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A review of soil pollution from LDPE mulching films and the consequences of the substitute biodegradable plastic on soil health

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Abstract: The plastic film mulching system has a significant role in increasing crop grain yields by changing the microenvironment of the plant. On the other hand, plastic mulching materials pollute the land and water because they are not degraded or disposed of properly. Biodegradable plastic mulches (BPM) may be used as a substitute for conventional low-density polyethylene (LDPE) to protect soil health. In this review, the effect of micro(nano)plastics on soil health and function has been discussed in light of their distribution in soil, changes in soil biochemistry, interactions between microplastics with soil microbes and plants, and their growth patterns. The nano-plastics are now incorporated into the food chain from the soil through plants and finally harm the whole ecosystem, including humans. The use of BPM has been practiced recently, but only 1% of the world's total plastic production is from biodegradable materials. In the second part of the review, the confusing terms "bio-based" and "biodegradable" were clarified based on their polymeric constituents. The physical parameters of different constituent materials for mulching purposes and their capability for sustainable solarization have been discussed. The effect of biodegradable mulches on soil health and other ecotoxic effects on plants, soil microorganisms, and other soil dwellers like *Daphnia magna*, *Vibrio fischeri* bacteria, green algae, slime mould, protozoa, invertebrates like earthworms, and common water fleas have been focused on in this review. In conclusion, the use of BPM for mulching purposes was reported to improve crop quality and yield and reduce weed growth in comparison to naked soil. The recent short-term studies ensured that mulches stayed unbroken throughout the growing season. But simultaneously, the biodegradable mulches affect soil health and have a substantial impact on physical parameters such as soil pH, electrical conductivity, aggregate stability, infiltration, nitrate-N, exchangeable potassium, etc. Therefore, a lot of long-term research is required for the use of BPM as a substitute for conventional LDPE as a mulching film in the agricultural field.

Introduction

In The American society coined and uses the term "plasticulture" to designate the various uses of plastics in modern agriculture (Figure.1). Among them, plastic film mulching systems have a significant role in increasing crop grain yields by changing the microenvironment of the soil through soil moisture maintenance, suppressing weed growth, and controlling soil temperature (Sun et al., 2020). The major advantages of using mulch have been displayed in Figure. 2. In the late 1800s, paper mulches coated with tar were employed before the invention of plastic mulches. Agriculture uses a wide variety of mulching materials, including polyethylene, paper, cowpea, grass, hairy vetch, rice, wheat, sugarcane straw, coffee husks, pine, eucalyptus peel wood, gravel-sand mulch, etc. According to Lamont (2005), polythene-made mulches have been

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used in agriculture for more than 50 years because they are simple to install and maintain, very durable, easily accessible for mass consumption, and capable of serving the intended purpose of mulch. Low-density polyethylene (LDPE), a polyethylene mulching material, is primarily employed because of its strong puncture resistance, water impermeability, and mechanical stretch qualities. Due to the agronomic advantages of the horticulture crop, the global demand for plastic mulch film increased from 4.4 to 7.4 million metric tonnes between the years 2012 and 2019 (Akhira and Mustaphaa, 2022). The biodegradable mulch film market is expected to grow from US$ 52.43 million in 2021 to US$ 64.3 million in 2024 (Haapala et al., 2015).

The main problem with polyethylene mulch is disposal after usage because it takes a very long time to break down due to its high chemical stability, water insolubility, and hydrophobic characteristics. Currently, materials are disposed of through burning, incineration, recycling, composting, and the use of landfills, all of which have a significant negative impact on the economy and the environment (Kyrikou and Briassoulis, 2007; Lamont, 2005). Burning plastics made of polyvinylchloride may even release persistent organic pollutants like furans and dioxins (Jayasekara et al., 2005). The mulching materials can fragment and pollute land and water since they are not recycled or disposed of properly. As a result, the leftover plastic mulch causes the shifting of edaphic biocoenosis (e.g., towards mycotoxigenic fungi), acceleration of carbon-nitrogen metabolism and depletion of soil organic matter. It may also enhance water repellence in soil and worsen the greenhouse effect. The interaction of the soil microenvironment, water system, and biological activity under plastic mulches is currently unknown. Ma et al. (2008) made it abundantly evident that crop yields were significantly decreased when the soil had 58.5 kg/ha of residual plastic film. Moreover, the pollutants that remain in the soil and impair both terrestrial and aquatic ecosystems can be absorbed by the left-over plastic debris in the soil and turn into toxic compounds that may harm human health as well (Derraik, 2002; Shimao, 2001). Professor Richard Thompson (Thompson et al., 2004) invented the term "microplastics" to track the extent of soil pollution caused by very small, minute plastics and the health risks to living things. The four categories of plastic particles are classified according to their sizes as follows: macroplastics (>25mm), mesoplastics (5–25 mm), microplastics (1–5 mm), and nanoplastics (1–100 nm). Microplastics are once again separated into primary and secondary microplastics. The smaller primary microplastics are produced by combining polyethylene and polystyrene, and they are used in the production of goods for the housing industry, automotive spare parts, the fashion and cosmetic industries, fishing nets, and the medical field. Microplastic contamination is caused by the packaging materials for personal care items, pellets, electronics, motor vehicles, or printers. Secondary microplastics are created when photodegradation brought on by electromagnetic radiation breaks down bigger pieces of plastic into smaller fragments. These particles build up and pollute both the ocean and land (Sharma et al., 2023). Currently, it is being noticed that the existence of nanoplastics in the atmosphere can be a great environmental hazard, and their concentration is progressively rising unintentionally. Nanoplastics can easily cross cell membranes due to their small size, which impairs cells' capacity for functioning biologically. The nanoplastics, which are naturally lipophilic, can easily adhere to the core of lipid bilayers in the gall bladder, pancreas, and brain of fish and other aquatic creatures (Free et al., 2014). Also, the leftovers from mulching films add microplastics to the soil through landfills, soil supplements, sewage sludge application, wastewater irrigation, compost and organic fertigation, air deposition, etc (Guo et al., 2020). The biological activity of soil organisms, such as feeding, digestion, and excretion processes, turns plastic waste into microplastics (Chae and An, 2018). Microplastics in the soil not only degrade their quality (de Souza Machado et al., 2018), but they also cause trophic transfer in terrestrial food chains and migration. The agriculture field where wastewater irrigation and plastic film mulching are used poses a serious threat to the ecosystem (Huerta Lwanga et al., 2017). Many studies have reported enhancement of the degradation of polyethylene components (Kasirajan and Ngouajio, 2012; Esmaeili et al., 2013). However, the three-dimensional structure, hydrophobic characteristics, and large molecular weight of the material prevent their breakdown. On the other hand, the use of biodegradable plastics (BPs), which may be totally broken down by microorganisms, may help to avoid the issue of environmental pollution caused by microplastics (Luyt and Malik, 2019). Certain bacteria, along with environmental oxygen, temperature, humidity, and other microorganisms, must interact with one another for the complete degradation of BPs (Emadian et al., 2017).

