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Mulching improves yield and water-use efficiency of potato cropping in China: A meta-analysis

Qiang Li[a,b], Hongbing Li[a,b], Li Zhang[a,b], Suiqi Zhang[a,b,*], Yinglong Chen[a,b,*]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

China is the world's largest producer of potato (*Solanum tuberosum* L.). Potato productivity in China is limited by water shortage. Mulching applications can effectively modify the plant hydrothermal micro-environment. However, the impacts of mulching on potato yield vary with climatic conditions and field managements. Here, we conducted a meta-analysis to evaluate the effects of plastic mulching and straw mulching on the yield and water-use efficiency (WUE) of potato cropping in China using data obtained from 131 peer-reviewed publications. The results showed that plastic mulching and straw mulching increased potato yield in average by 24.3% and 16.0%, respectively. The effects of mulching on the WUE of potato were also improved by 28.7% (plastic mulching) and 5.6% (straw mulching). At regional scale, plastic mulching performed better in Northeast China and Northwest China, while straw mulching performed better in Southwest China and South China. The yield and WUE of potato in response to mulching were affected by the mean growing season air temperature, water input, soil basic fertility and fertilizer applications. When compared to non-mulching control, the improvements of yield and WUE in potato were higher at mean air temperatures of 15–20 °C than at temperatures below 15 °C or above 20 °C during the growing season for both mulching practices. Increase in potato yield under black film was significantly higher than that under transparent film when air temperature was over 20 °C. Potato yield and WUE increases in mulching treatments were greater in areas with a water input of < 400 mm than in areas with a water input of > 400 mm. The mean effects of mulching on the yield of potato were greater at relatively low (< 100 kg ha^{-1}) or moderate (100–200 kg ha^{-1}) N rates than at high (> 200 kg ha^{-1}) N rates. Similar trends were observed for P and K rates. In conclusion, this meta-analysis demonstrated that mulching increases the yield and WUE of potato in China and that the adoption of mulching practices should be site specific.

1. Introduction

Potato (*Solanum tuberosum* L.) is currently the world's fourth-largest food crop after rice, wheat, and maize. As the world's largest producer of potatoes, China produced 95.6 million metric tons of potatoes in 2014, accounting for 25% of the world’s total production (FAO, 2014). Potato production plays an important role in ensuring food security in China. However, potato yields are limited by water shortage and sub-optimal field managements in some regions of China. Thus, adopting appropriate farming practices is necessary to enhance potato yield and meet the growing food demand in China.

Mulching is an effective method of altering the plant micro-environment to increase crop yield. According to the materials applied, mulching can be broadly divided into three main types: organic mulching (crop straw, leaves, geotextiles, etc.), inorganic mulching (pure plastic film, degradable film, etc.) and mixed mulching (plastic, straw, grass, gravel, etc.) (Kader et al., 2017). Plastic mulching and straw mulching are widely used in potato production in China. Plastic mulching was introduced to China in the 1970s and has since been widely applied, especially in the northern arid and semi-arid areas (Wang et al., 2005, 2009; Zhao et al., 2012). Straw mulching is a convenient mulching method in potato cultivation in regions where straw resources are locally available (Tang et al., 2015).

Mulching practices directly and indirectly exert positive impacts on micro-climates and crop yield. Plastic mulching influences the hydrothermal conditions of the soil by increasing soil temperature and reducing soil water evaporation (Wang et al., 2005). Mulching can protect soil from water erosion and thus reduce soil and water loss in

* Corresponding authors at: State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, China.
E-mail addresses: sqzhang@ms.iswc.ac.cn (S. Zhang), yinglongchen@hotmail.com (Y. Chen).

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arable lands (Prosdocimi et al., 2016). Mulching reduces nitrogen leaching and increases nutrient availability, thereby improving soil quality (Haraguchi et al., 2004). Plastic mulching suppresses weed growth and reduces competition with weeds for water and nutrients (Abouziena et al., 2008). As a result, mulching leads to increases in yield and water-use efficiency (WUE) (Qin et al., 2014; Zhao et al., 2014). Although mulching has many positive effects, it also has some disadvantages. Due to prolonged higher soil temperatures, applying plastic mulch over an entire growing season may reduce crop yield (Wang et al., 2009; Hou et al., 2010). Manual installation and removal of mulch materials is time consuming and labour intensive. In addition, large amounts of plastic film residue adversely affect the environment, soil structure and crop growth (Liu et al., 2014).

Field experiments are generally conducted in a single area and thus cannot evaluate the comprehensive effect of mulching on macro-scale areas. Meta-analysis is an integrated statistical method to synthesize the results of independent experiments and quantitatively evaluate treatment effects at regional or global scales (Hedges et al., 1999). In recent years, several review papers reported the effects of mulching practices on yield and WUE of particular crop species. For example, soil mulching contributed to as high as 20% and 60% of grain yield of wheat and maize, respectively (Qin et al., 2015). A study of Wang and Shangguan (Wang and Shangguan, 2015) found that on the Loess Plateau of China, plastic mulching performed better than straw mulching in improving wheat yield and WUE regardless no difference in evapotranspiration (ET).

