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

V.U. Divya, N.C. Sarkar

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

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 Kowl 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 bioiocenosis (e.g., towards mycotoxicogenic 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 adipateco-terephthalate), 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 microbiologically produced polyhydroxyalkanoates. Biodegradable polyesters which have been developed commercially or are in commercial development are polyhydroxyl alkanoates, polyhydroxy butrate, polyhydroxyl hexanoate, poly hydroxyl valerate, poly lactic acid, polycaprolactone, polybutylene succinate (PBS), polylactide, succinate adipate, aliphatic-aromatic copolymers, 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).

Polylefin 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 (hydroxalkanoates), 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 the 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$_2$O 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$_2$O 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 Rhizopuspeudalipase (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, absinth 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 2-3 months 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.

**REFERENCES**

Anonymous (2002). Biodegradable plastics—developments and environmental impacts.

Briassoulis, D., M. Hiskakis, E. Babou, S.K. Antiohos and C. Papadi. (2012). Experimental investigation of the quality characteristics of agricultural plastic wastes regarding their recycling and energy recovery potential. Waste Management. 32(6): 1075–90.

China Agricultural Statistical Yearbook (2011). https://en.m.wikipedia.org/wiki/Mulch www.ams.usda.gov/nop

Anderson, D.F., Garisto, M.A., Bourrut, J.C., Schonbeck, M.W., Jaye, R., Wurzberger A. and De Gregorio, R. (1995). Evaluation of a paper mulch made from recycled materials as an alternative to plastic film mulch for vegetables. Journal of Sustainable Agriculture. 7: 39–81.

Anzalone, A., Cirueda, A., Albar, J., Pardo, G. and Zaragoza, C. (2010). Effect of biodegradable mulch materials on weed control in processing tomatoes. Weed Technology. 24(3): 369–377.

Barlaz, M.A., Ham, R.K. and Schaefer, D.M. (1989). Mass-balance analysis of anaerobically decomposed refuse. J Environ Eng. 115: 1088–1102.

Briassoulis, D. (2006). Mechanical behaviour of biodegradable agricultural films under real field conditions. Polym. Degrad. Stabil. 91: 1256–1272.

Clarke, S.P. (1996). Recycling farm plastic films fact sheet. http://www.omafra.gov.on.ca/english/engineer/facts/95-019.htm.

Debeaufort, F., Quezada-Gallo, J.A. and Volely, A. (1998). Edible films and coatings: tomorrow’s packagings: a review. Crit. Rev. Food Sci. Nutr. 38(4): 295–313.

Doi, Y. (1990). Microbial polymers. VCH, New York.

De Prisco, N., Immirzi, B., Malinconico, M., Mormile, L. and Gatta, G. (2002). Preparation, physico-chemical characterization and optical analysis of polyvinyl alcohol-based films suitable for protected cultivation. J. Appl. Polym. Sci. 86: 622–632.

Felton, R. (2016). Detroit incinerator is hotspot for health problems, environmentalists claim. https://www.theguardian.com/us-news/2016/oct/23/detroit-garbage-incinerator-pollution-healthproblems-environmentalists.

Feuillolry, P., Cesar, L., Benguiugi, L., Grohena, Y., Pillin, I., Bewa, H., Lefaix,S. and Jamal, M. (2005). Degradation of polyethylene designed for agricultural purposes. J. Polym. Environ. 13: 349–355.

Fukuzaki, H., Yoshida, M., Asano, M. and Kuraoka, M. (1989). Synthetic of copoly (D, L-lactic acid) with relative low molecular weight and in vitro degradation. Eur. Polym. J. 25: 1019–1026.

Garthe, J.W. and Kowal, P.D. (1993). Resource recovery: Turning waste into energy. University Park, Pa.: Penn State Agricultural Sciences Cooperative Extension.

Goldberger, J., Emmet, R., Jones, Miles, C., Wallace, R and Inglis, D. (2013). Barriers and bridges to the adoption of biodegradable plastic mulches for US specialty crop production. Renewable Agriculture and Food Systems. 30(2): 143-153. doi:10.1017/S1742170513000276.

Griffin G, J. L. (1980). Synthetic polymers and the living environment. Pure Appl Chem. 52: 399–407.

Gu, J.D., Ford, T.E., Mitton, D.B., Mitchell, R. (2000). Microbial corrosion of metals. In: Revie W, editor. The Uhlig Corrosion Handbook. 2nd Edition. New York: Wiley. 915–927.

Guilbert, S., Gontard, N. and Gorris L, G., Jenkins, M., Beh, H., Griffin, K., Jayasekara, R. and Loneragan, G. (2001). Developing biodegradable plastic films from starch-based polymers. Starch. 53: 362–367.

Hemphill, D.D. (1993). Agricultural plastics as solid waste: what are the options for disposal? HortTechnology. 3: 70–73.

Hurley, S. (2008). Postconsumer agricultural plastic report. California Environmental Protection Agency, Integrated Waste Management Board.

Jayasekara, R., Harding, I., Bowater, I. and Lornergan, G. (2005). Biodegradability of selected range of polymers and polymer blends.
Plastic Mulch Pollution and Introduction of Biodegradable Plastic Mulches - A Review

Kamal M, R. and Huang, B. (1992). Natural and artificial weathering of polymers. In: Hamid SH, Ami MB, Maadhan AG (eds) Handbook of polymer degradation. Marcel Dekker, New York, pp 127–168.

