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It is time to name and frame the plastic particle footprint of the agri-food sector's practices and innovations

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Abstract

While plastics offer short-term benefits to the agri-food sector by increasing productivity and food safety, they are endangering these gains in the long-term. Soil, water, and food are becoming increasingly contaminated, with persistent interactive micro- and nano-plastics disturbing the functioning of the ecosystem and affecting human health. Plastic use is likely to grow further because of population increases, resource limitations, agrochemical regulations, climate change, and transitional technologies. Up to now, efforts to mitigate plastic pollution have been mainly focused on reducing the carbon footprint and managing plastic waste. This paper demonstrates that accounting for the long-term plastic particle footprint would pave the way for transparent reviews of strategies in the agri-food sector. This would enable decisions in favor of innovations that deserve to increase our plastic particulate footprint, to be accompanied by cross-sector trade-offs, putting an end to irreversible pollution that is not justified by significant improvements in human wellbeing.

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Introduction

Plastic is a versatile and readily available material that has conquered all sectors of activity around the world, contributing to their economic growth. Production and consumption of plastics have doubled over the last 20 years and are expected to double again over the next 20 years. Unfortunately, it invades and endangers all elements of our ecosystem. Efforts to reduce plastic pollution have intensively focused on the concept of circularity, whose flagship measure is recycling. It starts with effective plastic waste collection and results in a reduction in the carbon footprint. How can we understand the growing worldwide pollution by plastic particles, despite the numerous mitigation actions taken to reduce the carbon footprint of our ever-increasing plastic production and consumption?

This paper aims to explain why it is crucial to start taking a long-term view of the complex fate of plastic in order to be able to pave the way for a transparent review of environmental protection strategies, particularly in the agri-food sector, which is the largest plastic consumer. After providing a brief overview of the current knowledge on the increasing use and impact of plastics in the agri-food sector, the paper discusses existing mitigation actions in light of the long-term consequences of micro- and nano-plastic emissions.

Discussion

In line with demographic trends in the second half of the 20th century, plastics were seen as important catalysts for growth in the agricultural and food sectors, improving access to safe food. They have largely replaced traditional materials. Greenhouses, tunnels, mulch films, and drip irrigation, for example, have contributed to increased crop productivity. Polyethylene mulch film has replaced plant-based mulching to suppress weeds, conserve soil moisture, or accelerate the mineralization of soil organic matter, thereby contributing to enhanced crop productivity and quality[1,2]. By 2013, 3.6 Mt of plastic was used in agricultural films, predominantly in Asia and Europe[3]. Other examples to cite among many others, are single-use plastic packaging materials such as polyethylene terephthalate bottles or trays. Since the 1970s, they have replaced traditional glass, wood, or metal containers to facilitate preservation and transport of foods and beverages, and reduce food waste and losses.

At the turn of the third millennium, concerns about global health and climate change have made plastics an even more essential strategic material. They are involved in the development of new practices and dedicated items aimed at reducing carbon footprint, chemical inputs, water use, waste and losses, and environmental impacts. Novel high-yielding cultivars adapted to plastic mulch film have been developed to grow in cooler regions with extended cropping seasons and optimized water use for example[4]. The booming organic farming and agroecology make the use of plastic even more important because options to limit weeds or pests are, *de facto*, limited[5,6]. Fertilizers, pesticides, and seeds are coated with polymers to provide plants with the necessary chemicals release rate, avoiding emissions to water and air, or improving germination[7]. Plastic is crucial in an increasing number of other sustainable innovations such as agri-voltaics, digital agriculture, hydroponic systems, vertical farming, and intelligent packaging. Dedicated items containing high-performance plastic are used in solar panels, soil sensors, harvesting robots, drones, tubing, clamps, grow trays, grids, oxygen scavengers, and food spoilage indicators, etc.[7−9].

Simultaneously, although agriculture and food systems have been identified as the most significant influence on the environment and human health, plastic has emerged as one of the most critical pollutants. Their probably irreversible impacts on ecosystems and human health have led to a portfolio of national regulations and, more recently, to international negotiations for a global treaty[10]. The backbone of the plastic polymer chain is so resistant to natural biological attacks that it can last centuries or even millennia, while super-slowly fragmenting into interactive plastic particles. These plastics particles have been continuously released from the very beginning of the plastic production process up to the very end of its life. Even though wildlife entangled in floating plastic waste is deeply saddening, the most powerful threat comes from tiny plastic fragments named micro- and nano-plastics, which profoundly disturb the ecosystem and human health[11]. Because of their high surface area and physical-chemical reactivity, they are able to disrupt the cycling of biogenic elements and to facilitate pathogen dispersion. They also interact with emerging contaminants and affect nutrient sequestration and transport, essential element adsorption, and microbial functions, among others. Micro- and nano-plastics cross cell barriers such as in the human lung and intestine to reach the systemic circulation. They subsequently affect tissues such as the reproductive organs, placenta, and brain. They are associated, for example, with immune modulation, reproductive effects, and cardiovascular effects, among many others[12].