As one of the main food crops in China, potato is widely planted under various mulching practices. However, the effects of mulching practices often differ and are in some cases contradictory in the literature, since the effects may be influenced by different climatic conditions, soil characteristics, crop species, and field managements (Belanger et al., 2000). Thus, *meta*-analysis based on peer-reviewed literature provides a useful tool to evaluate the effects of mulching practices on potato yield and WUE. The objectives of our study were (1) to quantify the effects of two major mulching practices (plastic and straw mulching) on the yield and WUE of potato in China, and (2) to investigate how the effects of mulching vary with respect to location, temperature, water input and fertilizer applications.

2. Materials and methods

2.1. Data collection

A search of the peer-reviewed published papers was performed to collect data on the effects of mulching on potato yield and WUE in China up to December 2017. Data published in English were collected from the ISI-Web of Science (http://apps.webofknowledge.com/) and Google Scholar (Google Inc., Mountain View, CA, USA), and data published in Chinese were collected from the China National Knowledge Infrastructure (http://www.cnki.net/). Data collections were restricted to field experimental studies containing at least one of the two major mulching practices (i.e. plastic and/or straw mulching) and no-mulching control. A study was included if it contained available data on potato yield and/or WUE. Based on these criteria, 131 publications (15 in English and 116 in Chinese) containing 634 side-by-side comparisons (360 for yield, 137 for WUE and ET respectively) were compiled into the dataset. As not all studies reported potato yields along with WUE and ET, the numbers of comparisons for yield, WUE and ET were not equal. Detailed information on the included publications is listed in Appendix A.

According to diverse geographic, climatic conditions and natural cultivated regions of potato in China (Zongfan et al., 1989; Zhao et al., 2016; Xu et al., 2017), the study areas were grouped into seven geographic regions: North-central China, Northeast China, Northwest China, Qinghai and Tibet, The Middle and Lower reaches of Yangtze River, Southwest China and South China. 1) Northwest China: This area accounts for 36% of China's total potato acreage. The potatoes produced in this area are mainly used for seed potatoes, direct consumption and processing. Potatoes in this zone are usually planted in late April to early May and harvested from September through October. This zone includes Inner Mongolia, Gansu, Xinjiang, Ningxia and Shaanxi provinces. 2) North-central China: This area accounts for 6% of China's total potato acreage. The potatoes produced in this area are mainly used for processing and direct consumption. Potatoes in this zone are usually planted in May and harvested from September through October. This zone includes Hebei, Beijing, Tianjin, Shanxi, Shandong and Henan provinces. 3) Northeast China: This area accounts for 8% of China's total potato acreage. The potatoes produced in this area are mainly used for processing and direct consumption. Potatoes in this zone are usually planted in May and harvested in September. This zone includes Heilongjiang, Jilin and Liaoning provinces. 4) Qinghai and Tibet: This area accounts for 2% of China's total potato acreage. The potatoes produced in this area are mainly used for processing and direct consumption. Potatoes in this zone are usually planted in May and harvested in September. 5) Southwest China: This area accounts for 35% of China's total potato acreage. The potatoes produced in this area are mainly used for processing and direct consumption. Potatoes in this zone are usually planted in September through November and harvested from February through April. This zone includes Guizhou, Yunnan, Chongqing and Sichuan provinces. 6) The Middle and Lower reaches of Yangtze River: This area accounts for 8% of total acreage. Spring potatoes are planted in February through March and harvested during May or June. Autumn potatoes are planted in July-August and harvested in October-November. The potatoes produced in this area are mainly for export and direct consumption. This zone includes Jiangxi, Jiangsu, Zhejiang, Anhui, Hunan and Hubei provinces. 7) South China: This area accounts for 5% of total acreage. Potatoes in this zone are planted in October–November and harvested in February–March. The potatoes produced in this area are mainly for export and direct consumption. This zone includes Guangdong, Fujian, Guangxi, and Hainan provinces. Some general climatic information and crop system of each potato-cultivating region is shown in Table 1 (Zongfan et al., 1989; Cui et al.,

Table 1
General climate information of experimental sites in potato-cultivating regions and common cropping systems.

Region	Annual mean temperature (°C)	Accumulated temperature above 10 °C (°C)	Annual sunshine time (hour)	Annual mean precipitation (mm)	Cropping system
Northeast China	−4 to 12	1600–3800	2200–2900	400–1000	Single cropping
North-central China	6–15	3000–5000	2000–2800	400–1000	Single or double cropping
Northwest China	−4 to 14	2500–5000	2000–3300	50–800	Single cropping
Qinghai and Tibet	−4 to 8	500–2100	3000–4000	50–1000	Single cropping
The Middle and Lower reaches of Yangtze River	10–18	4500–6000	1100–2500	800–1750	Double cropping
South China	18–24	6500–9500	1200–2500	1000–2500	Double cropping
Southwest China	−4 to 20	2000–8000	900–2500	500–1500	Single or double cropping