Innovative approach of biodegradable mulches in sustainable agriculture for crop production and environmental conservation

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Abstract. The use of biodegradable plastic mulches in place of conventional plastic mulches in agriculture has been suggested as being more ecologically friendly. However, a number of obstacles, including concerns about performance and cost, have inhibited their implementation. In this study, we set out to determine the impact of biodegradable film mulches on plant production, crop yield, sustainability, nutrient supply, environment, cost-effectiveness, pros and cons with innovative approach. The material and method used in this study include the application of a literature review on biodegradable mulch (BDM) film. According to our findings, the biodegradable film mulch greatly outperformed the plastic mulch in terms of soil health, water use, nutrient availability, and microbial activity. These results imply that biodegradable film mulch has the potential to decrease plastic waste in agriculture while increasing soil health and crop output. In conclusion, using biodegradable film mulch with using innovative approach in agriculture might be an effective means to alleviate the environmental problems brought on by conventional plastic mulches.

1 Introduction

Mulch is an exterior covering that is often made of organic materials like leaves, straw, or peat and is used to protect plants to prevent weed development and moisture loss. In addition to organic mulches, inorganic mulch refers to synthetic materials such as plastics, landscape fabrics, stones and rocks that have various properties and impacts on the soil environment [1]. Mulch films have been made from a variety of materials, but polyethylene plastic has been shown to be the most efficient because of its high mechanical strength, low price, and capacity to function as a barrier for sunlight and water [2].

Mulching is a method that has been utilized in agriculture for many years [3]. Mulches are substances that are applied directly to the soil's surface for a number of reasons, including the protection of seedlings and young shoots through insulation, a decrease in evaporation, weed control, and the avoidance of soil erosion [4]. They in particular protect vulnerable crop species against unfavourable abiotic and biotic stressors that might emerge from harsh weather, insects, pests, and weeds. Mulches are therefore frequently utilized in agriculture to reduce agricultural yield loss [5].

In contrast to synthetic materials, biodegradable materials tend to be non-toxic, degrade more quickly and contain no heavy metals or poisons [6]. In the agricultural sector, these materials are frequently used to cover the soil where plants are planted. Sustainable agricultural practices investigation is now concentrating on biodegradable mulch films [7]. Vegetables and other specialized crops can produce sustainably using BDM films that are used as an alternative of traditional polyethylene (PE) mulches. BDM are disposed of by mineralization in soil or compost, as opposed to PE mulch.

Natural fibers and biodegradable biopolymers, which can disintegrate organically and do not leave any toxic residues in the soil, are used to make biodegradable mulch materials [8]. These substances may be bio-based, synthetic, or a combination of the two types of polymers [9]. Poly (butylene adipate-co-terephthalate) (PBAT), Poly (lactic acid) (PLA (derived from corn starch or sugar cane)), Poly (propylene carbonate) (PPC), Poly (hydroxyalkanoate) (PHA), Cellulose, Starch, Fiber and Proteins are a few of the components frequently utilized to generate biodegradable mulch [7, 10]. After 120, 210, 300, and 365 days in the natural environment, the degradation rates of degradable mulch were 7%, 37%, 57%, and 92%, correspondingly [11]. In general, Briassoulis and Giannoulis [12] study the performance (such as durability, sensitivity to external field conditions, tear resistance, impact resistance, penetration strength, water vapor permeability, CO2 transmission rates, and radiometric properties) of bio-based mulching films was found to be sufficient, offering new design options for sustainable and environmentally friendly agricultural procedures.

As a more environmentally friendly alternative to traditional plastic mulches in agriculture, biodegradable

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mulch has grown in favour. Several agricultural activities, including managing weeds, retention of humidity, regulating temperatures, soil wellness, crop yield and quality, can benefit from the application of biodegradable mulch [13, 7, 14, 15, 16]. It may assist with control soil temperature, creating an environment that is conducive to plant growth, as well as can help maintain soil moisture, minimizing the need for treatment [13]. It can improve soil physicochemical and microbiological characteristics [14] and additionally encourage microbial activity and nutrient cycling [16]. It has the ability to boost agricultural yields and enhance crop quality [15].