In the current review, soil contamination from microplastics originated from mulching materials, and their effects on soil health and microbial function have been discussed. The pertinent issue of whether or not using biodegradable plastic mulch (BPM) is a solution to

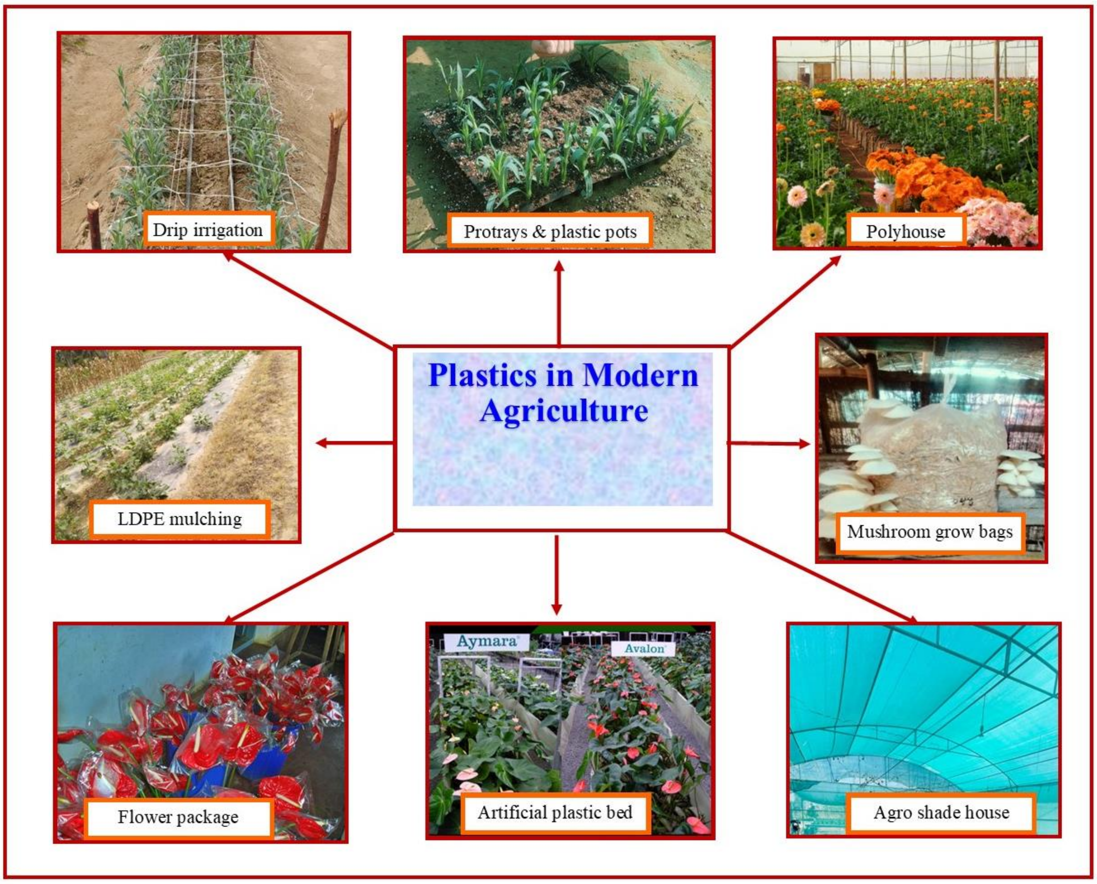


Figure 1. Plastics in modern-day agriculture

Figure 2. Advantages of mulching in agriculture

agriculture's plastic problem was interpreted, as was its efficacy for sustainable solarization, which is the primary function of agricultural mulching. The research on bioplastic degradation and its toxic effects on soil health is limited. In the current discussion, the assessment of the toxicity of biopolymeric ingredients and their additives to plants, soil microorganisms, and other soil-living organisms has been discussed in detail with relevant references.

microplastics both vertically and horizontally alters the major characteristics of soil, including structure, function, and microbial diversity (Rillig, 2012; He et al., 2019), which has an impact on plant and animal life and threatens the safety and quality of human food (Rillig et al., 2019). The significant amount of residual plastic film reduce the water conductivity of soil. It has an adverse effect on the number of microorganisms and their activity in the soil and finally the soil fertility, (Wang et al., 2015; Zhang et al., 2017). In comparison to linear-type microplastic particles,

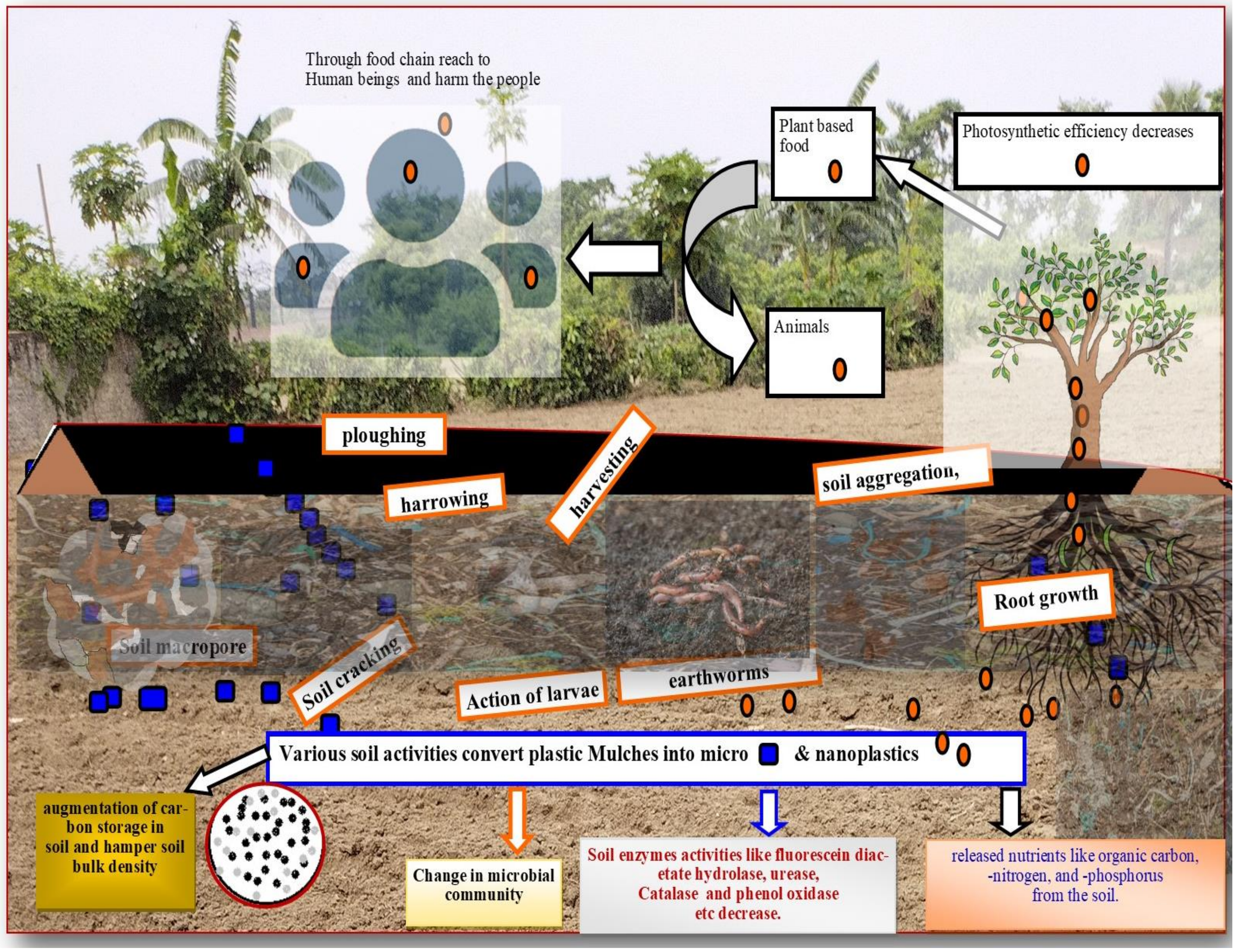


Figure 3. Schematic diagram of the formation of microplastics and nanoplastics and their role in changes in soil health, plants and animal

Effect of microplastics on soil health and function: Distribution of microplastics and their effect on soil

The soil biota, soil properties like soil cracking and soil aggregation, soil macropores (pores >75 mm), and different agricultural interventions like ploughing, harrowing, and harvesting, as well as numerous plant processes (such as root growth and uprooting), and the activities of various larvae, earthworms, vertebrates, etc., influence the distribution of microplastics originated from mulching materials (Figure 3). The distribution of

common mulching materials can yield fragmented microplastics, which can accumulate more loosely into soil aggregates. While the polyethylene and microplastics containing polyacrylic acid do not enhance water-holding capacity, the polyester fibres, on the other hand, significantly increase the water-holding capacity, decrease bulk density and caused the soil to aggregate in a water-stable manner (de Souza Machado et al., 2018). Besides this, several research studies have demonstrated that the microplastics in the soil modify the soil's ability to retain water and its permeability, both of which have an impact on water evaporation (Wang et al., 2015; de Souza Machado et al., 2018). Wan et al. (2019) demonstrated that the addition of microplastics to two types of clay soils increases water evaporation and desiccation cracking. Due to the changes in soil water dynamics, a number of physiological indicators of photosynthetic efficiency can also be affected, which could have an impact on plant performance (de Souza Machado et al., 2019).

