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Review

Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?

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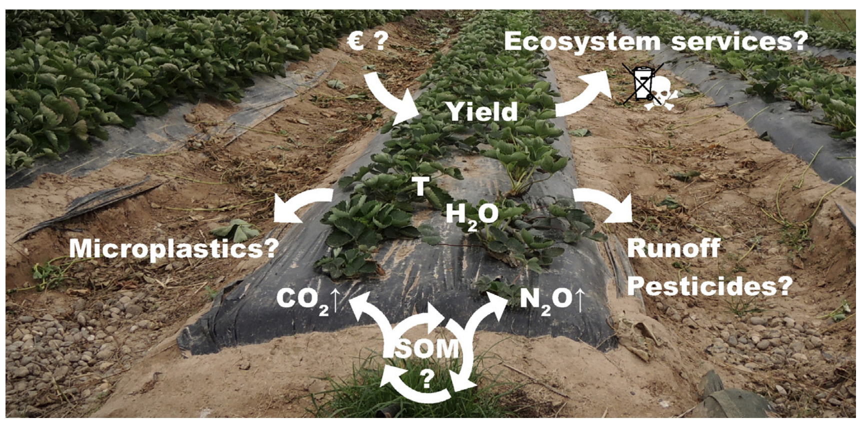
HIGHLIGHTS

- Plastic mulching increases yields, fruit quality and water-use efficiency.
- Potential pollution by plastic mulches: microplastics, phthalates, agrochemicals.
- Plastic mulching may promote soil degradation and soil water repellency.
- Biogeochemical processes in plastic-mulched soils are incompletely understood.
- The impacts of plastic mulching on ecosystem services need further attention.

GRAPHICAL ABSTRACT



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ABSTRACT

Plastic mulching has become a globally applied agricultural practice for its instant economic benefits such as higher yields, earlier harvests, improved fruit quality and increased water-use efficiency. However, knowledge of the sustainability of plastic mulching remains vague in terms of both an environmental and agronomic perspective. This review critically discusses the current understanding of the environmental impact of plastic mulch use by linking knowledge of agricultural benefits and research on the life cycle of plastic mulches with direct and indirect implications for long-term soil quality and ecosystem services. Adverse effects may arise from plastic additives, enhanced pesticide runoff and plastic residues likely to fragment into microplastics but remaining chemically intact and accumulating in soil where they can successively sorb agrochemicals. The quantification of microplastics in soil remains challenging due to the lack of appropriate analytical techniques. The cost and effort of recovering and recycling used mulching films may offset the aforementioned benefits in the long term. However, comparative and long-term agronomic assessments have not yet been conducted. Furthermore, plastic mulches have the potential to alter soil quality by shifting the edaphic biocoenosis (e.g. towards mycotoxigenic fungi), accelerate C/N metabolism eventually depleting soil organic matter stocks, increase soil water repellency and favour the release of greenhouse gases. A substantial process understanding of the

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interactions between the soil microclimate, water supply and biological activity under plastic mulches is still lacking but required to estimate potential risks for long-term soil quality. Currently, farmers mostly base their decision to apply plastic mulches rather on expected short-term benefits than on the consideration of long-term consequences. Future interdisciplinary research should therefore gain a deeper understanding of the incentives for farmers and public perception from both a psychological and economic perspective in order to develop new support strategies for the transition into a more environment-friendly food production.

Contents

1. Introduction

Rapid population growth poses a major challenge for both efficient and sustainable agricultural practices given the limited availability of arable land. In order to meet the increasing food demand (Godfray et al., 2010), plastic mulching has become a widely used technique for its instant economic benefits such as higher yields and improved crop quality (Lamont, 1993). However, after six decades of research (see Kasirajan and Ngouajio, 2012, for an extensive historical review), the knowledge of the sustainability of plastic mulches remains vague in terms of both an environmental and agronomic perspective.

Plastic mulches are primarily used to protect seedlings and shoots through insulation and evaporation prevention, thus maintaining or slightly increasing soil temperature and humidity (Tarara, 2000). Furthermore, the application of plastic covers is known to reduce weed and pest pressure (McKenzie and Duncan, 2001). Often reported benefits are minimisation of the development time for seed and fruit, yield increase, the prevention of soil erosion and weed growth and consequently reduction of herbicide and fertiliser use (Chalker-Scott, 2007; Espí et al., 2006; Lamont, 1993; Scarascia-Mugnozza et al., 2011). These prospects have made plastic films an upcoming technology, nowadays making up by far the largest proportion of covered agricultural surface in Europe (4270 km^2), an area four times larger than that covered by greenhouses and six times that of low tunnels (Scarascia-Mugnozza et al., 2011). While the agricultural surface covered with mulching films remains constant or shows only slightly growing trends throughout the world (5.7% annual growth until 2019) (Transparency Market Research, 2013), the covering rate in China increased dramatically between 1991 and 2004 with a growth rate of 30% per year (Espí et al., 2006). The National Bureau of Statistics of China (2012) reported a four-fold increase of plastic mulch use from 319 to 1245 megatons between 1991 and 2011.

However, the modification of the microclimatic conditions under plastic mulches not only enhances plant productivity but also increases biological degradation of litter and soil organic matter (SOM), which has recently been discussed as a trigger to rapid depletion of soil nutrients in general and carbon stocks in particular (Domagała-Świątkiewicz and Siwek, 2013; Zhang et al., 2015a). This may eventually reduce soil quality, i.e. impede the soil's capability to serve its intended purpose (Doran and Parkin, 1994). Furthermore, the excessive use of hardly degradable polyethylene (PE) has been apprehended to lead to substantial amounts of plastic waste residues accumulating each year (Albertsson et al., 1987). This, in turn, may potentially release toxic additives into the soil (Ramos et al., 2015).

The majority of recent reviews published on agricultural plastic mulching strongly focuses on the feasibility or efficacy assessments of biodegradable films (Brodhagen et al., 2015; Kasirajan and Ngouajio, 2012) which have, however, so far been hardly accepted as a functional alternative to PE. More general contributions compared various synthetic and natural mulching materials with each other (Chalker-Scott, 2007; Greer and Dole, 2003) or with respect to certain agricultural practices, such as ridge-furrow systems (Gan et al., 2013) and integrated weed control (Bond and Grundy, 2001; Case et al., 2005). The first and most general reviews published on plastic mulching (Lamont, 1993; Tarara, 2000) were animated with the beneficial prospects of plastic mulch use, however, merely discussing potential drawbacks. This trend still applies to the majority of current research articles emphasising individual effects of plastic mulching with particular focus on short-term agronomic benefits (e.g. He et al., 2013; López-López et al., 2015; Wang et al., 2010). In contrast, the long-term impact of plastic mulching as a standard agricultural practice is still virtually unknown in terms of potentially deteriorating soil quality or their post-crop fate, and therefore presents a challenge to bear a holistic sustainability evaluation. For this, it is important to combine the various