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Perspective

Does long-term use of biodegradable plastic mulch affect soil carbon stock?

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Soil organic carbon plays a paramount role in the global carbon cycle. Soils can be both a source as well as a sink for greenhouse gases. Even small changes in the content of soil organic carbon can have important implications for climate change. Agricultural management can affect the content of soil organic carbon to the better or worse. One such agricultural management practice is the use of plastic mulches. Plastic mulches provide multiple benefits, including increased soil temperature and moisture, reduced weed and pest pressure, and improved crop yield and quality. Most plastic mulches are made of polyethylene, which should be removed after harvest, but often plastic residues remain on the fields, leading to soil pollution.

Biodegradable plastic mulches are a potential solution to problems caused by polyethylene mulches. Biodegradable plastic mulches have been shown in many cases to provide equivalent agronomic benefits as conventional polyethylene mulches, but without having to be removed from the soil after use because they are designed to be tilled into the soil (Tofanelli and Wortman, 2020). The market for global biodegradable mulch films is predicted to reach a value of more than US $68 million by 2025, with an annual growth rate of 7.1% from 2021 to 2026 (IMARC, 2021). Thus, it can be expected that biodegradable plastic mulches will see continued and increasing use in agricultural production. In this perspective piece, we discuss whether biodegradable plastic mulches will affect the soil carbon balance.

Unlike conventional polyethylene plastic films, biodegradable plastic mulches are designed to be tilled into soil after crop harvest. In the soil, the mulch material is then transformed, by microbial actions, into CO_2 and microbial biomass, respectively. Some portion of the carbon (C) from biodegradable plastic mulches that is incorporated into living microbial biomass will transform into necromass after microorganisms die. This material can further form mineral-associated organic matter or be encapsulated in soil aggregates, and thus becomes persistent soil organic carbon. Thus, plastic-derived carbon can transfer into stable soil organic carbon, and this could potentially sequester that carbon for a long time (Fig. 1). Therefore, long-term use of biodegradable plastic mulch could have the potential to increase soil carbon stock, which would benefit soil health.

However, it is not known what proportion of the carbon of a biodegradable plastic much will finally be transformed into stable soil organic carbon. Regulations for biodegradable plastic mulches require that 90% of the organic carbon in the plastics (relative to absolute amount of organic carbon or to a control substance) are converted to CO_2 in standard laboratory tests. Thus, when biodegradable plastic is incorporated into soil, the majority of its carbon is released as CO_2, while the remainder may become part of soil organic carbon. If we conservatively assume that at most 10% of the carbon of a biodegradable plastic mulch is transferred into soil organic carbon every year of continuous use of plastic mulch films, then the soil carbon pool would increase by at most 7.3 g C m^{-2}, 14.6 g C m^{-2}, and 29.2 g C m^{-2} after 5 years, 10 years, and 20 years, respectively [with a rate of 1.46 g C m^{-2} $year^{-1}$, considering a mulch weight of 26.6 g m^{-2} and a C content of 55% for a typical biodegradable plastic mulch (Hayes et al., 2017)]. This corresponds to 0.1%, 0.2%, and 0.4% relative to the natural soil carbon stock in the top 30 cm of a typical soil, respectively (assuming a soil organic carbon content of 20 g kg^{-1} and bulk density of 1.2 g cm^{-3}).

