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Suitability of mulching with biodegradable film to moderate soil temperature and moisture and to increase photosynthesis and yield in peanut

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A R T I C L E I N F O

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A B S T R A C T

There is a growing interest in developing suitable biodegradable films for mulching crops to minimize the environmental impacts of polyethylene (PE) film. In order to verify whether biodegradable film can satisfy the changing needs of soil conditions in different seasons of crops, six treatments were conducted including four different ratios of starch/polybutyrate adipate terephthalate (PBAT) biodegradable films mulching, containing 0% (B1), 10% (B2), 15% (B3), and 20% (B4) starch, respectively, and PE film mulching and no mulching. A randomized complete block design with three replications was used to compare their effects on soil temperature and moisture, and peanut yield. The results indicated that soil temperature under the B3 treatment was higher than those under other three biodegradable films for the entire grow season. B3 mulching can warm the soil similar to PE film before 60 days after sowing (DAS), however, lowers soil temperature by about 0.4–1.4 °C after that. Soil moisture of B3 was similar to that under the PE film at 0–40 cm depth at 20 DAS, lower at 40–60 and 120 DAS, however, higher at 80–100 DAS with the infiltration of rains because of biodegradation. With less (B1 and B2) or more starch (B4), the soil temperature and soil water was lower in whole stage than B3. Compared with other treatments, peanuts mulched with B3 maintained higher LAI, chlorophyll content and net photosynthetic rate at late growth stages. The pod yield under B3 was similar, however, economic benefit was a bit lower than that of PE film because of the higher present cost of biodegradable film. Thus, the results revealed that suitable biodegradable film can satisfy the changing needs of soil conditions in different seasons. The findings suggest that creating more suitable biodegradable mulches to meet the changing needs will be a new direction for maximizing the use of biodegradable film and reducing the long-term plastic pollution (i.e., "white pollution").

1. Introduction

Arid and semiarid regions comprise almost 45% of the world's land area, and dryland farming systems are indispensable to food production in the world (Yang et al., 2015). Limited water resources, especially combined with lower soil temperatures during the seeding stage, are the main factors limiting field crop production in these regions (Liu et al., 2009). Use of plastic mulches can reduce soil evaporation, increase soil temperature (Tarara, 2000; Ramakrishna et al., 2006; Gan et al., 2013), improve water use efficiency (WUE) (Fisher, 1995; Mo et al., 2016), and increase plant growth and yield (Dong et al., 2009). Therefore, polyethylene (PE) mulches have been widely used in agriculture for over half a century throughout the world (Lamont, 2005; Kasirajan and Ngouajio, 2012). However, the dramatic increase in use of PE films has focused public attention on the environmental accumulation and pollution problems which could persist for centuries (Lopez et al., 2007; Moreno and Moreno, 2008). More and more PE films residue are left in the soil because of the difficulty for picking up after application, resulting in soil hardness, changes in permeability, and decline in soil fertility (He et al., 2009; Kasirajan and Ngouajio, 2012; Dong et al., 2013). Because biodegradable films can be decomposed by microorganisms, eventually into CO_2 and H_2O (Kapanen et al., 2008; Li et al., 2014), thus, they are desirable alternatives to traditional PE films for use as mulches in agroecosystems (Kyrikou and Briassoulis, 2007; Dintcheva and La Mantia, 2007). However, biodegradation is governed by different factors that include polymer characteristics, type

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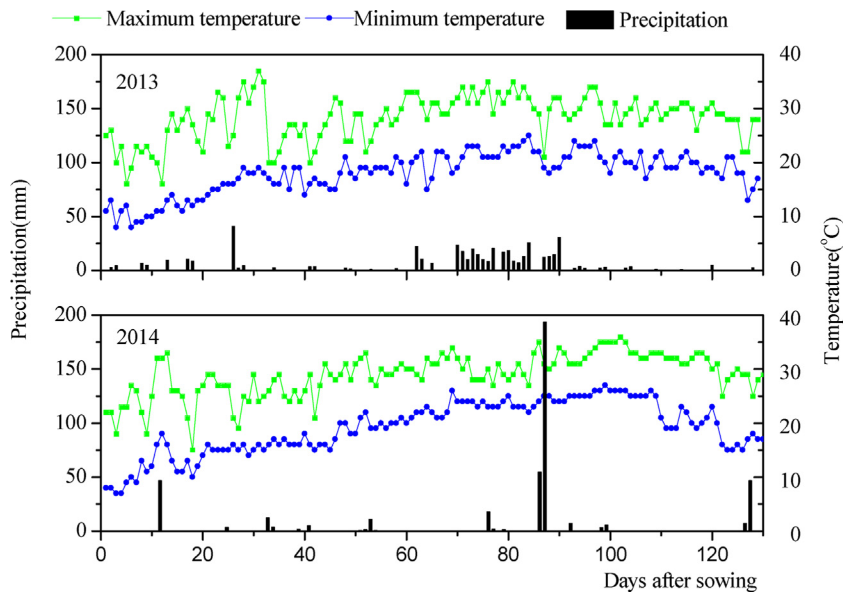

Fig. 1. Daily precipitation and air temperature during the growing period of peanut in 2013 and 2014.

of organisms, and nature of pretreatment (Kasirajan and Ngouajio, 2012).