Innovative approaches to utilizing biodegradable mulch materials in agriculture can make the application more productive. When assessing the efficiency, viability from an economic standpoint, and environmental friendliness of biodegradable mulch material in agriculture, there are some significant considerations. Crop productivity and water usage effectiveness can both be increased by using biodegradable mulch [17]. Research on biodegradable mulch materials indicate specific deficiencies in the currently being developed material. Some of the problems include worries regarding cost and performance, which have prevented common introduction. Therefore, it is required to study improving the performance and decreasing the cost of biodegradable mulch materials to make them more accessible and effective for use in agriculture.

1.1 Biodegradable mulch materials' impact on plant production for enhancing crop yield and sustainability

The use of biodegradable mulch films in agriculture is gaining popularity as an alternative to conventional plastic mulch films. One significant area of research is exploring the impact of biodegradable mulch films on plant production. By using BDM, the need for fungicides, insecticides, and herbicides can be reduced, leading to more environmentally friendly pest and disease management [18]. BDM also has the potential to reduce plant stress, making plants more resilient against weed diseases and other threats [19].

The use of mulch, especially biodegradable options, can have several positive effects on plant growth. It can increase soil and air temperatures, creating a favorable environment for plant development and ultimately boosting crop yields. However, it's essential to consider the potential impact of biodegradable plastic mulch films on ecosystem processes and microbial populations in the soil, as this can have consequences for soil health and nutrient cycling [20].

Furthermore, BDM can improve soil quality by enhancing nutrient content, preserving soil moisture, and increasing the efficiency of nitrogen utilization [21, 19]. In studies have shown that nitrate content, as well as the total and active fungal populations in the soil, increased quantitatively in soils with biodegradable mulch compared to polyethylene mulch one year after mulch application [11].

In a recent study, researchers successfully developed sprayable agricultural mulch films by incorporating sodium alginate and Undaria pinnatifida microparticles. These innovative mulch films not only retained soil moisture effectively but also significantly enhanced tomato plant growth and chlorophyll content, demonstrating their potential for sustainable agriculture [22]. In ultimately, the use of biodegradable mulch materials in agriculture shows possibilities in terms of increasing crop output, lowering dependency on chemical inputs, improving soil health, and supporting sustainable agricultural practises.

1.2 Benefits of weed management purpose through biodegradable mulch materials

In agriculture, biodegradable mulch films have demonstrated their efficiency in weed control, leading to increased agricultural yields [23]. These films have been shown to minimise weed pressure, that can assist enhance agricultural yields [14]. However, large-scale manufacture of weeding mulch films would frequently create major contamination owing to herbicide spread in the surrounding environment [7]. Wang et al. [7] design a green and simple coating strategy for biodegradable weeding mulch films. An herbicide was added to a poly (vinyl alcohol) water-soluble solution containing dopamine as part of their method. Effective weeding mulch films were created by a low-temperature coating technique on a biodegradable poly (butylene adipate-co-terephthalate)/poly (lactic acid) film. In general, biodegradable mulch films offer several benefits for weed control in agriculture, helping to boost yields while also addressing environmental concerns associated with herbicide use.

1.3 The influence of biodegradable mulch materials on improving the efficiency of nutrient supply

Biodegradable mulch films have been proven to have a positive impact on agricultural nutrient supply. BDM materials can improve soil nutrient status and nitrogen usage effectiveness, promoting plant growth and yield [16, 24]. Thompson et al. (2020) conducted research showing that biodegradable plastic mulch films contribute to increased nitrogen usage efficiency. This improvement is attributed to their ability to stimulate crop growth while reducing nitrogen losses [25]. Moreover, in the realm of organic horticulture, biodegradable mulch films are employed to enhance nitrogen management. They achieve this by increasing the availability of accessible nitrogen, leading to higher crop nitrogen absorption and overall crop production, all the while reducing nitrogen losses during the growing season [16]. In addition to these benefits, mulch made from biodegradable materials has the potential to enhance soil fertility and maintain a balanced nutritional profile. This nurturing environment, in turn, facilitates plant development and higher crop yields [15, 19]. As a whole, biodegradable mulch films

offer a range of advantages when it comes to improving agricultural nutrient supply.