Kim, H.S., Kim, H.J., Lee, J.W. and Choi, I.G. (2006). Biodegradability of bioflour filled biodegradable poly (butylene succinate) bio composites in natural and compost soil. Polym Degrad Stab 91 (5): 1117–1127.

Kasirajan, S. and Ngouajio, M. (2012). Polyethylene and biodegradable mulches for agricultural applications: a review. Agron. Sustain. Dev. (2012). 32: 501-529 doi: 10.1007/s13593-011-0068-3.

Kathiresan, K. (2003). Polythene and plastics-degrading microbes from the mangrove soil. Rev Biol Trop. 51:3–4.

Lamont, W. J. (2005). Plastics: modifying the microclimate for the production of vegetable crops. HortTechnology. 15:477-481.

Levitan, L. and Barro, A. (2003). Recycling agricultural plastics in New York state. Environmental Risk Analysis Program, Cornell Center for the Environment, CornellUniversity, Ithaca. http://cwmi.css.cornell.edu/recyclingagplastics.pdf.

Liu, E. K., He, W. K. and Yan C. R. (2014). ‘White revolution’ to ‘white pollution’— agricultural plastic film mulch in China Environmental Research Letter (2014), 091001 (3pp) doi:10.1088/1748-9326/9/9/091001.

Mooney, B.P. (2009). The second green revolution? Production of plant based biodegradable plastics. Biochem J. 418:219-232.

Moore, J. and Wszelak, A. (2016). Plastic Mulch in Fruit and Vegetable Production: Challenges for Disposal. Report No. FA-2016-02.biodegradablemulch.org.

Moreno, M. and Moreno, A. (2008). Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop. Scientia Horticultrae. 116: 256–263. Retrieved from www.elsevier.com/locate/scihorti

Olsen, J.K. and Gounder, R.K. (2001). Alternatives to polyethylene mulch film: a field assessment of transported material in capsicum (Capsicum annuum L.). Aust J Expt Agr. 41:93–103.

Pranamuda, H., Chollakup, R. and Tokiwa, T. (1999). Degradation of Polycarbonate by a Polyester-Degrading Strain, Amycolatopsis sp. Strain HT-6. Appl Environ Microbiol. 65(9): 4220–4222.

Schonbeck, M.W., (1995). Mulching practices and innovations for warm season vegetables in Virginia and neighbouring states. 1. An informal survey of growers VA Assoc. Biol. Farming, Blacksburg, VA, 24 pp.

Schonbeck, M.W. and Evanylo, G.K. (1998). Effects of mulches on soil properties and tomato production I. Soil temperature, soil moisture and marketable yield. J Sustain Agric. 13: 55–81.

Shogren, R.L. (1999). Preparation and characterization of a biodegradable mulch: paper coated with polymerized vegetable oils. J Appl Polym Sci. 73:921–967.

Shogren, R.L. (2000). Biodegradable mulches from renewable resources. J. Sustain. Agr. 16:33-47.

Smith, A. (1931). Effect of paper mulches on soil temperature, soil moisture and yields of crops. Hilgardia. 61:592-601.

Springman, R. (2014). Agricultural plastics: Turning the corner to sustainability. April 25, 2014 presentation at Illinois Sustainable Technology Center. http://www.istc.illinois.edu/about/seminarpresentations/20140425.pdf

Srinidhi, A and Nazareth, D. (2018). Beating plastic pollution in agriculture – World Environment Day special. Beating plastic pollution in agriculture – World Environment Day special Swift, G. (1997). Non-medical biodegradable polymers: environmentally degradable polymers. In: Domb AJ, Kost K, Wiseman DM (eds) Handbook of biodegradable polymers. Harwood Academic, Amsterdam, pp 473–511.

Tomita, K., Kuraki, Y. and Nagai, K. (1999). Isolation of thermophilic degrading poly (L-lactic acid). J Biosci Bioeng. 8:752-755.

Torres, A., Li, S., Roussos, S. and Vert, M. (1996). Screening of microorganisms for biodegradation of poly (lactic acid) and lactic acid-containing polymers. Appl Environ Microbiol. 62:2393–2397.

Valavanidis, A., N. Iliopoulos, G. Gotsis and K. Fiotakis. (2008). Persistent free radicals, heavy metals and PAHs generated in particulate soot emissions and residue ash from controlled combustion of common types of plastic. Journal of Hazardous Materials. 156(1–3): 277–84.

Waterer, D. (2010). Evaluation of biodegradable mulches for production of warm season vegetable crops. Can J Plant Sci. 90:737–743.

Wang, Y.Z., Yan, H.J., Lee, J.W. and Choi, I.G., (2006). Biodegradability of photo biodegradablely ethylenemulching films. J Polym Environ. 14:277–283.

Wang, L., Yang, K.K., Wang, X.L., Zhou, Q., Zheng, C.Y. and Chen Z. F. (2004). Agricultural application and environmental degradation of photo biodegradable polyethylene mulching films. J Polym Environ. 12:7–10.