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Plastic Mulch Pollution and Introduction of Biodegradable Plastic Mulches: A Review

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ABSTRACT

The use of plastic mulch in agriculture has increased dramatically in the last 10 years throughout the world. The adverse effects of plastic mulch pollution in agriculture forced the scientists to search for alternatives. Studies in Xinjiang showed that residual plastic film mulch levels of 200 kg m^{-2} in the topsoil (0–20 cm) affected the emergence rate of cotton seeds and reduced cotton production by 15%. Soil mulching for 5–20 consecutive years led to a 122–146% increase in the salt content of the topsoil. Efficiency of both plastic mulches and biodegradable mulches compared in terms of crop production, period of weed control, etc.

Key words: Biodegradable mulches, Plastic mulches, Weed control.

The use of plastic mulch in agriculture has increased dramatically in the last 10 years throughout the world.This is due to benefits such as increase in soil temperature, reduced weed pressure, moisture conservation, reduction of certain insect pests, higher crop yields and more efficient use of soil nutrients. In India, it can come in handy to realize the overall aim to double farm income domestically by 2022 (Srinidhi and Nazareth, 2018).

The idea of using polyethylene film as mulches came in mid 1950's.Dr.Emery M. Emmert of the University of Kentucky was one of the first to recognize the benefits of LDPE and HDPE (Kasirajan and Ngouajio, 2012).Crops grow through slits or holes in thin plastic sheeting. This is often used in conjunction with drip irrigation. Certain plastic mulches also act as a barrier to keep methyl bromide, fumigant in soil.

However, disposing of used plastic films, which cause pollution, has led to development of photodegradable and biodegradable mulches (Kasirajan and Ngouajio, 2012).

Plastic Mulch Pollution Problem in India and China

Plastic mulches produced from petroleum based plastics, usually polyethylene causing a considerable waste disposal problem (Halley *et al*. 2001).It interfere with root development of the subsequent crop. Plastic requires pickup and disposal at the end of the season (Schonbeck 1995).

Film fragments left in fields can also accumulate pesticides and other toxins applied to crops causing risk for sheep, goats and other livestock grazing on crop stalks because of their potential to ingest plastic material or the chemicals that leach from it. When cotton crops are grown in plastic-contaminated soil, the lint is in risk of being contaminated. Steps such as those taken by smart cities like Muzzaffapur and progressive states like Maharashtra in banning single use plastics and enforcing penalties for non-compliance will certainly help (Srinidhi and Nazareth, 2018).

The volume of plastic film mulch used in China increased four-fold from 3,19,000 tons to 1,2,45,000 tons from 1991 to 2011 (According to China Agricultural Statistical Yearbook) generated large amounts of mulch residue. Plastic film mulch technology evolving from 'white revolution' to 'white pollution' .Studies in Xinjiang showed that residual plastic film mulch levels of 200 kg m^{-2} in the topsoil (0–20 cm) affected the emergence rate of cotton seeds and reduced cotton production by 15%.

Soil mulching for 5–20 consecutive years led to a 122–146% increase in the salt content of the topsoil.Degradation of polyethylene residual mulch film is negligible with the possible formation of environmentally harmful chemical products such as phthalate esters, di-(2- ethylhexyl) phthalate, aldehydes and ketones (Liu *et al*., 2014).

Plastic Mulch Disposal

Plastic mulch disposal is mainly done through landfilling, incineration and recycling.Burning of polyvinylchloride plastics produces persistent organic pollutants, furans and dioxins (Jayasekara *et al*., 2005).

High costs in gathering and discarding films and the recycling process, plastic films, often discarded in a dump or burned with the subsequent emission of toxic substances to atmosphere and soil (De Prisco *et al*., 2002). Most of the agricultural plastics photodegraded due to exposure to UV light, which make them unacceptable as recycles (Levitan and Barro, 2003).Plastic films with more than 5% contaminants by weight will not be accepted for recycling (Clarke, 1996).

