Biodegradable plastic mulch films in agriculture: feasibility and challenges

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1. Introduction

Plastic film mulching plays an important role in agriculture owing to its ability to improve grain crop yields and water use efficiency (WUE) by maintaining soil moisture, suppressing weeds and increasing soil temperature (Sun et al 2020). China has the largest plastic film mulching system in the world (Yang et al 2015). The amount used and the area treated with polyethylene plastic film (PE) has increased steadily to 1.4 million cubic tons or more than 17.8 million hectares in 2018, equivalent to about 15% of the total cropland in China (National Bureau of Statistics of China 2019). Despite the benefits of plastic film mulch technology, it has also resulted in a number of pollution hazards (Kasirajan and Ngouajio 2012). As a result, perceptions of the application of plastic film mulch technology are evolving from considering it a ‘white revolution’ to ‘white pollution’ (Liu et al 2014). To overcome negative environmental problems caused by persistent plastic waste from PE, biodegradable plastic mulches (BDMs) have been developed as a promising alternative to PE films, providing a sustainable and environmentally friendly solution for agricultural activities.

The impact of BDMs on crop productivity and ecological safety remains unknown. However, this information is necessary to formulate policies and the large-scale promotion and application of BDMs. Here, we summarized the current scientific evidence from the evaluation of crop production nationwide. We performed a meta-analysis on available data to assess the contribution of BDMs to yield improvement throughout China and provided a comprehensive analysis of the research undertaken to date (supplementary table S1 and supplementary figure 1, which are available online at stacks.iop.org/ERL/16/011004/mmedia). Our goal was to contribute to the evaluation of BDMs and to answer whether they can be considered a substitute for PE in the future.

2. Feasibility

Overall, BDMs can improve crop yields and WUE. Compared with no mulching (NM) treatments, BDMs treatments increased maize, wheat, cotton and potato yields by 26%, 24%, 26% and 18%, respectively (figure 1). However, there was no significant difference in the effects of BDMs and PE on maize, wheat or cotton yields. These results collectively show that BDMs treatments can meet the requirements of increasing crop yields relative to those under NM treatments.

Increasing crop WUE is an important way to address the shortage of agricultural water resources. Plastic film mulching technology has remarkably improved WUE in China. In comparison with NM, under PE treatment, the WUE of maize, wheat, cotton and potato increased by 25%, 20%, 20% and 19%, respectively, and under BDMs treatment, the WUE increased by 24%, 23%, 15% and 20%, respectively (figure 1). Similar to the yield trend, the use of BDMs can effectively increase WUE. There was no significant difference in the WUE between the BDM- and PE-treated plots.

The use of mulching technology could effectively increase crop yield in dry climates. Crop yield increased by 28.4% under PE and by 28.2% under BDMs compared to that under NM (figure 2). However, crop yields only increased by 17.4% and 16.0% under PE and BDMs, respectively, in humid
Figure 1. Comparison of crop yield (a), WUE (b) and soil temperature (c) as a result of different types of plastic filming mulching as compared to no mulching (NM). BDMs: biodegradable plastic mulches; PE: polyethylene plastic film; Overall: average of the entire data set; WUE: water use efficiency. Error bars represent 95% confidence intervals. The letter ‘n’ indicates the number of observations.

regions. These findings indicated that the amount of film mulching used should be reduced according to local climatic conditions in humid climates, thereby reducing the risk of residual film pollution. To help address future crop production challenges, we suggest that BDMs can provide agronomic benefits in water-stressed regions.

Film mulching can also increase soil temperature in winter and early spring. In northern China, low air and soil temperatures usually delay seed germination and dry matter accumulation in the main crops, such as maize and wheat. In comparison with NM, PE can increase the soil surface temperature by 2.8 °C (figure 1). In comparison with NM, BDMs significantly increased soil temperature. However, the soil temperature of BDMs is 0.9 °C lower than that of PE. Besides, yield improvement did not increase between BDMs and PE, which may imply that the effect of mulching on soil temperature had less of an impact than water on yield increase.

Different companies use different degradation materials to produce BDMs with different functional properties (Kasirajan and Ngouajio 2012). In general, the functional properties of various BDMs are quite different (supplementary table S2). There are two main reasons: first, properties can be determined by the characteristics of the BDMs; second, properties can be determined by the different formulations and additives of various companies. Most BDMs satisfied the requested functional properties and led to agronomic performance as high as PE. Biodegradable polymer blends performed better than a single polymer. However, the water vapour permeability of all BDMs was significantly higher than that of PE. This result is predictable because most bio-based polymers are hydrophilic, and this property of BDMs in turn will affect crop growth in arid areas.