1.4 The environmental impact of biodegradable mulch materials

A significant subject for consideration is the effect of biodegradable mulch materials on the environment. PE mulch films are usually used for a few months and then discarded, taking over 300 years to degrade [26]. Thus, they accumulate, representing a serious environmental problem, not only because they contribute to increasing the amount of plastic waste but also because it is impregnated with the agrochemical substances sprayed during the cultivation period [27]. Moreover, it has been documented that after mulch removal, small fragments remain in the soil as a consequence of their embrittlement caused by the prolonged exposure to UV radiation and chemical substances [27, 28].

Importantly, the breakdown products of biodegradable mulch films should not be hazardous or stay in the environment, but should be completely digested by microorganisms [18]. In addition to being inexpensive and environmentally benign, biodegradable mulch materials have been demonstrated to benefit soil microorganisms, nutrient balance, plant development, and soil erosion [29]. Such products can improve water usage efficiency, reduce soil evaporation, and boost rainwater collection and are more environmentally friendly than conventional plastic mulch films [15].

Notably, biodegradable mulch film significantly has improved crop water usage efficiency as compared to bare soil controls (by 64.5-73.1%), which may justify its use in place of traditional plastic mulch film for agricultural applications in arid locations [15]. Mulching is seen as a vital practice for farmers to conserve water and improve agricultural sustainability, especially in dryland areas [10]. Appropriate mulching techniques within agro-ecological systems can harness these advantages [29].

Although by altering the microclimate and enhancing crop development, biodegradable plastic mulch can assist in addressing climate change challenges [30]. Biodegradable plastics have been shown to improve environmental sustainability, and their use can aid in the reduction of global plastic pollution [31]. Overall, biodegradable mulch materials have several environmental advantages and have the potential to solve the worldwide plastic pollution problem.

1.5 Evaluating the cost-effectiveness of biodegradable mulch materials

Due to their potential cost-effectiveness, biodegradable mulch products are becoming more and more valuable. The major conditions for mulch to be deemed biodegradable in the case of organic agriculture are that it is entirely made of bio-based materials and that it is at least 90% biodegradable by soil microorganisms in the field during a 2-year period [11, 32]. Biodegradable mulch is typically turned to carbon dioxide, water, and natural compounds by microbial activity in the soil. Mater-Bi estimates the cost of biodegradable mulch for 1.5 1000-m roll at roughly $350 [11]. According to research that compared the economic viability of eight different biodegradable mulching options for open-air pepper plants, the cost of mulching materials ranged from 7.5% to 14.1% of overall biodegradable prices to between 13.1% and 16.2% of total expenses [33]. Another study positively assessed the cost, degradability, and effects of plastic mulch on soil NO3-N, microbial alterations, watermelon production, and quality [11]. Currently, the most promising replacements for non-degradable plastic mulching are ecologically conscious and cost-effective biodegradable films [34] and BDM offer potential cost-effectiveness while adhering to specific organic agriculture criteria.

1.6 Pros and cons of applying biodegradable mulch in agricultural field

The most significant mechanism for changing organic molecules in nature is biodegradation, or the breakdown of chemicals by the activity of living organisms. The usage of biodegradable plastic products could be a creative way to dispose of commercial plastic agricultural wastes [35]. Although the environmental impact depends on the precise material used and the circumstances surrounding disposal, reducing plastic waste in the ecosystem is still a considerable benefit [36].

Agricultural ecosystems and soil microbial populations may be impacted by biodegradable mulch materials [37, 23]. While some research show that biodegradable mulch films degrade minimally in soil in some settings [9], others stress their favourable influence on soil physicochemical and microbiological characteristics [14]. While biodegradable mulch films made of polymers that disintegrate through microbial activity offer promise, their widespread adoption should be approached with caution [38]. The sustainability of biodegradable plastics depends on both material production and waste management strategies [31].

Mulching materials effectively suppress weed growth, enhance crop yields and quality, and improve water usage efficiency, leading to increased farmer profitability [15]. Zein-based mulching films have emerged as a cost-effective and environmentally friendly alternative to polyethylene mulching, particularly in terms of soil health [37]. Additionally, they aid in weed suppression and soil erosion reduction [13]. Research has shown potential benefits in crop productivity and growth, particularly in cotton and maize [15]. These materials can also influence soil microbial populations and ecosystem functioning, which can impact soil health and nutrient cycling [20, 18]. However, further study is needed to fully understand their long-term effects on soil health and nutrient biogeochemistry [20].