In some areas progress has been made in recycling, including the Recycling Agricultural Plastics Program (RAPP)

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at Cornell University and the Florida Agricultural Plastic Recyclers (FLAG), which have developed ways to clean used mulch film efficiently. A 2008 report from California states that about 36% of producers surveyed recycle some of their agricultural plastic and that on-farm plastic pick-up would greatly increase their recycling rate (Hurley 2008). According to a 2013 report from Moore Recycling Group, there has been a rise in plastic film recycling (items like grocery bags), but recovery of used agricultural film has declined by 11% for dirty agricultural plastic film and by 98% for clean ag film. This decline is partially due to China's 2013 "Green Fence" program which implemented strict regulations for the quality of recyclables they will accept (Moore and Wszelak, 2016).

Contaminants in agricultural plastics can be up to 40–50% by weight from pesticides, fertilizers, soil and debris.Polyethylene mulches contain nearly as much potential energy per unit weight as oil and could be incinerated to produce heat or electricity (Hemphill 1993; Lamont 2005). Most power plants and incinerators are not designed to burn dirt- and debris-covered plastic and operators are reluctant to make attempts to do so .Many landfill operators reject plastic mulch film as unsuitable landfill material due to its level of contamination. There is potential to recover energy from plastic film through incineration, but as with recycling, there are obstacles (Hemphill 1993, Briassoulis *et al*., 2012). Facilities that produce fuel from used plastics often operate 24 hours a day, seven days a week, thus they need a predictable fuel supply. Agricultural film tends to be widely dispersed, seasonal and low in volume, which makes it harder to use for fuel production (Hemphill 1993, Springman 2014). Other concerns with incineration include pesticide residues and emissions (Garte and Kowal 1993, Felton 2016).Burning PE can release carcinogenic substances, such as dioxin and other toxic particles into the air (Valavanidis *et al*., 2008) (Moore and Wszelak, 2016).

One of the main criticisms of landfilling is the fact that wastes in the landfills, including plastics, either do not degrade or degrade at a very slow rate. (Kasirajan and Ngouajio, 2012).

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 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. The introduction of biodegradable materials, which can be disposed directly into the soil, can be one possible solution to this problem.

Alternatives to Polyethylene Films

Paper-based mulches used in agriculture since 1914, when paper was used to reduce weed pressure in sugarcane fields (Smith 1931). Asphalt-impregnated paper mulches, successfully used in pineapple (*Ananas comosus*) production in the 1920s in Hawaii, increasing quality and yields (Smith 1931). Paper mulches, considered as an alternative to plastic but suffer from very rapid degradation and usually begin to break apart just a few weeks after exposure to soil, rain and wind (Anderson *et al.* 1995; Shogren 1999, 2000).Although thicker paper and fiber mats can be used to lengthen lifetimes, these can be very expensive to use. Current research indicates that mats do not biodegrade easily and can only partially prevent weed growth (Halley *et al*. 2001).

Degradable Mulches

The use of biodegradable or photodegradable mulch films-alternative to petroleum-based products,reduce labor cost to remove the mulch products after use (Debeaufort *et al*. 1998; Guilbert *et al*.1996).At the end of their lifetime, it can be incorporated directly into the soil or into a composting system (Moreno and Moreno, 2008).In the 1960s and 1970s, scientists started to investigate the possibility of using biophotodegradation as a self-destructive disposal technique for plastic film (Moreno and Moreno, 2008).There are two types of degradable mulches and these are:

- **Photo-degradable mulches:** It get disintegrated under the sunlight over the designated mulching period.
- **Bio-degradable mulches:** It gets disintegrated under natural environmental conditions and gets mixed in soil after mulching period.

Biodegradable Plastic Mulches

It is mainly made from plant starches, sugars or polyester fibers, petroleum resources**.**These starches can come from plants such as wheat and corn**.** It may be a bit more permeable. At the end of the season these mulches will start break down from heat**.** Microorganisms in the soil break down the mulch into two components, water and carbon dioxide leaving no toxic residues behind**.** Polymers such as poly (lactic acid), poly (butylene adipatecoterephthalate), poly (ε-caprolactone) and starch-based polymer blends or copolymers can degrade when exposed to bioactive environments such as soil and compost**.** It's much more delicate and should be placed on a day which is not too hot and with less tension than other synthetic mulches (https://en.m.wikipedia.org/wiki/Mulch).

