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Distribution characteristics of residual film over a cotton field under long-term film mulching and drip irrigation in an oasis agroecosystem

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ABSTRACT

Without an efficient mulch film recovery, the residual plastic film (RPF) causes pollution hazards to agronomic systems and natural environments. Here, we examined the distribution characteristics of RPF in the topsoils (0–40 cm) in an oasis agroecosystem in Northwest China. After cotton harvest in 2016, we collected 2304 soil samples from six cotton fields with different years of continuous mulching management (5, 9, 11, 13, 15 and 19 a). A total of 2471 pieces of RPF were separated and weighted. The weight of each RPF fragment was calibrated by its size measured in digital images. Our results showed that the amount of RPF ranged from 121.85 to 352.38 kg ha^{-1} across the six fields, remarkably exceeding the national standard of China (75 kg ha^{-1}). The occurrence frequency of RPF fragments maximized at 5–15 cm depth. With the increase in soil depth, RPF fragments became smaller, and their total mass decreased linearly. After the constant mulching practice, RPF accumulated at an annual rate of 15.69 kg ha^{-1}, mainly occurring at 0–30 cm depth. The accumulation of the larger RPF fragments (> 25 mg per piece) primarily took place from 5 to 15 years after mulching started. It took over 15 years for the larger RPF fragments to degrade into smaller ones (< 25 mg per piece), which accounted for 65% of the total number of RPF fragments in the field with 19-year of mulching. RPF fragments with a weight larger than 100 mg mostly concentrated at the surface (0–10 cm), whereas, the other smaller RPF fragments showed an evident downward migration. That said, with the constant mulching management, RPF pieces became more fragmented and distributed deeper, making mulch film recovery more challenging. To the best of our knowledge, this is the first time that the dynamics of RPF distribution in the soil profile after long-term mulching have been characterized. If the current mulching method continues, the accumulated RPF is going to cause severe soil pollution and risk the sustainability of the oasis agroecosystem.

1. Introduction

Since the 1950s, plastic film mulching has been widely used in modern agriculture to improve crop production and fruit quality around the world (Kasirajan and Ngouajio, 2012; Lament, 1993; Lamont, 2005). In China, the use of the plastic mulching film in agriculture has increased dramatically in the past 30 years, with the amount of usage surging from 6000 tons in 1982 to 1.2 million tons in 2011 (Bu et al., 2013; Liu et al., 2014; Yan et al., 2014). Plastic film mulching has been proved efficient in increasing surface soil temperature (Tripathi and Katiyar, 1984), conserving soil moisture (Enrique et al., 1999), preventing soil degradation (Wan and El-Swaify, 1999), improving fertilizer-use efficiency (Marinari et al., 2015), and controlling weed growth (Erenstein, 2002), all of which promote the development and yield of crops (Li et al., 2013; O'Loughlin et al., 2017). For instance, under the condition of film planting, grain and cash crop yield can increase up to 35% and 60% in China, respectively (Liu et al., 2014). The mulching film practice has, therefore, become particularly crucial in Northwest China, where drought and water deficiency are the primary limiting factors of agriculture (Huo et al., 2017; Liu et al., 2016).

However, the plastic films used in China are hardly degradable, difficult to recycle, and persist as small segments in topsoils after harvest (Yan et al., 2014). The residual plastic film (RPF) has significantly impacted soil properties and caused detrimental pollution problems (Liu et al., 2014). For example, RPF decreases soil porosity and impedes subsurface water movement (Li et al., 2013; Niu et al., 2016), further

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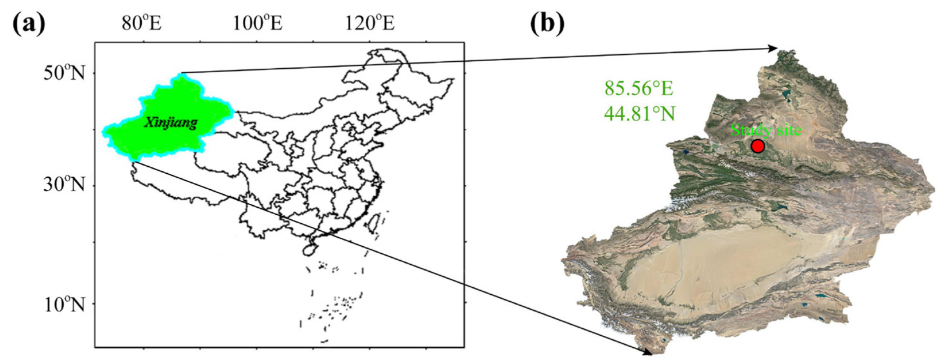

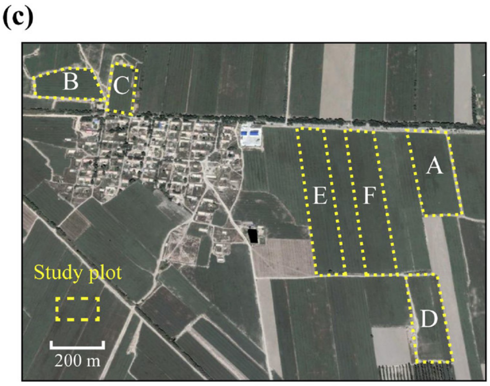

(d)