Recent research suggests that biodegradable mulch films could be used in greenhouse and high tunnel crop production, providing an eco-friendly alternative to traditional plastic mulches. Nevertheless, it is important to recognize that the traditional high-temperature film blowing procedure used to manufacture weeding mulch

films on a wide scale may cause environmental contamination as a result of herbicide dispersion. Green manufacturing methods for biodegradable mulch films are thus urgently needed in order to efficiently manage weeds without harming the environment [7].

Although Biodegradable Mulch Material is ecologically sustainable and innovative, it contains both identified and undiscovered GAPs. Biodegradable mulches degrade due to the action of naturally occurring microorganisms such as bacteria, fungus, and algae. It is still difficult to use biodegradable mulch materials effectively during the growth season in a range of conditions followed by prompt biodegradation. The next generation of biodegradable mulch solutions should be tailored to match the growing season performance expectations of users [39]. The majority of degradation processes are complicated, poorly defined, and hence poorly understood from a microbiological and chemical standpoint [40]. Additional investigation and analytical developments are required to pinpoint the crucial polymer characteristics and environmental factors that influence how biodegradable mulch films degrade [27]. Before BDM are extensively used by farmers, however, a thorough knowledge of the long-term impacts of BDM incorporation on the sustainability of soil ecosystems is required [41].

1.7 Innovative approach requirement for biodegradable mulch

Innovative ways to biodegradable mulch are being explored to solve the environmental issues associated with typical synthetic mulch films [37]. Since most plastic mulch films are not biodegradable, there are problems with how to dispose of plastic debris. China also makes extensive use of plastic mulch, which produces a lot of plastic garbage [42]. Mulch films made of bio-composite materials based on polysaccharides may take the place of plastic mulch films. These films have strong mechanical characteristics and the potential to be useful at controlling weeds [23]. Sustainable agricultural practices studies are now concentrating on the creation of biodegradable mulch films. Utilizing biodegradable polymers or renewable resources, like cellulose, starch, fiber, and proteins numerous new biodegradable film types have been developed [7].

To create biodegradable weeding mulch films, a simple and environmentally friendly coating method has been created. This method involved incorporating a herbicide into the coating solution before applying it to the mulch film's surface. Slow release of the herbicide from the coating successfully stopped the development of weeds [7]. During the period of 230 days, the ground-breaking biodegradable Mater-Bi film N5 was put to testing in a strawberry production. The film's 120-day optimal shelf life was sufficient for the whole strawberry cultivation season. Crop yields, fruit quality, and their nutritional qualities were unaffected by the movie [43]. In the course of the research, farmers growing aubergine in the South Saurashtra Agro-climatic Zone has recorded the highest growth, yield, quality and insect pest infestation parameters in the Silver Mulch application produced with an innovative approach [44].

It is essential to remember that biodegradable mulch films must be reasonably priced and must not adversely affect soil health. The European Committee for Standardization (CEN) has released the standard EN 17033:2018, "Plastics-Biodegradable Mulch Films for Use in Agriculture and Horticulture: Requirements and Test Methods," which aims to define the end-of-life, effect, and performance characteristics of biodegradable mulch films. The standard was approved as a reference in European nations, and Din Certco is currently testing biodegradable films in soil mulch in accordance with this standard [43]. Based on this problems and the world population's imminent growth that will demand an increase in food production, biodegradable mulch researches can carry out to develop strategies that increase crop yields by optimizing the resources and reducing traditional plastics' consumption.

2 Conclusion

In conclusion, while innovative approach of biodegradable mulch films show promise as an environmentally friendly alternative in agriculture, their adoption should be carefully regulated, taking into account a variety of aspects such as their environmental impact, cost-effectiveness, and long-term implications on soil health and ecosystems. The development of biodegradable mulch materials and innovative recycling technologies developed as an alternative to conventional plastics in agriculture are among the solutions to plastic waste and many problems. Biodegradable mulch material is essential to support sustainable development in a circular economy. More research and sustainable manufacturing processes are required to realize their full potential.

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