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MICRO-FIELD RAIN-HARVESTING FARMING SYSTEM IN SEMIARID PAKISTAN: A CRITICAL TOPIC TO ADDRESS

WEN-XUAN SI[1], PU-FANG LI[1], MUHAMMAD ASHRAF[2], FEI MO[1], XIAO-JIE HUI[1], ASFA BATOOL[1], JAVAID MANSOOR[3], MUHAMMAD AFZAL[3], JIAN ZHANG[1]* AND FENG-MIN LI[1]*

[1]*School of Life Sciences, State Key Laboratory of Grassland Agro-ecosystems, Lanzhou University, Lanzhou 730000, China;*
[2]*Pakistan Science Foundation, Islamabad, Pakistan;*
[3]*Department of Agronomy, University College of Agriculture, University of Sargodha, Sargodha, Pakistan.*
[*]*Corresponding author's email: fmli@lzu.edu.cn and zigo4732@163.com*
WX Si and PF Li equally contributed to this work

Abstract

Arid and semiarid areas account for more than 90% of national land area in Pakistan, and over 50% of these lands are suitable for developing rainfed agriculture. Improving the efficiencies of on-field rainwater collection and utilization is a critical approach to enhance crop productivity and water use efficiency (WUE) in semiarid Pakistan. In recent decades, an innovative micro-field rain-harvesting farming technology, ridge and furrow mulching (RFM) with plastic film, has been developed in the Loess Plateau of northwest China, leading to massive increases in grain yield and WUE in dryland crops. This farming technology has been widely adopted and extended in rainfed agricultural areas where small household farmers account for the majority of population. Semiarid Pakistan has similar climatic and socioeconomic conditions with Chinese Loess Plateau, displaying a great potential to extend such a low-cost but high-efficiency farming technology. In this review paper, we present the background and advantages of this rainfed farming system and its applicable potential in Pakistan. The opportunities and challenges during the extension of this farming strategy are also discussed. In view of our previous studies and local natural & socioeconomic data, we believe that the introduction of this farming technology into Pakistan may lead to an expected increase in food and forage production and ecosystem sustainability. This may provide promising strategies to cope with climate change for regional ranifed agricultural system.

Key words: Rainfed agriculture, Ridge and furrow mulching, Water use efficiency, Food security, Pakistan.

Background

The effects of climate change on agricultural ecosystem have received considerable attention worldwide (Delgado e*t al*., 2012; Parry & Ruttan 1991). Particularly in rainfed agricultural areas, there exists a huge potential to utilize natural rainfall and increase crop production worldwide. However, high evaporation and surface runoff loss severely limits soil water availability and threatens agricultural sustainability in this area (Gicheru *et al*., 2004). This issue has become more serious as a result of global climate change (Ali & Rab, 2017). Arid and semiarid areas comprises of over 90% total land areas in Pakistan (Fig. 1, Table 1), in which almost 50% lands are suitable for developing rainfed agriculture. In a long run, grain yield per unit area and rainwater use efficiency remains at a relatively low level in semiarid rainfed agricultural areas.

Pakistan and China are also two countries which are likely to suffer the most from global warming. Over last three decades, micro-field rain-harvesting farming technology has been extensively used in northwest China, and resulted in double increase in grain production and rainwater use efficiency particularly in Gansu Province. It is generally characterized as ridge and furrow mulching (RFM) with plastic film or other materials (grass straw, gravel or crop straw etc). Previous studies showed that the RFM farming technology can significantly improve crop productivity and soil and water conservation (Mo *et al*., 2016; Wang *et al*., 2016). As indicated in Table 1, the proportions of semiarid and semi-humid areas occupy almost 30% of total lands in Pakistan. Spatially, these lands are mainly allocated at northeast and middle parts of Pakistan. According to the definition and suitability area of RFM farming system, those areas with annual precipitation of 300-800 mm area can be viewed as suitable rainfed agricultural areas. Regarding geographic and climatic conditions, almost 50% of the arable lands are suitable for developing rainfed agriculture in Pakistan (Fig. 1).