More important, the suitable soil moisture and temperature for crops is changing in different growing stages. For example, peanut, a mainstay of the livelihoods of millions of farmers in semi-arid regions of the world, is sensitive to drought and heat (Mwale et al., 2007; Koolachart et al., 2013; Rosas-Anderson et al., 2014). However, more than two thirds of the peanut worldwide is grown under rainfed conditions (Liu et al., 2009; Singh et al., 2014). Drought reduced pod yield of 22–53% (Songsri et al., 2008). When peanut was exposed to drought at seed-filling stage, yield reductions were recorded up to 56–85% (Koolachart et al., 2013). Meanwhile, maintaining soil temperatures at specified levels (27–32 °C) is vital to improve growth and pod yield (Sorensen and Wright, 2002; Awal and Ikeda, 2002b, 2003a, 2003b). To control the soil conditions for peanut, film mulching has been a common cultivation practice in the world Since 1970 s (Dong et al., 2009; Zhang et al., 2012). Yet, peanuts exposed to soil temperatures above 35 °C during the reproductive period could cause significant yield losses (Vara Prasad et al., 2000). Using a biodegradable film can get lower soil temperature than that under PE mulches, which could be favorable in areas and seasons characterized by supra-optimal soil high temperatures responsible for damages to the crops; however, using PE may be advantageous in areas with cooler soil conditions (Moreno and Moreno, 2008). In comparison with the use of PE film, average soil temperature under biodegradable mulch can be 2–3 °C lower at 10 cm soil depth in the late stage; however, water storing capacity can also be reduced when the degradation of biodegradable film is faster (Zhao et al., 2011). Review of the available literature shows that research data about biodegradable films specially designed for use on agronomic crops (i.e., peanut) to moderate the soil moisture and temperature regimes is scarce. Thus, it is vital to test whether biodegradable film can satisfy the changing needs of soil conditions in different seasons of crops.

Controllable biodegradations can be achieved from biodegradable films made from a mixture of starch and PBAT (Olivato et al., 2012). Although starch is an excellent raw material having the characteristics of regeneration, cheap, easy to store and transport (Guilbert and Gontard, 2005), films with starch only are fragile and it is necessary to decrease the rigidity by blending with other biodegradable materials (Brandelero et al., 2011). The mixture of hydrophobically modified starch and PBAT, a thermoplastic biodegradable polymer with a slow degradation rate, may produce a high quality biodegradable plastic film (Muller et al., 2001). However, the suitable starch proportion in PBAT-based biomulches for dynamically changing soil conditions to meet the needs of crops is still unknown.

The objectives of this study were to use peanut as a model crop to test whether biodegradable film can satisfy the changing needs of soil conditions in different growing stages of crops. Therefore, we evaluated: (i) the effects of biodegradable films of different capacity for degradation based on four ratios of PBAT/starch on soil temperature and moisture regimes; (ii) influence of changes in soil temperature and moisture regimes on the LAI, chlorophyll content, net photosynthetic rate and yield of peanut; and (iii) the economic benefits under different biodegradable films.

2. Materials and methods

2.1. Experimental area and materials

Field experiments were conducted during 2013 and 2014 at the experimental farm of the Peanut Research Institute of Shandong Province, Laixi, Shandong Province, China. The study area has a warm temperate continental monsoon climate. The mean annual precipitation is approximately 635.8 mm, the mean annual temperature is 11.7 °C, the total annual sunshine is 2656.3 h, the frost-free period is 183 days. The water requirement of peanut is 361–439 mm (Su et al., 2002; Abou Kheira, 2009). Precipitation during the peanut-growing periods amounted to 494.6 mm in 2013 and 422.7 mm in 2014 (Fig. 1). However, the precipitation distribution was significantly different over the two growing seasons, (e.g., excessive rain fell during 60–90 days after mulching in 2013, whereas most of the rainfall was distributed over 80–90 days in 2014). During 2013, the high temperature ranged between 21 and 36 °C and the low between 15 and 25 °C. During 2014, the high temperature ranged between 16 and 37 °C and the low between 8 and 25 °C.

Predominant soil at the experimental site is a silt loam with sand 73.9%, silt 21.8% and clay 4.3%. The properties at the 0–20 cm depth prior to experiment in 2013 were: pH 5.3, soil bulk density of 1.36 g cm^{-3}, soil organic matter 14.9 g kg^{-1}, available N 45.7 mg kg^{-1}, available P 124.0 mg kg^{-1}, and exchangeable K 147.3 mg kg^{-1}. Soil gravimetric moisture contents at wilting point and field capacity were determined to be 3.52% and 23.77%, respectively, using the pressure plate method.

The peanut variety "huayu 22", provided by the Shandong Peanut