Influence of Plastic particles on the soil biochemistry

The enzymes present in soil are important to regulate a variety of biochemical processes, act as indicators of soil fertility, and interfere with the carbon, nitrogen, and phosphorus cycles of nutrients in the soil (Allison and Jastrow, 2006). Liu et al. (2017) and Huang et al. (2019) have shown that the microplastic in soils affects the expressivity and functions of the enzymes fluorescein diacetate hydrolase, urease, catalase, and phenol oxidase, which might result in short-term changes in soil quality. The augmentation of the organic carbon pool of soil by microplastics may lead to an alteration of carbon storage in soil and hamper soil bulk density, a crucial component of soil fertility that depends on soil carbon storage (Rillig, 2018). Liu et al. (2017) found that after 14–30 days, the presence of a higher concentration [28% (w/w)] of microplastics increased the amount of dissolved organic matter, which ultimately releases nutrients like organic carbon, nitrogen, and phosphorus from the soil. In contrast, the [7% (w/w)] microplastic concentration reduced the accumulation of dissolved organic matter.

Microplastics and soil microbial interactions

The presence of microplastics alters the distribution of anaerobic and aerobic bacteria and the physical characteristics of soil, such as porosity and moisture (Rubol et al., 2013; Naveed et al., 2016; Rillig et al., 2017). The pore space shifting, caused by microplastics, destroy microhabitats of soil and the extinction of native microorganisms (Veresoglou et al., 2015). The addition of microplastic in the soil changes the composition of the microbial community and reduces substrate-induced respiration (SIR) rates (Judy et al., 2019). The microplastic accumulation significantly increases dissolved organic carbon which is a substrate for the growth of microorganisms. This organic carbon has a clear impact on soil function and microbial communities, as well as causing eutrophication of water and the generation of greenhouse gases (DeForest et al., 2004). Due to the presence of microplastics in the soil, the rate at which soil fungus and arbuscular mycorrhizal fungi (AMF) colonisation on plant roots is slowed down (de Souza Machado et al., 2019). Hence, it can be concluded that the addition of microplastics from various sources, mostly from mulching plastics, can change the characteristic features of the soil and apply certain selection pressures on the growth of the soil microorganisms, which ultimately alters the community structure and variety of microbes in the soil (Rillig et al., 2018).

Impact of microplastic pollution on plant growth

Due to their strong adhesiveness, microplastics strongly adhere to the surfaces of plant roots, where they are subsequently absorbed (Li et al., 2020; Sun et al., 2020). It was previously thought that micron and submicron-level plastic particles were not absorbed by plants; but a new study has shown that 0.2 micron and 2.0-micron-level plastic particles are also easily absorbed by the roots of crops like lettuce and wheat along with water and nutrient transport, eventually manifesting in the edible portion of such plants (Li et al., 2020). As a result, microplastics enter the food chain directly, spread through it, and ultimately harm people. Moreover, the presence of microplastics in the soil has a significant negative impact on plant growth and development (Fig 3). Many authors have noted this phenomenon in higher plants like lettuce, broad beans, wheat, green onions, and maize (Qi et al., 2018; de Souza Machado et al., 2019; Gao et al., 2019; Jiang et al., 2019; Wang et al., 2020).

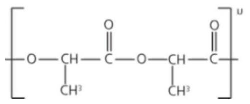
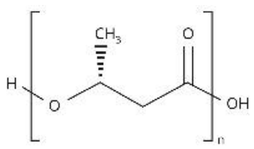
Biodegradable plastic mulch: a plastic-free alternative for agriculture

The use of biodegradable plastic mulch (BPM) helps to avoid the significant negative impacts of polyethylene mulch on soil health. The idea of BPM was first proposed in the 1980s, but up until now, its widespread application has been hindered by its low soil degradation (Kasirajan and Ngouajio, 2012). Governments, business houses, and universities have recently made a considerable effort to create a workable solution to the social, economic, and environmental crises created by the use of traditional plastics; bioplastics may be a good replacement for traditional plastics. Recently Moshood et al. (2022) reported that just only 1% of the 370 million metric tonnes of plastic manufactured worldwide are bioplastics.

Biodegradable vs. bio-based plastic used in mulching

The terms "bio-based" and "biodegradable" are sometimes used interchangeably, but they do not indicate the same meaning. Bio-based plastics are made from biological materials other than petroleum, but they might not degrade naturally, though some bio-based plastics are also biodegradable. The term "bio-based" is exclusively

Table 1. Different types of single polymeric constituents of biodegradable plastics and their chemical structure, sources, properties and degrading microbes based on the development of mulching film.

Name of the polymer	Chemical Structure of basic unit	Source	Properties	Degrading microbes*	References*
Poly-lactic acid (PLA)		Potato, sugarcane bagasse, maize, and other agricultural fermentation wastes	1. Cyclic dimer of D- (synthetic) or L-lactic acid (natural), made by polycondensation or lactide ring opening polymerization. 2. The average glass transition temperature (Tg) is 64ºC, the elongation at break (εB) is around 6%, and the tensile strength is about 32 MPa	Members of the phylum actinobacteria (Pseudonocardiaceae). Other taxa include members of the family Micromonosporaceae, Streptomycetaceae, Streptosporangiaceae, and Thermomonosporaceae.	Butbunchu and Pathom-Aree, 2019.
polyhydroxy butyrate (PHB)		*Pseudomonas olevorans, Ralstonia eutropha* and *Bacillus megaterium*	1.Synthesized through condensation reaction of 4-hydroxybutyric acid (4HB) or the ring-opening polymerization (ROP) of the γ-lactone 2. a crystallinity range of 60% to 80%. 3. Tg - I20ºC, εB 6**%** tensile strength of the neat PHB is 11.9 MPa	*Cupriavidus necator, Methylobacterium rhodesianum, Bacillus megaterium, Alcaligenes faecalis, Pseudomonas lemoignei, Aspergillus fumigatus,* and *Penicillium funiculosum*	Zhou et al., 2023

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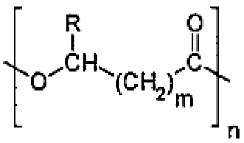
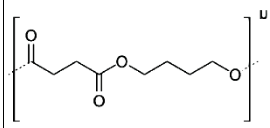
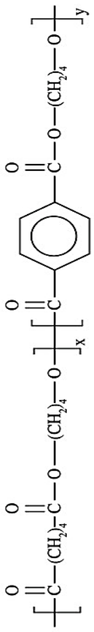
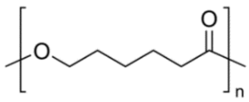
Polyhydroxyalkanoates (PHA)		*Alcaligenes latus*, *Cupriavidus necator*, and *Pseudomonas putida* assistanaerobic degradation of municipal sludge, palm oil mill effluent, marine sediments to form volatile fatty acids like propionic, acetic, and butyric acids which are further polymerized into PHAs.	1. Polymerization process of hydroxyalkanoate (HA) monomers through ester bond formation by PHA synthases, 2. Tg is -50°C to 60°C, εB 5% to 1000%, (depend on constituent materials) and tensile strength ranges from 20 MPa to 70 MPa.	*Pseudomonas stutzeri*: aerobic degradation *Clostridium botulinum*: anaerobic degradation *Aspergillus fumigatus*: a fungus that can degrade PHA in compost. *Nannochloropsis oculata*: an alga that can degrade PHA in seawater.	Wang et al., 2022
polybutylene succinate (PBS)		Condensation product of succinic acid and 1-4 butanediol. Succinic acid is produced through bacterial fermentation by *Actinobacillus succinogenes*, *Escherichia coli*, *Saccharomyces cerevisiae*, *Anaerobiospirillum succiniciproducens*, *Corynebacterium glutamicum*, *Mannheimia succiniciproducens*, and *Basfia succiniciproducens*. 1-4 butanediol produced either by fermentation or chemical synthesis from petrochemicals.	1. The polymerization procedure of PBS involves two main steps: esterification (succinic acid and 1-4 butanediol) and polycondensation (PBS oligomers). 2. The Tg of PBS is about -10 to 45°C; εB of PBS 400 %, tensile strength of pure PBS is about 30–35 MPa	Degradation involves two main steps: hydrolysis and mineralization. *Amycolatopsis* sp., *Penicillium sp.* *Terribacillus* sp., *Pseudomonasstutzeri*	Savitha et al., 2022; Samaimai et al., 2021