Study plot	Mulching start year	Total years of mulching practice	Area (ha)
A	1998	19	13.33
B	2002	15	13.33
C	2004	13	9.87
D	2006	11	11.87
E	2008	9	15.80
F	2012	5	15.80

Fig. 1. Field experiments were conducted in an oasis agroecosystem in Xinjiang, located in the Northwest of China (a), which is characterized by an arid desert climate and a large agricultural irrigation demand (b). Residual plastic film (RPF) was collected from six cotton fields (85.56 °E, 44.81 °N) near the city of Shihezi, where drip irrigation under the mulch film was practiced for a long term (c). (d) The start year of mulching practice, total years of mulching practice to the experiment date, and the size of the selected cotton fields.

impairing the absorption of water and nutrients of crops from the rhizosphere (Jiang et al., 2017; Yan et al., 2006). Besides, RPF inhibits the activity of soil enzymes and the biodiversity of microbial community (Bu et al., 2013; Wang et al., 2016), and thus dampens soil fertility (Cuello et al., 2015). Additional negative effects of RPF on agriculture include restraining seed germination and seedling growth (Wang, 1998), influencing root morphology and growth (Dong et al., 2015), reducing crop yield and fruit quality (Liu et al., 2014), enhancing greenhouse gas emission (Cuello et al., 2015; Kim et al., 2017), and risking food security due to the absorption of pesticides (Nerín et al., 1996; Yang et al., 2005). Furthermore, recent pot experiments in the greenhouse demonstrated the negative impacts of the accumulated RPF on plant height, stem diameter, and fruit quality and yield (Zou et al., 2017). Therefore, without an efficient mulch film recovery, the 'white revolution' which was envisioned to advance agriculture science and technology is turning into the 'white pollution' (Kyrikou and Briassoulis, 2007; Liu et al., 2014). To combat the white pollution, some efforts have been pursued to improve the recycling machinery to increase the efficiency of mulch film recovery (e.g., Bertone, 2000; Guo et al., 2017; Llop and Pérez, 1992). Also, biodegradable and photodegradable plastic films have been tested and adopted as an alternative to the plastic film in the mulching practice to mitigate the pollution hazards to the soil environment (e.g., Briassoulis et al., 2015; Kasirajan and Ngouajio, 2012; Kijchavengkul et al., 2008; Moreno and Moreno, 2008; Zhao et al., 2005). Nonetheless, the cost of the biodegradable and photodegradable plastic films holds back their large-scale application in China.

Despite the adverse effects on soil environment and food security, the global usage of plastic film is predicted to increase from 4.4 million tons in 2012 to 7.4 million tons in 2019 (Sintim and Flury, 2017). Such a constantly growing trend in the total area with the plastic film is also true in China, especially Northwest China (Zhang et al., 2016). Some studies have examined the soil contamination problems caused by RPF in Northwest China. For example, Zhang et al. (2016) investigated the status of the mulch film residue across Xinjiang (one of the primary regions under mulch film management in China) and suggested that among the various crops studied, the cotton fields had the highest amount of RPF. They indicated that crop species and the thickness and mulching time of the film jointly determined the amount of RPF. In another study, Dong et al. (2015) established a gradient of RPF density (i.e., 0, 250, 500, 1000, 1500, 2000 kg ha^{-1}) to quantify the effects of RPF on cotton yield and soil properties. According to their prediction, after 120-year of mulching cultivation, the cumulative reduction in the yield caused by RPF was even more significant than the cumulative yield increase due to the constant mulching management. Nevertheless, the gradient of the RPF studied in Dong et al. (2015) might not represent the typical status in Northwest China as reported in Zhang et al. (2016). Most recently, Jiang et al. (2017) signified the substantial influence of RPF on soil properties and soil water distribution in the Minqin Oasis, Northwest China. Their results showed that the presence of RPF decreased the correspondence between flow pathways and the maize root zone, and, therefore, limited the water use efficiency. Results of Zou et al. (2017) demonstrated that once RPF was more than 80 kg ha^{-1}, tomato yield in the greenhouse in Northwest China would undergo a sharp decline. These previous efforts emphasized the importance to investigate the accumulation and distribution of RPF in soils in Northwest China, in particular in the farmlands under the long-term mulching practice, which remains inadequately addressed so far.

In the arid and semi-arid environments, plastic film mulching can be carried out together with drip irrigation to maximize water use efficiency (Rashidi and Seyfi, 2007). The combination of film mulching and drip irrigation has been applied to vegetable, corn, and cotton cultivations in Northwest China and provides a potential solution to balance the needs of the rising agricultural production and the sustainability of the oasis agroecosystem (Li et al., 2004). However, little attention has been paid to the accumulation of RPF in the agroecosystem where mulching is implemented with drip irrigation. Given the most considerable contribution of cotton field to the total amount of mulch residual in Xinjiang (Zhang et al., 2016), we selected six cotton fields with different mulching cultivation years (from 5 to 19 years) in a typical oasis agroecosystem to shed new insights into the distribution characteristics of the residual plastic film under constant film mulching and drip irrigation. The RPF fragments were sampled in the field at different depths and weighted in the laboratory. To our best knowledge, this is