As similar as semiarid Pakistan, the Loess Plateau of China also belongs to rain-fed agro-ecosystem with the monsoon type (Liu *et al*., 2009; Ye & Liu, 2012). Low and unpredictable precipitation is the major factor limiting agricultural productivity (Gan *et al*., 2009; Siddique *et al*., 2001; Turner 2004). In 1978, agronomic plastic sheets as a water-saving cultivation technology were firstly introduced to China (Zhou *et al*., 2012). Thereafter, plastic mulching technology started to be used and then incorporated into the ridge-furrow system, which gradually evolved into current RFM farming system. Over last three decades, the RFM farming system has exerted positive impacts on regional food security in northwest China (Li *et al*., 2001). It required low economic input and was extensively adopted by local small household farmers. Also, it has been well adopted as one effective measure to mitigate soil erosion and reduce surface runoff (Kornecki *et al*., 2005), increase water use efficiency (WUE) and optimize yield formation (Li *et al*., 2000). The major mechanism was that the RFM system can increase topsoil temperature and reduce evaporation at field scale. The RFM farming system has been widely accepted to develop environmentally sustainable agricultural production (Gan *et al*., 2009).

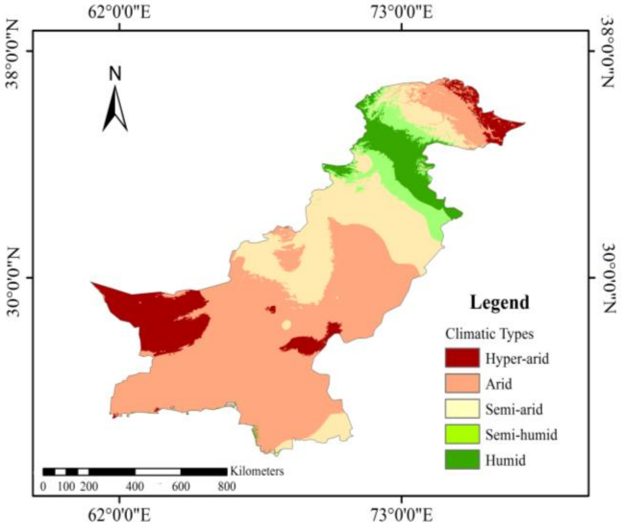

Fig. 1. Spatial distribution of different climatic zones in Pakistan.

Table 1. Climatic zone classification and its proportion in Pakistan.

Climatic zones	Areas/km^2	Ratio
Hyper-arid	95067.43	10.80
Arid	475689.26	54.04
Semi-arid	203954.85	23.17
Semi-humid	51406.83	5.84
Humid	54135.63	6.15
Total	880254	100

The ridge is generally used as a surface to collect rainwater and the crops are usually planted in the furrow where rainwater is collected and stored in the soil around root system (Fig. 2) (Mo *et al*., 2016; Wang *et al*., 2016). Our previous studies showed that this tillage system had a great potential to increase grain production and WUE in dry areas of developing countries in which smallholder farmers consist of major population (Mo *et al*., 2016; Wang *et al*., 2016). Currently, the RFM farming technology has been extended in a large area of semiarid Loess Plateau of China, particularly in Gansu Province. The design of this technology regarding staple food crops such as maize and wheat can be seen in the schematic diagram (Fig. 2). Generally, mulching materials consist of transparent film (polyethylene film with the thickness of 0.008 mm), black film and crop or grass straw etc. In addition, the sizes of ridge and furrow and their ratios can be modified according to local rainfall amount, thermal condition and soil characteristics. They also varied from geographic locations, crop types and genotypes. In general, the distances between two rows are alternatively 60 cm and 30 cm respectively (Fig. 2). The large ridge (60 cm wide and 10 cm high) was alternated with the small ridge (30 cm wide and 15 cm high). In semiarid Loess Plateau of China including Gansu, transparent plastic film has been commonly used in the RFM farming system.