Early attempts to develop plastic mulches, starch-based polymers have shown enhanced biodegradability but remain too expensive and sometimes too heavy for agricultural applications (Feuilloley *et al*. 2005; Halley *et al*. 2001; Olsen and Gounder 2001). European nations are the front runners of biopolymer research.Chinese researchers focusing on refinement of microbially produced polyhydroxyalkanoates. Biodegradable polyesters which have been developed commercially or are in commercial development are polyhydroxyl alkanoates, polyhydroxyl butyrate, polyhydroxyl hexanoate, poly hydroxyl valerate, polylactic acid, polycaprolactone, polybutylene succinate (PBS), polybutylene succinate adipate, aliphatic–aromatic copolyesters, polyethylene terephthalate, polybutylene adipate/terephthalate and polymethylene adipate/terephthalate (Anonymous 2002). PBS is one of the commercially used biodegradable plastics with a range of desirable properties, including good mechanical properties,

the ability to be melt-processed, biodegradability and environmental compatibility (Kim *et al*. 2006).

Microbial Degradation of Biodegradable Plastic Mulches

Microbial degradation is by naturally occurring microorganisms such as bacteria, fungi and algae (Mooney, 2009).

Bioplastics (biopolymers) obtained from growth of microorganisms or from plants which are genetically engineered to produce such polymers. To be biodegradable, some parts of the polymer main chain must be similar to naturally occurring substances; microbes use their existing enzymes to break the polymer chain at those specific locations and use them as a source of energy. Weak links present in the chain also can facilitate attack by particular microorganisms. Portions of polymers that are small enough are transferred into microbial cells and consumed as a food source. Chemical structures of pyruvic acid and lactic acid are similar to that of polylactic acid (Kasirajan and Ngouajio, 2012).

Polyolefin and vinyl families, the main chain of the polymer consists of carbon atoms, which make the polymer very stable to degradation or biodegradation.

Ester bonds in biodegradable polyesters, such as adipate/ terephthalate, polylactic acid and poly (hydroxyalkanoates), make those polymers susceptible to chemical degradation involving hydrolysis. Hydrolysis creates random main chain scission, causes rapid molecular weight reduction. This reaction accelerates the biodegradation since smaller molecules are more susceptible to enzymatic reactions. The chemical structure of the polymer is the main factor determining whether the polymer can or cannot biodegrade and its biodegradation or erosion mechanism. During degradation, the polymer first converted to its monomers and then these monomers are mineralized. The initial breakdown of a polymer can result from a variety of physical and biological forces (Swift 1997). Physical forces, heating/ cooling, freezing/thawing, or wetting/ drying, can cause mechanical damage such as the cracking of polymeric materials (Kamal and Huang, 1992). The growth of many fungi can also cause small-scale swelling and bursting, as the fungi penetrate the polymer solids (Griffin 1980). Two categories of enzymes involved in biological degradation of polymers: extracellular and intracellular depolymerases (Doi 1990; Gu *et al.* 2000). When O_2 is available, aerobic microorganisms are mostly responsible for destruction of complex materials, with microbial biomass, CO_2 and H_2O as the final products. Under anoxic conditions, anaerobic consortia of microorganisms are responsible for polymer deterioration. The primary products will be microbial biomass, CO_2, CH_4 and H_2O under methanogenic (anaerobic) conditions (Barlaz *et al*., 1989). It could be made from polylactic acid a biodegradable polymer derived from lactic acid. This is one form of vegetable-based bioplastic. This material biodegrades quickly under composting conditions and does not leave toxic residue(Kathiresan, 2003). First stage of degradation of polylactic acid (2 weeks) is via hydrolysis to water-soluble compounds and lactic acid, follow by rapid metabolism of these products into CO_2, water and biomass by a variety of microorganisms.

There have been reports on the degradation of polylactic acid oligomers (molecular weight ~1,000) by *Fusarium moniliforme* and *Penicillium roquefort* (Torres *et al*., 1996) and the degradation of polylactic acid by *Amycolatopsis* sp. (Pranamuda and Tokiwa 1999) and by *Bacillus brevis* (Tomita *et al*., 1999).