polybutylene adipate-co-terephthalate (PBAT)		Made from petrochemicals	It is a copolyester of adipic acid, 1,4-butanediol and terephthalic acid. 2. Tg of PBAT is about -30°C. it is very ductile and flexible at room temperature. εB is around 400 %, which indicates that PBAT can stretch a lot before breaking. The tensile strength is about 16 MPa, which is relatively low compared to other plastics.	*Bacillus* strains (lipase enzymes) *Isaria fumosorosea*, *Paraphoma*-related fungus and *Cryptococcus flavus* (cutinase-like enzymes) break down the ester bonds in PBAT.	Burford et al., 2021
Polycaprolactone (PCL)		A cyclic ester derived from petroleum.	1. Polymer made from the ring-opening polymerization of ε-caprolactone, 2. It has a melting point of around 60°C. Tg 60°C; εB 1000%, tensile strength 10 MPa to 32 MPa.	Extracellular enzymes such as esterase, cutinase, and lipase of *Alcaligenes faecalis*, *Candida antarctica*, *Thermobifida fusca*, and *Pseudozyma japonica*.	Nawaz et al., 2015
*References presented here based on 5th column i.e., degrading microbes					

used for a material's manufacturing process, not at the end of its existence. The action of naturally existing microorganisms degrades biodegradable plastics, which may be petroleum- or bio-based, and quickly breaks them down into natural components like carbon dioxide, water, and biomass (Rahman and Bhoi, 2021). Bioplastics can be roughly classified into three groups: i) those that are both biodegradable and bio-based, such as polymers derived from starch, cellulose, lignin, and chitosan, as well as polyhydroxy alkanoates, polylactic acid, and bio-based polybutylene succinate; ii) those that are derived solely from renewable resources but are not biodegradable, such as bio-based polyamides, polyethylene, and bio-PET; and iii) materials that are only biodegradable, for example, poly caprolactone, poly vinyl alcohol, and poly butylene adipate terephthalate, those are made from fossil fuels but they decompose naturally (Moshood et al., 2022).

Polymeric constituents of BPM and their physical parameters for mulching purposes

Biodegradable plastic mulches (BPM) are mainly made up of a large number of synthetic and natural polymers. A single polymer, a blend of polymers, or a composite polymer can be used to create biodegradable polymers. The biodegradable single-polymer mulch is made from cellulose, proteins, lipids, starch, and different types of polyesters like polylactic acid (PLA), polyhydroxy butyrate (PHB), polyhydroxy alkanoates (PHA), polybutylene succinate (PBS), polybutylene adipate-co-terephthalate (PBAT), and polycaprolactone (PCL) (Moshood et al., 2022) and their chemical structure, sources, properties, names of degrading microbes etc are described in the table1. The most widely used biodegradable plastic is called PBAT and is a random copolymer block made up of adipic acid (A), 1,4-

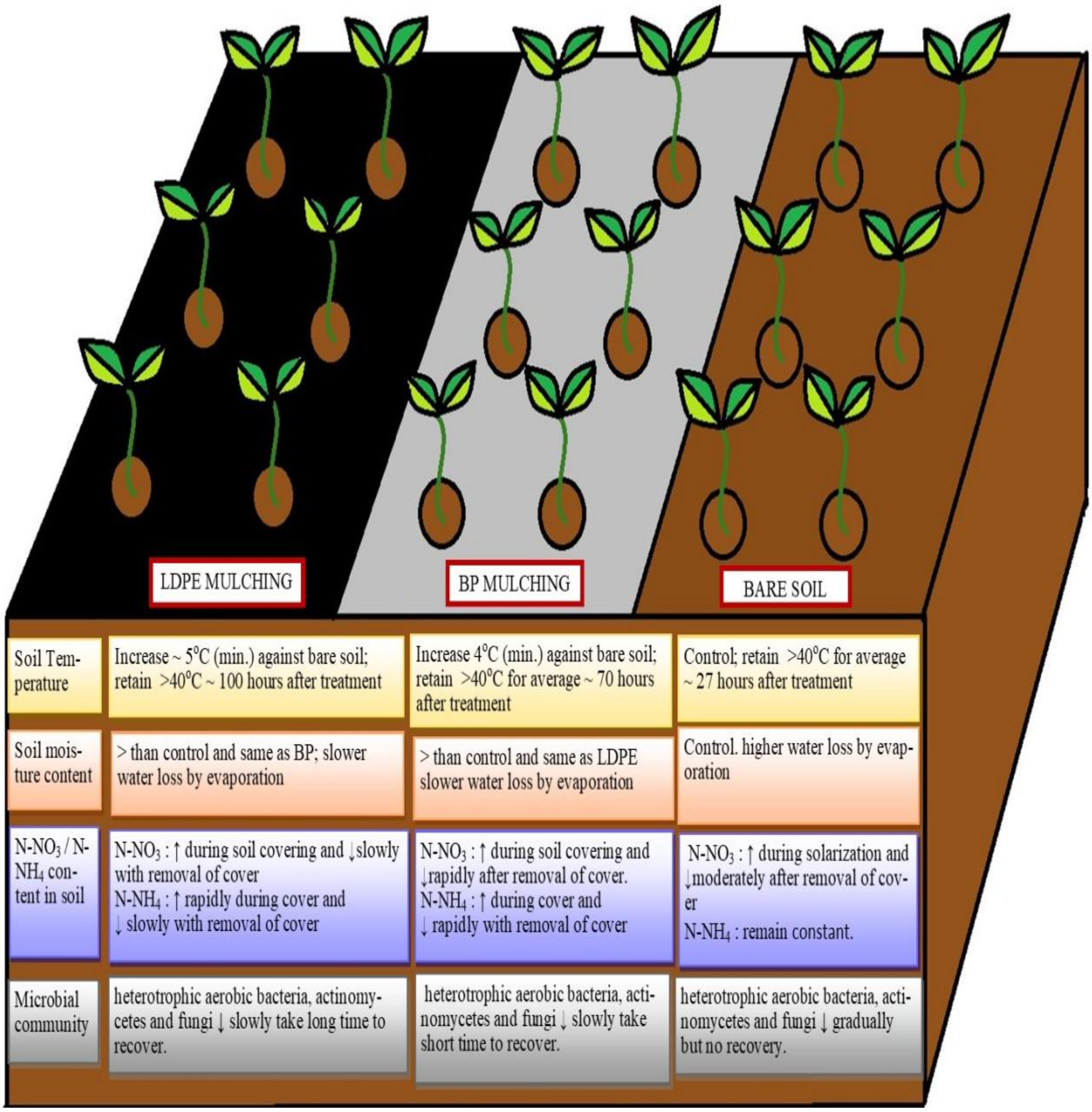


Figure 4. Comparison of LDPE and BP mulching on the effect of solarization against bare soil as control.

butanediol (B), and diacid groups of terephthalates (T). It has an elongation of roughly 200–300% and good tensile strength. According to the Biodegradable Products Institute (BPI) certification system, it is "compostable". Two groups of researchers (Coltelli et al., 2008; Shah et al., 2008) reported that PBAT has ester linkages, which are hydrolysed to increase biodegradability, and T groups, which improve stability and mechanical properties. Polybutylene succinate (PBS) and PBS-co-adipate (PBSA) are more frequently used polymers for biodegradable plastic production. A study found that a lot of naturally occurring fungi, which may break down PBSA and PBS in the soil, increased the rate of degradation (Koitabashi et al., 2012).