Farming system of ridge and furrow mulching (RFM) with plastic film

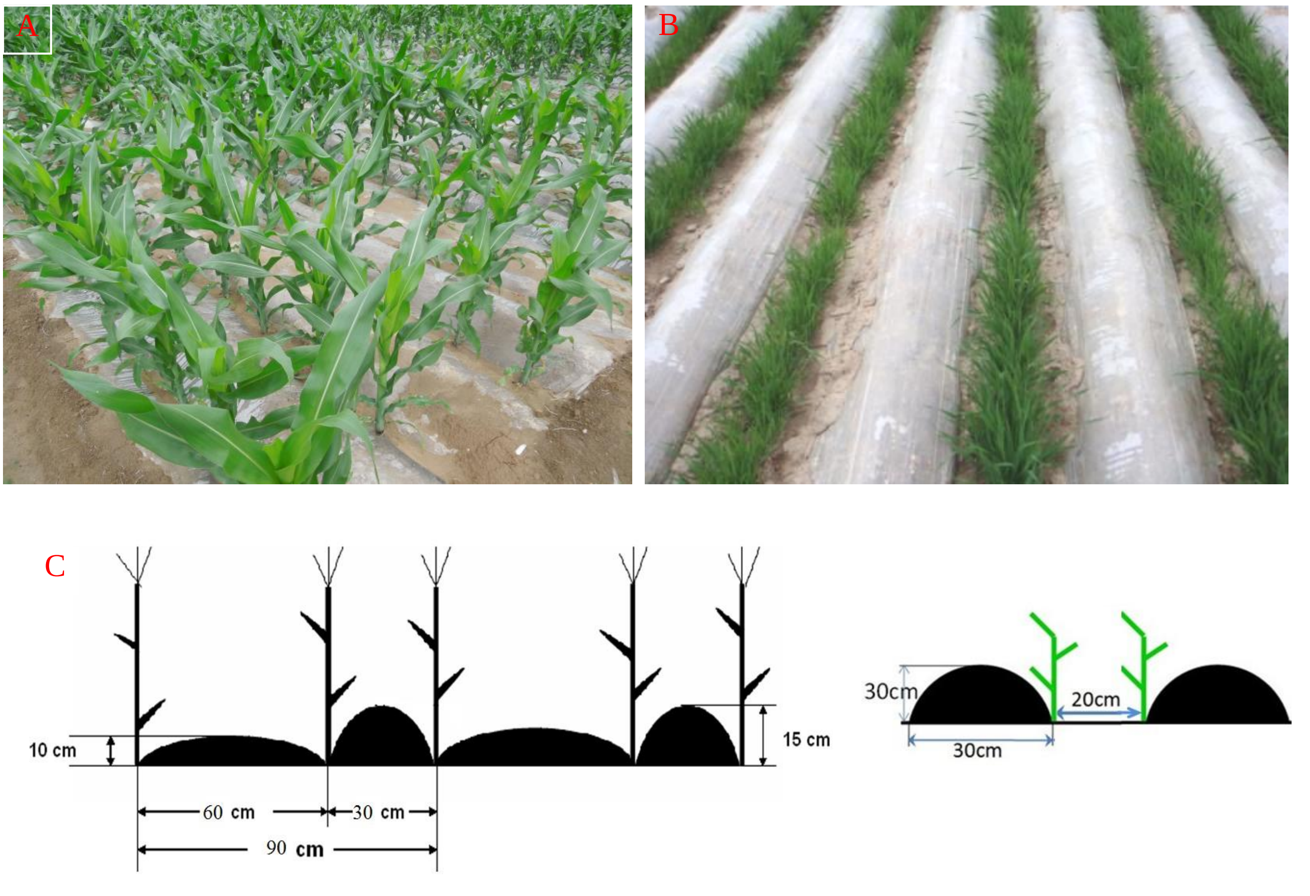

Fig. 2. Farming system of ridge and furrow mulching (RFM) with plastic film in maize (A and C) and wheat (B and D). (Field photos were taken in the experimental site of Sargodha, Pakistan by the research group of Lanzhou University, China in 2015).

Semiarid Pakistan mainly falls intosubtropical monsoon climate zone. This area is generally hot and dry, with an average annual rainfall of less than 550 mm (Fig. 3). It is mainly allocated at northwest Pakistan and some parts are in the middle of Pakistan. In terms of air temperature, June and July are the hottest months of the year, in which extreme high temperature at noon is frequently over 40℃. In the provinces of Sindh and Baluchistan, extremely temperature can reach up to 50℃ or higher. In contrast, northeast mountain areas are frequently cool, with the altitude of more than 2000 m. The difference in air temperature between day and night is probably up to 14℃. The lowest temperature season is from December to February. In general, there are two growing seasons, i.e., long rainy season from April to September, and short rainy season from October to next February. Considering the thermal condition, there is a great potential to extend the RFM farming system in semiarid Pakistan.

In semiarid Pakistan, small farmers occupy majority of total population. Due to the lack of capital availability, they have low adoption rate to those expensive technical innovations in developing countries (Mati *et al*., 2011). In principle, any innovative technologies introduced must be economical, easy-operated and efficient, i.e., 3 "E" standard; otherwise it would be impossible to extend the technologies. Major investment categories of the RFM system introduction mainly include labor cost and commercial plastic sheet purchase. According to current regular price of plastic sheets, each roll of sheet is sold by 180 USD per ha, a relatively low price affordable for local farmers. Also, the RFM cultivation technology is easy-operated. Most of farmers can learn it quickly due to its technical simplicity, including ridges and furrows making, and plastic sheet mulching at field scale. Therefore, the three "E" standard can be adopted widely in semiarid Pakistan.