Enzymatic degradation of low molecular weight polylactic acid (molecular weight ~2,000) has been shown using esterase-type enzymes such as Rhizopusdelemer lipase (Fukuzaki *et al*., 1989).

Effect in Crop Production

Anzalone *et al*., (2010) evaluated the weed control efficiency of several biodegradable mulches as alternatives to black polyethylene mulch. The treatments were rice straw, barley (*Hordeum vulgare*) straw, maize harvest residue, absinthe wormwood plants (*Artemisia absinthium*), black biodegradable plastic, brown kraft paper, polyethylene, herbicide, manual weeding and unweeded control. Best weed control and lowest weed biomass were achieved with paper followed by polyethylene and biodegradable plastic.

Tomato yield was the highest for polyethylene followed by paper, manual weeding, biodegradable plastic and rice straw and was clearly related to weed control. Paper, biodegradable plastic and rice straw are potential substitutes for polyethylene and Herbicides. Selective forms of biodegradable mulch tended to break down well before the end of the growing season, this early failure did not negatively impact the performance of any of the crops tested, as long as supplemental weed control was provided. Supplemental weed control would be more important for slow-growing, erect crops like peppers and eggplants than for the more robust and sprawling crops like corn, cucurbits and sweet potato (waterer, 2010).

Period of Biodegradation

The induction periods of four kinds of photo-biodegradable polyethylene films range from 46 to 64 days, which basically satisfies the needs of agricultural cultivation. All photo-biodegradable polyethylene films can be degraded, in which almost no film exists on the surface of the ridges after 2-3months or so after the induction periods. The photo-biodegradable polyethylene films buried in soil have also good degradability (Wang *et al*., 2004).

CONCLUSION

Comparative Advantages of Biodegradable Plastic Mulching Over Plastic Mulching

Biodegradable films warm soils less than polyethylene mulches favorable in areas and seasons having high temperatures responsible for damages to the crops, although PE may be advantageous in areas with cool conditions (Goldberger and Jones, 2013).

PE had more negative effect on soil microbiological properties than the BD films (Moreno and Moreno, 2008). Complete biodegradability means growers do not need to remove and dispose of agricultural plastics—activities that

can be quite labor intensive and expensive (Goldberger and Jones, 2013). Degradation into nontoxic compounds is the main advantage of BD films.

Disadvantages of Biodegradable Plastic Mulching

Although more expensive to purchase than polyethylene plastic mulch, biodegradable mulches may be considerably cheaper when the costs associated with removal and disposal are taken into account. According to the current US National Organic Program (NOP) rules, certified organic growers are allowed to use polyethylene plastic as mulch if the plastic is removed at the end of the growing season. In contrast, organic growers are not allowed to use biodegradable plastic mulch products because the products do not conform to NOP standards.Unpredictable breakdown of biodegradable mulches can serve as a significant adoption barrier (Goldberger and jones, 2013).

Use in Organic Farming

None of films currently meet the requirements of the USDA organic standards.But it is possible in the future. Farmers can check with certifying agent regarding the status of any biodegradable mulch they want to use on their organic fields prior to use. Substances that biodegrade become part of the soil and those substances must be approved for use in organic farming. The mulch must also biodegrade in a certain time frame and any materials used to make the mulch must be bio-based. A bio-based material is a material intentionally made from substances derived from living (or once-living organisms. Currently available (but not approved) biodegradable mulches are typically made with corn or wheat starches.
(www.ams.usda.gov/nop)

Introduction of films produced with biodegradable raw materials,can accomplish the same functions as conventional PE, but without the environmental drawbacks. Field tests of some of these biodegradable films provided promising results. The effect of biodegradable plastic mulch in crop production with regards to microclimate modification, soil physical, chemical and biological properties, soil moisture, weed control, soil nutrients and pest and disease management needs to be studied extensively.

Currently, the materials and technology to develop biodegradable mulch films for agricultural application exist. The major limitation remains the high cost of those materials that prevent their adoption by farmer. At present, biodegradable plastic represents just a tiny market as compared with the conventional petrochemical material. Bio plastics will comparatively prove cheaper when oil prices will continue to hike up.

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