In one study, 100% spun bond PLA was used as a mulching film, but it was less durable and, weakened more quickly than biofabrics after 34 days of use (Wortman et al., 2016). In a second study, 100% melt-blown PLA was used as a mulching film, but after 20 weeks of soil exposure, it was less durable but weakened more quickly than biofabrics (Li et al., 2014). Both types of mulching materials improve soil moisture content in comparison to bare soil and reduced weed emergence. Liling et al. (2016) pointed out that biodegradable mulch film made up of the alginate polysaccharide, derived from *Macrocystis pyrifera* (giant kelp), had the maximum tensile strength, the highest elongation at break, and the lowest water vapour permeability (3.031 x 10-11 g/msPa) (136 MPa). The properties of any good mulching film such as outstanding tensile strength, high break length elongation, strong impermeability, low water vapour pressure, a low price, and comprehensive breakdown within the required timeframe, are enhanced after incorporation of different combinations of fillers, fibres, and additives with the basic materials. The polymer blends are broadly of three types: (i) those of natural origin, (ii) those of synthetic origin, and (iii) hybrids of both natural and synthetic origin. The hybrid of both natural and synthetic blended materials is widely employed because of the greater mechanical strength of the synthetic one, better biodegradability and lower cost associated with a large supply of natural polymers. The agricultural biodegradable plastic mulches are mainly produced from the polymers PCL, PHB, PLA, PBS, PBAT, polysaccharide cellulose, and starch.

Akhir and Mustapha (2022) explained the different parameters of biodegradable composites, such as PBAT/thermoplastic cassava starch (TPS); glucomannan from Konjac (KGM); alginate (ALG); vinasse from sugarcane (Vin); starch/PBAT; PBAT/PLA; PLA; and PBAT mixtures with phenoxy herbicide, 2-methyl-4-cholorophenoxyacetic acid. After careful consideration, they concluded that PBAT-based polymer composites and blends exhibit the best qualities for weed control film, having a high level of flexibility, excellent tensile strength, little solar radiation value to inhibit the growth of weeds, and excellent barrier properties, but they degrade at a moderate rate. The disintegration rate of PBAT-based mulching film increased after incorporation with other natural and synthetic polymeric materials. This type of blended mulching film has sufficient mechanical strength and a low production cost.

Biodegradable mulching film for sustainable solarization

The eradication of several soil-borne plant pathogens, fungi, weeds, and nematodes is an essential step in good cultivation practices for several horticultural plants. Commonly, formalin, methyl bromide, methyl iodide, chloropicrin, vapam, etc. are used as soil fumigants, which are very toxic for the users and other flora and fauna in nearby areas of the agriculture field and harmful for some of the cultivated crops, such as cruciferous vegetables. The temperature of the soil has an impact on a number of structural, biochemical, and biological properties, including evaporation, nutrient and water uptake, microbial breakdown of organic materials, germination of seeds, and emergence of seedlings (Al-Shammary et al., 2016). After these dangerous fumigants are phased out, a sustainable heat-based method called soil solarization is a very affordable and simple technique (Chellemi et al., 1997). In this method, transparent plastic is used to cover the soil for a certain period of time to generate heat at a depth of 5 cm in the soil to raise the temperature to 45-55ºC. Many soil-borne plants pathogens, including *Verticillium dahlia*, *Rhizoctonia solani*, *Fusarium* spp. and *Sclerotinia minor*, die as a result of this increased warmth condition (Pinkerton et al., 2000; Tamietti and Valentino, 2006), which also causes a decrease in nematode population (McGovern et al., 2002; Stapleton and Heald, 1991). Sofi et al. (2014) inferred that due to solarization, the percentage of moisture content is also raised, which again stimulates the decomposition of organic matter and the formation of toxic volatile chemicals that are hazardous to many phytopathogens (Oka et al., 2007). Moreover, during and following soil solarization, available nitrogen concentrations in the form of NO_3 and NH_4 are increased (Birthisel et al., 2019). A higher temperature in the topsoil layer was noted after covering it with both mulching films. According to a search conducted by Di Mola et al., (2021) on the effects of biodegradable (BIO films) and polyethylene (LDPE) mulching on solarization, chemical properties, and the growth of soil-borne microorganisms, the highest temperature in the 0–10 cm soil layer did not differ between the polythene (46.7°C on average) and biodegradable (47°C on average) mulch treatments. However, for polythene and BIO films, the average maximum temperatures in the 10 to 20 cm layer of soil were 43.2°C and 41.9°C, respectively. Soil solarization affects the soil moisture content and alters microclimate conditions (Sofi et al., 2014). Di Mola et al., (2021) also found that covered soil had an increase in moisture content of 16.5% (mean value of two films) compared to uncovered soil (15.4%). Both the LDPE and BIO film treatments resulted in an increase in the NO_3^- and NH_4^+ content of the soil, but the BIO covering prevented a high amount of ammonia in the soil because it contained less water in the soil and had slightly reduced temperatures than common LDPE film, which are likely favourable for the development of nitrifying bacteria. Moreover, the soil characteristics, bacterial and eukaryotic populations, and other microenvironments that are connected to the various cover films are altered by the heat effect. Based on this, Di Mola et al. (2021) concluded that the BIO film is an excellent substitute for conventional LDPE film for soil solarization and has significant environmental benefits (Figure. 4).

Biodegradable mulching film for sustainable crop production

The concept of using biodegradable polymers is a long-term strategy to reduce the accumulation of low-density polyethylene and other plastic waste that contaminates the soil. Different national governments encourage to increase the number of manufacturers and users of biodegradable plastics, while non-degradable plastic is prohibited (European Commission, Horizon 2020). Now, the issue of whether biodegradable mulches have properties resembling those of LDPE in use and if natural microorganisms are capable of breaking down the various polymers and additives used to make biodegradable plastics may come into focus. In response to the first inquiry, numerous studies conducted over the past ten years have found that traditional mulch and plastic biodegradable material produce good crops of lettuce, melon, tomato, cucumber, and pumpkin (Brault et al., 2002; Iapichino et al., 2014; Cirujeda et al., 2012; Cowan et al., 2014; Wortman et al., 2016; Ghimire et al., 2018). In a study, Hayes et al., (2019) compared the performance of three biodegradable mulching materials, Mater-Bi®, Ecovio®, and a PLA/PHA blend, on pie pumpkin (*Cucurbita pepo* L.), green pepper, and sweet corn as test materials in two different parts of the USA with greatly varied climates and soil types. In this experiment, the common polyethylene mulch, paper mulch, and soil without mulch were used as controls. Each year, the BDMs were ploughed into the ground following the grain harvest. The outcome has shown that all mulching materials were efficient in terms of crop quality, yield, and weed control in comparison to naked soil, and they remained intact throughout the crop production season except for paper mulch.

Effects of Biodegradable Mulches on Soil Health

It has already been discussed that biodegradable mulches are equivalent to plastic mulches as far as agronomic performance is concerned. The effect of biodegradable mulches on the health of the soil is less well understood. According to the United States Department of Agriculture (2019), soil health is a crucial component of sustainable agriculture and food production. It refers to the soil's ability to carry out its essential functions in a living ecosystem. Measurements of the physical, chemical, and biological parameters of the soil—including its bulk density, water retention capacity, infiltration capacity, aggregating stability, pH, electrical properties, organic matter, and respiratory rate—are used to determine the health of the soil (U.S. Department of Agriculture 2008). Sintim et al. (2019) evaluated the soil health of fields under field pumpkin (*Cucurbita pepo*) production at two sites in the USA after using four mulches with biodegradable properties, like Naturecycle, BioAgri®, PLA/PHA, and Organix, one common plastic mulch, and one paper (cellulosic) mulch. They concluded that different indicators determining soil health, soil properties, and soil activities were changed more based on the time and site of cultivation than the nature of mulching materials used, but some properties, such as electrical conductivity, pH parameters of soil, aggregating stability, infiltration rate, amount of nitrate-N, and potassium exchangeable capacity, were significantly affected by the mulch treatment, but the results were not consistent. However, they assumed that the use of plastic mulch with biodegradable properties would be a viable alternative to the common polyethylene sheet.

