86% (Qin et al., 2011), 13–21% (Liu et al., 2011a) and 25% (Yang and Zhao, 1995). Gao et al. (2004) and Zhang et al. (2005) stated that rice grain yield increase by 1–13% with RT. Tisdall and Hodgson (1990) review research on RT in Australia, and stated out that RT is used successfully in Australia, mainly for vegetables or irrigated crops grown on poorly drained alfisols and vertisols. The better yields from crops grown on ridges compared with those on fiat land were attributed mainly to better soil aeration. Conclusively, the main reasons for higher yielding in the RT were that the soil moisture conditions and air permeability, and nutrients supply are largely improved. Therefore, in arid and semi-arid region with an annual precipitation of