In term of output benefits, we calculated the average grain yield per unit area in wheat and maize in semiarid rainfed agricultural areas of China and Pakistan (Fig. 4). This is mainly to make a preliminary assessment on the potential of micro-field rainfed farming system in Pakistan. According to multiple-year rainfall records, Mianwali and Faisalabad are defined as two typical rainfed agricultural areas in Pakistan. The data was extracted from local public yearbook of agricultural development. Conventionally, local cultivation technology is mainly dominated by flat planting in semiarid Pakistan. In comparison with the RFM planting technology, flat planting technology showed obviously low rainwater collection and storage efficiencies. We chose the yield data from 2011-2012 for maize and wheat and made a comparison between semiarid Pakistan and Gansu Province of China. In semiarid Pakistan, Mianwali and Faisalabad were typical semiarid areas according to their annual precipitation level. In this study, we chose both sites as the data resource to reflect the general yield level of semiarid Pakistan. During the period from 2011 to 2012, the RFM farming system had been already extended throughout Gansu Province of northwest China. The yield data to some extent reflected local overall level of crop production. The data indicated that average grain yield in either maize or wheat was obviously greater in Gansu of China than that of semiarid Pakistan. The magnitude of increasing yield was 22.9% and 41% in wheat and maize respectively (Fig. 4), showing a great potential to extend such a farming system in Pakistan.

Opportunities and challenges; Micro-field rain-harvesting farming system can significantly increase field productivity and WUE in staple food crops such as maize and wheat, and lead to relatively high economic income (Mo *et al*., 2016; Wang *et al*., 2016). The introduction of RFM farming system to semiarid Pakistan has faced fine opportunities and somewhat challenges. It can decrease soil temperature in cool early spring, and prevent on-site evaporation of soil water. Existing studies showed that the RFM system can inhibit the emergency of on-field weeds and insect pests (black plastic mulching as the best), which therefore saved a lot of workforce input and avoided the usage of pesticide. Also, this system showed fine potential to extend at large scale due to its operational simplicity. On the other hand, available land area consist of 30% total land area in Pakistan, and per capita arable land is about 2 times that of China. Almost 80% of the cultivated lands are highly dependent on irrigation in Pakistan. While there exist relatively perfect irrigation systems in Pakistan, average WUE of crop appears to be somewhat low in terms of total water consumption. In this case, the development of rainfed agriculture without irrigation proves to have critical importance and great potential in Pakistan.

In the Loess Plateau of China, the RFM farming system has been explored and widely used as a micro-rainwater harvesting practice. Many studies has proved that the RFM system has led to massive increases in soil water availability. Compared with the Loess Plateau, semiarid Pakistan is endowed with suitable climatic conditions for developing rainfed agriculture. Considering the mechanism implications, the most outstanding effect of mulching is to reduce evaporation and inhibit soil and water erosion (Kertesz and Loczy, 1996; Ren *et al*., 2009), and enhance the infiltration of rainwater into soil (Ramakrishna *et al*., 2006; Ghosh *et al*., 2006). Technically, the ridges can collect and reallocate rainwater into the furrows with the aim to minimize surface water runoff, thereby improving soil water status in the root zones of crops planted in the furrows. As mentioned above, there are two growing seasons in one year in Pakistan, including long and short rainy seasons (Ali *et al*., 2017). In a long run, crop growth is frequently exposed to periodical drought stress. The RFM system can provide necessary soil moisture conditions to benefit crop growth. On the other hand, high temperatures can negatively affect vegetative growth and seed abortion. The cooling effect at reproductive stage under ridge-furrow mulching system can alleviate the influence of hot stress on plant growth. However, in those areas with average temperature of over 30℃, plastic mulching may aggravate the negative effect of hot stress on crop production. We need to admit the disadvantages of the RFM system in this review.

Finally, soil organic carbon plays an important role in soil quality development. Our previous studies showed that the RFM farming system led to a pronounced increase in soil organic carbon (Mo *et al*., 2016; Wang *et al*., 2016). Soil carbon sequestration of agroecosystems is a critical issue to establish sustainable agroecosystems (Srinivasarao *et al*., 2012). Global soil carbon pool (2500Gt) is the biggest C storage in the terrestrial ecosystem, and the soil C pool is 3.3 times the size of the atmospheric pool (760Gt) (Lal, 2004). Actually, soil carbon sequestration is a critical strategy to achieve food security through improving soil quality (Lal, 2004). Returning higher amounts of crop residue to soil would play an increasingly positive effect on soil carbon content (Rasmussen *et al*., 1998). As for the RFM farming system, increased biomass production can bring about more residue returning to soil, and therefore potentially contribute to soil carbon pool in semiarid areas.