The soil covered with biodegradable mulch, when ploughed, discharges some compounds that come into close contact with soil microorganisms and plants. During discussion on the use of biodegradable materials as mulch in agricultural fields, three different time periods can be considered. (1) Mulch storage: during storage conditions in a dry place; lowered temperature, and darkness, the biodegradable plastic mulches endure photo-, oxy-, and biodegradation if they are covered by impermeable material. The film made of polybutylene adipate terephthalate and polylactic acid kept all of its properties as it is and showed integrity after more than one year of storage (Künkel et al., 2016; Hayes et al., 2017). (2) During mulch covering: after they are installed, elements like rainfall, wind currents, solar radiation, irrigation, fertilisers, herbicides, pesticides, activities of labour, soil microorganisms, cultivated plants, weed growth, weed development, etc. influence the structure and properties of both LDPE and biodegradable material-based mulches and leach several constituents like additive compounds and polymeric substances into the soil. Serrano-Ruiz et al., (2020) revealed that even after a brief exposure to rain or irrigation water, the leaching and movement of additive materials and monomer components from biodegradable plastics is significantly higher than that of common plastic mulch. Moreover, the structure of the carbon in the polymer backbone of the film is altered by air oxygen and solar radiation, making it more brittle and susceptible to fragmentation (Ammala et al., 2011). The agrochemicals commonly used in agriculture fields are absorbed or adsorbed by the mulching materials and released in the soil, where they may be toxic to different soil-living organisms (Silva et al., 2019; Ramos et al., 2015). Both the plastic and biodegradable mulching materials are non-sterile, and they release specific microorganisms in the agricultural soil; the specificity depends upon the materials used to make the mulching materials (Zhang et al., 2019; Kirstein et al., 2019). Again, the native soil microorganisms may colonise immediately after the installation of mulching materials and start biodegradation, producing several monomeric compounds and different by-products in the soil that may alter the biotic community of the soil. This alteration further depends on the location and other weather conditions. In the case of LDPE mulches, complete biodegradation will take more than 100 years, whereas biodegradable materials take a few months for complete deformation (Touchaleaume et al., 2018). As a result, this type of mulching material very quickly changes the biotic community of the treated soil. In addition, the incorporated additive components and monomeric compounds from biodegradable mulches can form a wide range of chemical compounds that may accumulate with unknown harmful effects on living biota (Chae and An, 2018; Miles et al., 2017). Moreover, the effect of micro- and nano-level compounds developed from biodegradable materials on terrestrial environments has not been properly identified, and a lack of sufficient data in this regard limits our understanding of the surface functions of soil-decomposed plastic materials (Shruti and Kutralam-Muniasamy, 2019). (3) Mulching materials after the harvesting of crops: immediately following crop harvest, the biodegradable mulching materials are integrated into the cultivable soil; later, a new cycle of crop cultivation and mulch degradation will start. The soil's mixed macro, micro, and nano materials, additive substances, monomer components, and by-products of the decomposition process are continuously released until they completely mineralize into CO_2 and H_2O; thus, a high rate of decomposition is required to prevent the buildup of biodegradable products. According to the international standards (EN 17033, 2018), the mulching material will be recommended as biodegradable if 90% of the materials are degraded in less than two years in the topsoil of any agricultural field in an aerobiosis process at 20–28°C. Numerous studies on biodegradation in lab experiments showed that the decomposition of plastic mulches depends on the type of material, the size of the fragments, and the incubation parameters, such as oxygen level, pH, humidity, temperature, availability of nutrients, etc. (Ardisson et al., 2014; Al Hosni et al., 2019; Tosin et al., 2019). In nature, the incubation parameters for biodegradation depend on soil type, location, environmental conditions, and depth of soil (Haider et al., 2019; Li et al., 2014). In the present literature review, works in this field are very limited. Kapanen et al., (2008) revealed that after one year in soil, a starch-based biodegradable mulch film weighed less than 4 percent of its original weight. In contrast, a recent study shows that 26–83% degradation may occur based on the nature of materials in biodegradable mulch, the kind of soil, and environmental conditions, such as warmer climates facilitating higher biodegradation rates than cooler climates (Sintim et al., 2020). Ghimire et al. (2020) recovered macroscopic fragments in the agricultural field after four years of repeated use of biodegradable mulches. Although there is little information on micro- and nano-plastic accumulation in cultivation fields, it is anticipated that biodegradable plastics will produce fragments more quickly than conventional plastics because they are exposed to more microbes on their surfaces (Tosin et al., 2019).

Ecotoxicity assessment of biodegradable plastic mulches

The ecotoxicity assessment is pertinent for biodegradable plastic mulches because the biodegradable materials are ultimately incorporated into the cultivable soil. The utility of biodegradable and compostable mulches has increased in the last six years, prompting interest in studies looking at how they affect key ecosystem creatures (Bandopadhyay et al., 2018; Sintim and Flury, 2017; Li et al., 2014), but only a small number of papers have discussed the research related to the impact of disposable mulching materials on plant species and bacterial communities in soil.

Ecotoxicity Assessment of BPM on Plants

The toxicity of biodegradable plastic mulches can be assessed by evaluating the growth of plants in agricultural fields or on aqueous soil extracts where biodegradable plastic fragments are present (Souza et al., 2020; Qi et al., 2018; Muroi et al., 2016; Sforzini et al., 2016; Palsikowski et al., 2018). The ecotoxicity evaluation was carried out by planting seeds in soils that had accumulated 1% (w/w) plastic fragments and that had been buried previously about 6–7 months ago. The germination percentage and dry weight of plants like barley, cress, rape, and sorghum did not show any significant variation in the presence of biodegradable materials in soil (Muroi et al., 2016; Sforzini et al., 2016). But in another study by Fritz et al. (2003), it was revealed that 20–50% of plant biomass is decreased in the case of cress, rape, and millet plants when the soils are fortified with polyesteramide-based film fragment [2% (w/w)]. Qi et al., (2018) reported that the soils having LDPE [1% (w/w)] and BDM mulch affected both the vegetative and reproductive growth of wheat plants and the effect of plant growth depended on fragment size; the fragments between 50 and 1000 nm produced stronger consequences than those between 4 and 10 mm, while the synergistic activity of soil earthworms added major effects on plant growth in the presence of plastic fragments. But Palsikowski et al. (2018) did not find any cytotoxic, genotoxic, or mutagenic effects of an aqueous soil extract having an Ecoflex® (PBAT) [2% (w/w)] biodegradable plastic film component buried in soil for more than 6 months on onion plant growth. However, the blending of Ecoflex® (25%) and polylactic acid (75%), as mulching materials, showed chromosomal aberration in the onion root tip squash. In a similar experimental design, the effect of soil-extracted aqueous solutions containing Ecoflex® mulch alone or UV radiation stabilizers mixed with mulch after 6 months buried in soil could not produce any significant effect on lettuce seed germination and its early growth. This soil extract also did not show any kind of mutagenic or genotoxic effects on the onion root tip test (Souza et al., 2020). The potential impact of an aqueous extract of biodegradable mulches such as BioFilm, Mater-Bi, BioFlex, Bioplast-SP4 and SP-6, Mirel, Ecovio, paper, and polyethylene mulch films on seed germination of tomato and lettuce as well as plant growth was assessed by Serrano-Ruiz et al. (2018). The germination percentage of both lettuce and tomato was reduced by Bioplast films containing solution, and the root development of lettuce was significantly decreased by all the treatments besides polyethylene and paper mulch. The above-mentioned stem growth of lettuce was also restricted with both BioFlex and Bioplast treatments but increased with paper-extracted mulches. They showed tomato plants were more sensitive than lettuce in the test. In contrast to lettuce, the root growth and aerial plant growth of tomatoes were decreased by all the treatments except polyethylene and BioFlex. It was found that in the case of both plant species, the proline content was increased by a biochemical marker of plant stress. In contrast to biodegradable plastic mulches, LDPE had minimal effects on wheat (Qi et al., 2018). To test the ecotoxic effect of individual components, additives, and by-products of biodegradable mulches, Martin-Closas et al. (2014) grew tomato and lettuce plants on *in vitro* culture media supplemented with succinic acid, 5 to 500 mg L^{-1} 1,4-butanediol monomers, adipic, and lactic acids and revealed dose-dependent effects. Adipic acid showed the highest cytotoxic effect on both plants and all the chemical components enhanced proline content in both lettuce and tomato plants. Also, they stated that all four of these substances are easily liberated into water, both during their biodegradation into the soil and even when the plastic mulch is installed on fields (Serrano-Ruiz et al., 2020). The PLA microplastics at very low concentration [0.1% (w/w)] in buried conditions were found to be responsible for decreasing the seed germination percentage of perennial ryegrass and as well the height of plants in soil having such biodegradable mulches (Boots et al., 2019). They also reported the alterations of chlorophyll a and b, which ultimately affected the photosynthetic activity. In another study, Wang et al., (2020) also reported the reduction of plant biomass and chlorophyll amount and alteration of arbuscular mycorrhizal fungi association in the roots of maize plants when they are grown in PLA microplastics [10% (w/w)] containing soils. Because nano-plastics may easily pass through biological membranes and directly into plant tissue, they have a significant negative impact on ecosystems and ultimately affect the food chain (Ng et al., 2018; Rillig et al., 2019). Some of the research did not identify the phytotoxicity of biodegradable nanoplastics (Serrano-Ruiz et al., 2021), but some research shows that nanoplastics are incorporated into the shoots through absorption by plant roots and lead to growth alteration in the affected plants (Lian et al., 2020; Giorgetti et al., 2020).