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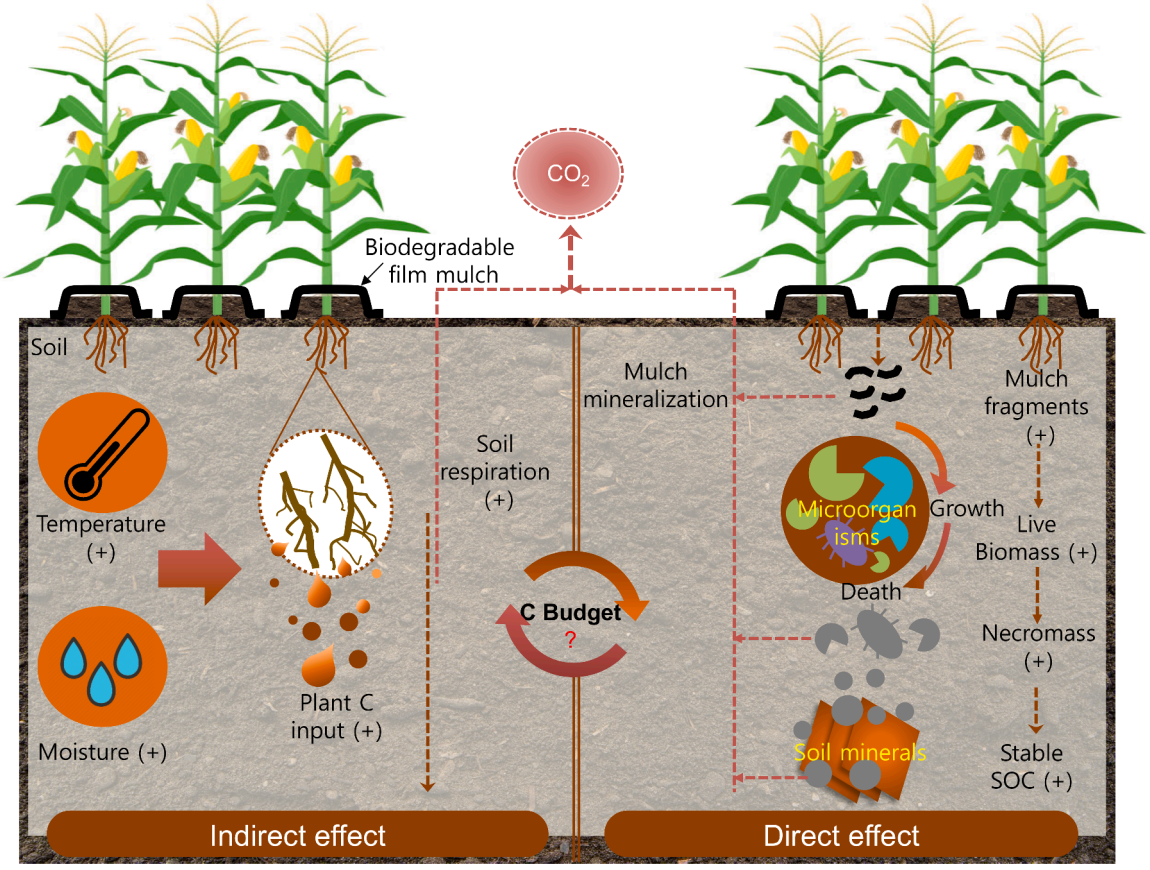

Fig. 1. Indirect and direct effects of biodegradable plastic mulch on soil organic carbon (SOC). "+" indicates positive response under biodegradable plastic mulch and "?" indicates response is not known.

Apart from the direct input of carbon through soil incorporation of biodegradable plastic mulches, the use of plastic mulches indirectly affects soil organic carbon through modification of soil microclimate, and consequently microbial and plant activities (Fig. 1). As a barrier on the soil surface, mulch reduces evaporation and gas exchange, leading to increased soil temperature and moisture. This in turn results in elevated soil respiration (C output), but also typically increases gross primary productivity (C input). We would expect that the indirect effect of biodegradable plastic mulch on the soil carbon stock is similar to the impact of the polyethylene mulch, for which there is no direct carbon input if polyethylene mulch is completely removed after harvest. Most previous empirical and meta-analysis studies reported no change or a decrease in soil carbon after conventional polyethylene plastic mulching as compared to no mulch farming (Mo et al., 2020; Yu et al., 2021).

The overall impact of biodegradable plastic mulch on soil carbon stock is the sum of its indirect and direct effects (Fig. 1). The direct effects, even over a period of 20 years (tens of g C m^{-2}), are several orders of magnitude smaller than the absolute carbon pool in topsoil (thousands of g C m^{-2}), and moreover also smaller than measurement uncertainties in the soil carbon pool (hundreds of g C m^{-2}). Indirect effects on soil carbon stock have not shown consistent impacts. We thus do not expect that long-term use of biodegradable plastic mulches substantially affects soil C stock. Nonetheless, long-term field experiments are needed to verify the expected negligible impact of biodegradable plastic mulches on soil carbon stocks and trace the pathways of carbon released from biodegradable plastic mulches.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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