Potential of RFM farming technology in semiarid Pakistan

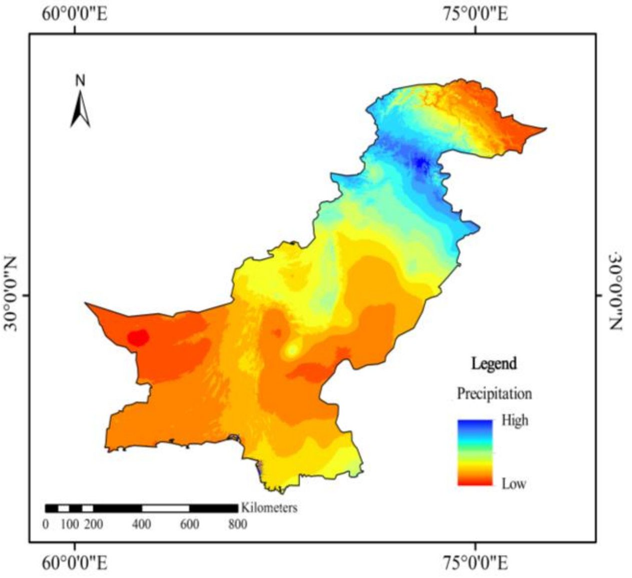

Fig. 3. Pakistan rainfall distribution map.

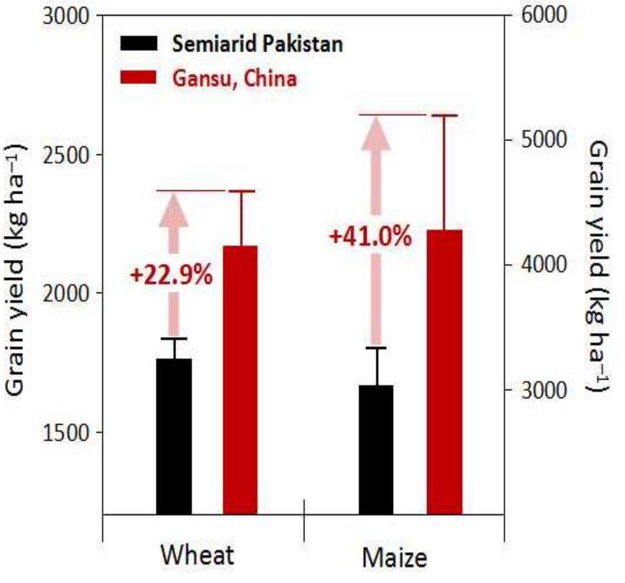

Fig. 4. Comparisons on average grain yields of wheat and maize in typical rainfed agricultural areas between semiarid Pakistan (taking Mianwali and Faisalabad as examples) and northwest China (i.e. Gansu).

Conclusion and perspectives: Low and unstable agricultural productivity is a tremendous challenge due to increasing population and widespread poverty under climate change in global semiarid areas, including Pakistan. Smallholder-based rainfed farming system is principal form of crop production in this area. In terms of technology innovation, on-field rainwater harvesting system may provide a promising solution to boost local crop production and agricultural system sustainability. In recent years, the RFM farming system has been deeply explored and widely extended in semiarid Loess Plateau, especially in Gansu province with similar climate condition to semiarid Pakistan. This system has contributed to huge enhancement in crop productivity and rainwater use efficiency. Local smallholder farmers benefited from the system, achieving significant improvement in livelihood and agro-pastoral development. However, whether this system is effective and feasible in semiarid Pakistan still remains an unanswered fundamental question. In present paper, we summarize the latest progress of this farming system and discuss its perspectives. We also discuss the similarity of social and environmental conditions between semiarid Pakistan and northwest China. It can be argued that the RFM system is suitable for agricultural production and ecosystem conservation in semiarid Pakistan.

For the introduction of RFM farming system to semiarid Pakistan, our research group has completed two growing seasons of field experiments in Sargodha (the data would be published in near future). Preliminary study has confirmed the suitability and reliability of this farming system in Pakistan. The RFM system was found to improve soil water availability and ecological hydrological process by preventing evaporation and retarding water loss. Therefore, it can act as a promising approach to increase crop productivity, and hence cope with food security and improve small household farmers' livelihood in semiarid Pakistan. However, the introduction of RFM system to Pakistan requires the joint efforts from Pakistani and Chinese colleagues, which would experience a long process from field experiment, technology exploration, technology demonstration to large-scale extension. It is convinced that the introduction of this farming technology may lead to increased food and forage production in Pakistan and provides promising strategies to cope with climate change.

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