According to the European Commission (2017) and the US Environmental Protection Agency (2019) the use of phthalate esters is getting popular as a plasticizer additive due to its low cost as compared to bio-based alternatives, but it is a high-priority pollutant because of its harmful properties like endocrine disruption, promotion of mutations, and causing cancer (Rowdhwal and Chen,

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2018). The use of phthalates in biodegradable mulches is avoided by a few firms (Ambrogi et al., 2017). However, it is nevertheless prevalent in other nations due to strict laws (Ghosh, 2017). The matter is very serious when phthalate esters are used in biodegradable plastic mulches because the molecules are retained in the soil after their complete biodegradation. Du et al. (2009) reported the leaching of di-(2-ethylhexyl) phthalate (DEHF) into the field from plastic (LDPE) mulches and its incorporation in ten vegetable crops. The US Environmental Protection Agency's daily intake criterion for DEHP was very nearly met in the consumable parts of wax gourd and Chinese cabbage. There are also many reports that the supplementation of phthalate esters on plants like turnips, maize, and other fodder plants reduces plant growth and development (Kong et al., 2018; Li et al., 2014), with the associated restriction on plant development. In addition, phthalate esters disrupted plant growth by interfering with the changes in endophytic bacteria and fungus communities present on the surface of roots and leaves (Kong et al., 2019; Kong et al., 2018). Therefore, biodegradation is not only the solution to replacing LDPE with biodegradable plastic mulch, but its constituents should not affect the ecosystem.

Ecotoxicity assessment of BPM on soil microorganisms

Following installation on the soil surface, the biodegradable plastic mulch directly interacts with the soil microorganisms, particularly at the buried edges of the mulch and underside, which are in direct contact with the soil. Similarly, mulch ingredients also mix with the soil from the films. As a result, it alters the microbial communities in the soil. Therefore, the influence of biodegraded mulches on microorganisms in soil should be assessed from the onset of their installation in the soil to their incorporation in the soil after crop harvesting. Following 30 days of PBSA (polybutylene succinate adipate) biodegradable plastic wrapping, Koitabashi et al. (2012) demonstrated remarkable changes in fungal populations in soil, with the predominance of *Penicillium*, *Aspergillus*, and the protozoan species *Acanthamoeba*. The changes in microbial communities in the agriculture field also depend on soil quality. Zhang et al. (2019) studied the alteration of microorganism communities in two agricultural lands by the use of PLA/PBAT (polylactic acid/polybutylene adipate terephthalate) mulch in cotton fields for seven months, and they found the dominant bacterial populations were Actinobacteria, Acidobacteria, Chloroflexi, and Proteobacteria, in comparison, to no-PLA/PBAT mulch. Even in the absence of mulch, the decomposing bacterial population (*Sphingomonas*, *Bacillus*, *Streptomyces*) is much more prevalent in one field than in the other, indicating that field was better suited for the application of biodegradable PLA/PBAT mulch. The soil microbiome is also changed by the integration of biodegradable mulches in soil (Table 2). A correlation between polybutylene succinate-co-adipate (PBSA)-degrading fungi and esterase activity as well as the rate at which PBSA film degrades was revealed in a study. In comparison to other soil samples, Yamamoto-Tamura et al. (2015) found biodegradation is more rapid in the soil where substantial fungal populations that degrade PBSA were observed to have strong esterase activity. After the plants grew in the soil containing buried biodegradable mulching fragments for four months, Qi et al. (2020) observed the promotion of bacterial communities in the rhizosphere, including *Bacillus*, *Variovorax*, and *Clostridium*. Similarly, Muroi et al. (2016) demonstrated the presence of soil bacteria and fungi, particularly *Setophoma terrestris*, a fungal phytopathogen, after burrowing Ecoflex® mulch fragments for 7 months. Two bacterial genera, *Caenimonas* and *Hyphomicrobium*, that were previously grown on plastic also formed biofilms in that soil. To find out the influence of biofilm on the environment, a large number of factors such as the nature of the mulch, season, soil microenvironment, and presence of biodegradable natural flora of microorganisms should be considered.

Kong et al. (2018) noticed the reduction of bacterial diversity in soil and the alteration of bacterial communities from spiking biodegradable plastic mulch in the soil. Dibutyl phthalate (DBP), an organic compound commonly used as a plasticizer, has a significant detrimental impact on the mutual interactions between fungal species, alters the variety of fungal communities in soil, and disrupts the structure of the ecological network (Kong et al., 2019). Research on the impact of biodegradable mulches on soil microorganisms beyond a year is very rare. After tilling PBAT-starch-based mulch into the soil for a year, Kapanen et al. (2008) did not notice any changes in the potentiality of nitrogen fixation in the soil, which is carried out by ammonia-oxidizing bacteria. Similarly, two years of mulching with polycaprolactone and PBSA did not change the number of bacteria or the composition of the bacterial population in the soil (Masui et al., 2011). But in contrast, according to reports, using biodegradable mulches for one or two years changes the soil microbiome. Moreno and Moreno (2008) found that after using biodegradable mulch for a year, there was a greater increase in soil organic matter mineralization and microbial biomass carbon in the soil than with LDPE film mulches. Both Sintim et al. (2019) and Li et al. (2014) noted that soil health indicators, including bacterial growth

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and activity, are influenced two years after the use of biodegradable mulches and that these impacts vary depending on the location, seasonality, and production method. In contrast to locational and seasonal variability, Bandopadhyay et al. (2020) showed that biodegradable and LDPE mulch had very little impact on enriching the soil microbial and fungal population and their activities.

Ecotoxicity Assessment of BPM in Other Organisms

Based on the scant short-term study data, the ecological impact of biodegradable plastic ground cover on plants and soil bacteria has been explained in the previous two chapters. Only two research studies on the effects of bioplastic mulches on other living things are currently available. Fritz et al. (2003) reported the inhibition of the growth of cress and millet, rape plants, *Vibrio fischeri* bacteria, and *Daphnia magna* crustaceans but an increase in the earthworm population when the poly(ester-amide) film was used as mulching material. On the contrary, Sforzini et al. (2016) did not observe any ecotoxic effects of PBAT-corn starch-based Mater-Bi® mulching film on sorghum, cress plants, *Vibrio fischeri* bacteria, green algae, slime mould, protozoa, invertebrates like earthworms, or common water fleas. Likewise, a prior study also found that Mater-Bi® had no significant ecotoxic effects in soil that had been tilled for a year and enriched enchytraeid worms and the bacteria *Vibrio fischeri* (Kapanen et al., 2008). The earthworms, together with plants and soil microorganism activities, are included in the European minimum requirement for compostable mulching ecotoxicity. Through enhancing soil structure and nutrient cycling, earthworms serve as ecosystem engineers for agricultural soil health (Bertrand et al., 2015). The PLA-based plastic particles [0.1% (w/w)] embedded in the soil decreased earthworm biomass but did not cause mortality (Boots et al., 2019). According to a previous study by Zhang et al. (2018), LDPE and other biodegradable plastic mulches had no effect on earthworm mortality; instead, they consumed only soil-covered starch-based BDM compost. It was discovered that earthworms helped break up and bury plastic debris, which facilitated microorganism biodegradation (Sanchez-Hernandez et al., 2020).