Today, we must face the fact that the immediate benefits of plastic in the agri-food sector are dangerously offset by its negative long-term impact on the functioning and productivity of agroecosystems and on food safety. Released micro- and nano-plastics affect the quality and yield of crops, as well as the physical, chemical, and biological properties of soils, thereby decreasing their overall agronomic quality[13]. Micro- and nano-plastic contamination comes from farming practices such as the use of mulch and the numerous others items made from plastic[14], the use of contaminated organic or inorganic fertilizers, and also from more distant sources, travelling through the soil, water and air. The contribution of mulching films and sewage to contamination of the soil by microplastics was very roughly estimated to be 35% and 65%, respectively, for a global median stock of microplastics in the soil estimated as 3.6 Mt. This figure is up to two orders of magnitude higher than the estimated stock of microplastics on the ocean's surface, and is less than 1% of the 4,900 Mt of plastics discarded between 1950 and 2015. The remainder is mainly hidden in poorly explored landfills and/or present in the form of unmeasurable plastic particles, such as nanosized ones[15].

Plastics particles have been detected in a very large range of processed foods and beverages. They originate from plastic in contact with the food (packaging, cookware etc.) or from previous contamination (e.g. that occurring in the field)[16]. Circular agriculture and food systems may even worsen this pollution by circularizing and create enrichment cycles for undesirable persistent compounds such as plastic particles. Micro- and nanoplastics are, for example, contaminating residues (such as food wastes, manure, peels, washing water, oil seed cake, straw, etc.) that are intended to be further converted into fertilizers, chemicals, or materials in biorefinery plants for substituting fossil-based chemicals and plastic items[17,18].

Up to now, efforts to mitigate plastic pollution have been mainly focused on plastic waste management through collection, sorting, and, above all, plastic recycling, which is known to be inefficient to face the rising global plastic consumption[19]. Because micro- and nano-plastics emissions start from the very beginning of plastic production and continue during the item's usage stage, a perfectly well managed plastic waste cannot eradicate pollution from particles of a plastic item, especially if the plastic has a long lifespan[20]. This inevitable plastic aging, combined with contaminant sorption, strongly limits the applicability of mechanical recycling technologies. Most recycling technologies are actually producing downcycled plastics. These downcycled plastics are used to further substitute for traditional materials (e.g. recycled polyester terephthalate fibers substituting for wool) in new applications of low-quality plastics, without reducing consumption of virgin plastic and long-term plastic particle emissions[21].

Overall, long-term micro- and nano-plastics emissions are insufficiently taken into account. For example, landfilling usually puts an end to the life of plastic in most papers and flow schemes, although it has been clearly demonstrated to be an important source of plastic particles emissions[22]. Most environmental assessments are currently based on lifecycle analysis, a range of methodologies still waiting for the required consensus on the long-term fate and impacts of plastic particles to account for plastic particles' impacts[23]. To compensate for such current limitations in lifecycle assessments, a conservative particulate plastic footprint has recently been proposed[24]. It represents the amount of plastic that ends up in the environment, namely the initial mass of a plastic item minus the amount whose polymeric structure is completely broken down into small molecules (such as carbon dioxide and water) through incineration, for example. This metric plastic particulate footprint could be reported as an elementary flow alongside other indicators such as the carbon footprint. It would enable to create and rely on a complete source-to-sink flow diagram of micro- and nano-plastics. Such a plastic particulate footprint would improve our ability to better weigh up the benefits of alternative solutions, and the overall decision-making process for mitigating plastic pollution.

In conclusion, plastic use is deeply embedded in the global agri-food system and is likely to grow further with population increases, resource limitations, agrochemical regulations, climate change, and technological innovations. No miracle technology is likely to significantly curb our current pharaonic and ever increasing plastic consumption to save the next generation. Therefore it is now essential to reassess our relationship with plastic by moving beyond the misleading "carbon footprint and waste management" framework. Since eliminating the accumulated microplastics from our environment, soil, food, and bodies is an unrealistic hope, the irreversibility of plastic pollution requires a precautionary approach. This means putting an end to the widespread use of a material whose both safety for future generations and benefit for the current generation have not been proven. It is clearly time to take action instead of demanding, looking for, and waiting for further knowledge on the complex impacts of aged plastic particles. We must urgently start a thorough review of our strategy by naming and framing the plastic particle footprint in our practices. Such naming and framing is necessary to understand efficient pathways toward mitigating plastic pollution and discussing the essentiality of plastic. This will create transparency, empowering stakeholders to make informed choices and drive demand for responsible plastic use. This effort is particularly important for the agri-food sector, which is the largest consumer of plastic.

Agroecology and organic production systems promise sustainable agriculture and healthier, less contaminated food[25]. These sectors could therefore be appropriate for initiating such a change and go beyond the usual minor worldwide stipulations regarding the collection and downcycling of plastic mulch films and plastic packaging. Assessing the plastic particle footprint of agroecological and organic production practices, whether conventional or innovative, would enable us to re-evaluate the role of plastic, raise awareness and transparency among producers and consumers, develop fair arbitration in favor of essential plastics, and revise the current plastic legislation. Efforts to name and frame the plastic particle footprint would pave the way for a transparent review of strategies in many other sectors. Decisions in favor of agricultural innovations and transitional technologies that deserve to increase our plastic particulate footprint must, in return be accompanied by cross-sector trade-offs to put an end to pollution that is not justified by any improvement in human wellbeing.

Author contributions

The author confirms sole responsibility for all aspects of this study and approved the final version of the manuscript.

Data availability

No new data were generated or analyzed in this study.

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Conflict of interest

The author declares that there is no conflict of interest.

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