The ecological safety of BDMs can be evaluated by ecotoxicity tests. The ecotoxicity tests for different types of BDMs are reviewed in supplementary table S3. Overall, different types of biodegradable materials, including poly(butylene adipate-co-terephthalate) (PBAT), polylactic acid (PLA), and starch-based materials, displayed no toxicity in different ecotoxicity tests and no threat to ecological safety. However, the current research on ecological safety is based mainly on short-term ecotoxicity tests (i.e. acute responses), and there is still a lack of evidence concerning their performance in the long term (Henry and Markus 2017). In fact, the potential eco-toxicity of biodegradable plastic may stem from not only polymers and the compounds released from polymers during the biodegradation process but also additives such as plasticizers, heat stabilizers, and antioxidants (Sforzini et al 2016). The amount of additives is usually too small to cause differences in tests of acute responses, but these may accumulate as a result of long-term applications. Long-term toxicity tests are necessary to determine the ecological safety of BDMs fully.

3. Challenges

3.1. Develop and enforce production standards for biodegradable films

Since different types of degradable materials can be made into biodegradable films, there are noticeable differences among products. We need to develop universal standards that are more conducive to the
application and promotion of biodegradable membranes. Due to insufficient tensile strength characteristics of biodegradable polymers, some BDMs were not conducive to mechanized mulching in agricultural production. In addition, due to the need to increase the function of the film, it is necessary to add additives to the BDMs production process. Since some additives may pose a hazard to soil ecology and crops, we need to reduce the hazards of additives. Therefore, production standards should fully consider functional properties, ecological safety, crop adaptability, etc. The final degradable film product is not only suitable for crop growth but also has no impact on the environment.

3.2. Develop new testing and evaluation systems for the biodegradation of plastic film mulch

The testing and evaluation of BDMs biodegradation are now mainly tested in the laboratory. In laboratory testing, we must not only strengthen the detection of the degradable properties of BDMs but also pay attention to enhancing the analysis of the additives of different BDMs. Hazardous additives will affect the agricultural soil environment and thus damage crop growth. Therefore, passing the necessary laboratory test does not indicate that a BDM has good adaptability and availability in complex and diverse ecosystems. Although laboratory evaluations provide good insight into the potential of BDMs for mechanical laying, direct field evaluation is essential. The standard of biodegradation in the soil must include a reasonable testing range of temperature and soil moisture, soil types and crop, and associated microbial communities (Marion et al. 2017). In situ testing should be performed under selected field conditions based on typical soil types, farming systems, and crops. Therefore, the development of new evaluation systems could clarify the uncertainty of soil pollution caused by the long-term use of BDMs, providing the necessary guidance for agricultural production.

3.3. Improve crop adaptability and regional suitability of biodegradable mulch films

The main effects of plastic film mulching are soil warming, moisture conservation and weed prevention. To achieve these functions, BDMs should contain suitable degradation characteristics, a reasonable start-up period and a degradation rate for crop growth. Currently, most BDMs are ruptured and degraded prematurely, and the coverage time is shorter than the safe period of crop mulching, which leads to losing the biological benefits of mulching. In addition, BDMs degradation is affected by sunlight, temperature extremes, water, wind, etc. Due to the variation of natural environments in different regions, BDMs degradation times and degrees are also different. Therefore, we suggest developing BDMs with high activity and low costs according to local factors, such as soil environment type, light intensity and time, in different regions through formulation improvements, additives (such as carbon black) or thickness enhancements to meet the temperature and water requirements of crop production.
3.4. Reduce the production cost of BDMs and promote large-scale application

The high price of BDMs is one of the factors limiting its large-scale promotion in China. On the one hand, it is necessary to reduce the cost of products through large-scale production and formulation improvements. On the other hand, it is necessary to evaluate the cost of film mulching comprehensively. To increase PE recycling, the mandatory national standard of ‘Polyethylene Blown Agricultural Floor Covering Film’ (GB 13735–2017) was officially implemented on 1 May 2018. This mandatory national standard stipulates that film thickness must exceed 0.01 mm, which is more conducive to recycling the film. Due to the increased thickness of PE that is required, the price of PE has also increased. The increase in the costs of PE may encourage farmers to choose BDMs.

4. Conclusions and future perspectives

BDMs improved crop yield and WUE by 20%–25% and 12%–23%, respectively, and there is no significant difference between BDMs and PE. PBAT, PLA, and starch-based materials show no toxicity on short-term ecotoxicity tests (i.e. acute response). In addition, BDMs incorporation into the soil can result in enhanced microbial activity and enrichment of fungal taxa. BDMs has good application prospects in specific crops in some regions, and it can replace PE mulch. However, for large-area applications of biodegradable mulch films, the following measures should be implemented in practice: (a) to establish long-term monitoring and observation networks covering representative soil types, farming systems, and crops; (b) to strengthen the research and development of biomaterials and improve the applicability of biodegradable mulch films; (c) to enforce a standard for biodegradation film production; (d) to develop new testing standards for the biodegradation of plastic film mulch; (e) to establish a biodegradation of plastic film mulch-integrated compensation policy; (f) to establish supporting agronomic techniques and measures according based on the characteristics of mulch products and agricultural production; and (g) to improve the production process of BDMs and reduce production costs. In the future, with further improvements in degradable film production technology and a cost reduction, biodegradable film is expected to replace the PE and address the food security issues environmentally.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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