Nematode *Caenorhabditis elegans* is regarded as a model organism for ecotoxicological investigations in contaminated soils, and it is also used to examine the terrestrial toxicological effects of plastic mulches. The small differences between Low - density polyethylene and bioresorbable (Ecoflex®-PLA blends) mulching microplastics showed a noticeable effect when the nematode *C. elegans* consumed them, which caused a decrease in growth and reproduction of the nematode (Schöpfer et al., 2020). In an in vitro investigation the

hepatocarcinoma human cell lines the Ecoflex® mulch containing soil preparations had no genotoxic, cytotoxic or mutagenic effects (Souza et al., 2020). Ma et al. (2017) reviewed the ecotoxic effects of specific components leached from bioplastic mulches on ground invertebrates and demonstrated how low DEHP concentrations (1 mg. Kg^{-1}) in the soil can alter earthworm's physiological function, including oxidative enzyme activity, a decrease in the concentration of critical proteins, DNA damage, and cell membrane damage. Similarly, according to Yin et al. (2018), DEHP treatment (0.01 to 100 mg/L) decreased the population of *C. elegans* by reducing their ability to produce oocytes and increasing the number of apoptotic germ cells.

Conclusion

In order to boost productivity by reducing weed populations, preventing water loss through evaporation, controlling soil temperature, etc., the use of plastic mulch films in the growing of vegetables and other specialty crops is now becoming highly popular throughout the world. But increasing microplastic pollution is a great threat to every life form. Hence, biodegradable plastic films are essential options for usage as mulches in order to maintain the sustainability of agroecosystems. A significant amount of research has gone into developing biodegradable plastic mulches that can be integrated into the soil at the completion of the growing season, where they will be broken down by microorganisms into CO_2, H_2O, and biomass. On reality, the dynamics of biodegradation involve fragmentation, compound liberation, and ultimately the breakdown of the elements by soil microorganisms.

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Table 2. Use of different types of bio-degradable plastic mulch and their effect on soil microbial community.

Types of mulching materials	Name of the Crop fields	Effect	References
PBAT	Cabbage	When compared to PEM mulching, the use of BDM increased the relative abundance of the *Proteobacteria* and Acidobacteria phyla, while it decreased the relative abundance of the Chloroflexi, Gemmatimonadetes, Bacteroidetes, Planctomycetes, Nitrospirae, Verrucomicrobia, and Latescibacteria. In comparison to PEM mulching, the use of BDM enhanced the relative abundance of Ascomycota, Basidiomycota, and Olpidiomycota while decreasing the abundance of *Mortierellomycota* and *Chytridiomycota*.	Zhang et al., 2023
poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV)	*Zea mays* L.	The PHBV affects plant growth by lowering down the foliar nitrogen content and foliar metabolic function but in dose-dependent manner. The presence of PHBV in the soil also reduces the plant's availability of nitrate and ammonium. The suppression of microbial activity and reduced level of bacterial diversity alters the overall metabolic pathway of the soil.	Brown et al., 2023
1% (w/w) Bio macroplastics; 1% (w/w) Bio microplastics	Wheat	The bacterial population like *Bacillus* and *Variovorax* on the rhizosphere was found to be increased significantly and a dodecanal type of volatile substance was released from the soil after treatment with biodegradable microplastic.	Qi et al., 2020
PBAT/PLA	Grain	In comparison to the polyethylene plastisphere, the structure of the bacterial community was significantly different on PBAT/PLA plastisphere where alpha diversities were much smaller. Again, the bacterial community structure was significantly different from soil and PE plastisphere. The Proteobacteria and Actinobacteria dominated in PBAT/PLA surface as they degrade it.	Li et al., 2023
PHBV is a co-polymer of hydroxybutyrate and hydroxyvalerate	cereal production (e.g., wheat, barley, maize) and grassland (*Lolium perenne* L.) in rotation.	The mulching materials of PVHV, augmented in the soil at different rates, alter the bacterial abundance proportionately. The population of proteobacteria significantly increased, but the proportional abundances of firmicutes and gemmatimonadetes were reduced when 1% and 10% PHBV were added to the soil. In contrast, when PHBV augmentation rates were lower (0.01% and 0.1%) Verucomicrobia and Acidobacteria both showed an increase in abundance compared to control and higher concentrations (1% and 10%). As a result, significant variation in alpha diversity was noticed.	Chu et al., 2023

Biodegradable films [polybutylene co-adipate co-terephthalate (PBAT) + polylactic acid (PLA) content > 95%]	garlic–maize	In a study of subsequent two years, the microbial activity significantly increased in biodegradable plastic mulch (BPM) and polythene mulch (PEM) in comparison to no mulch; in the first year, the increased percentage at 0–10 cm soil layer was 23.47% and 20.09%, and in the second year, 58.97% and 55.00%, respectively. But in the 10–20 cm soil layer, no significant variation among the three treatments was observed in the first year, whereas 94.12% of microbial activity was increased in the next year in the BPM treatment with respect to no mulching.	Zhang et al., 2022
BioAgri (blend of starch and PBAT), Nature cycle (Blend of starch and polyesters); Organix A.G. Film 1 (blend of PLA and PBAT); PLA/PHA, Weed Guard Plus R (Cellulose), Polyethylene (Linear low-density polyethylene)	Vegetables	Mulch treatment has no impact on bacterial richness or diversity. Mulch treatments reduced N-acetyl- β-glucosaminidase and Xylosidase activity. Probably the mulch cover has an indirect effect on microclimate conditions which leads to that changes in extracellular enzymes expression.	Bandopadhyay, et al., (2020)
Mater-Bi (grade EF04P), a biodegradable plastic material	Grain field	When biodegradable plastic is incorporated into the soil, it causes a 49% increase in CO_2 release in loamy soil but a 435% increase in CO_2 release in sandy loam soil. The nitrification potential increased by 29% in sandy loam soil, but only by 26% in loamy soil.	Mazzon et al., 2022
starch, polylactic acid (PLA) and polybutylene adipate terephthalate (PBAT)	Soil from agriculture field	The biodegradation performance was studied by calculating the weight loss percentage of biodegradable plastic mulches (BPM) in different soils and data were taken at regular intervals upto 360 days. The weight loss percentage was recorded 40 to 50 at different soils. The highest degradation percentage was noticed at first 30 days where 36 to 42% weight loss was calculated. The weight loss percentage coincided with an increase of 1.53–2.25 times dissolved organic carbon in comparison to the control soil rate. The degradation rate was much slower from 30 to 360 days.	Meng et al., 2023

The composition of the mulch plays a major role in its effective use, proper degradation, and keeping the physical, biochemical, and biological parameters intact. A good number of studies recommend the use of biodegradable plastic film for soil solarization as well as mulching materials for the agronomical benefits of major vegetables and other horticultural plant production. A few studies have also shown that the presence of some biodegradable mulching film components changes plant development and growth, while a few others showed that certain components of mulching films are likely to be safer for crop production. The sensitivity of plants to mulching components is species-dependent. The effects of biodegradable plastic mulches on soil microbes and other soil living things have not yet been adequately studied, similar to studies with plants. To ensure the soil's health and the sustainability of various mulching materials in agro-systems, thorough long-term research is necessary.

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Conflict of Interest:

The authors declare that there is no conflict of interest.

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