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HYDROMULCH: A SPRAYABLE BIODEGRADABLE MULCHING TECHNOLOGY FOR SUSTAINABLE CROP PRODUCTION

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ABSTRACT
A viable substitute for traditional polyethylene (PE) mulch in sustainable crop production is hydromulch, an innovative sprayable, biodegradable soil-cover technology. In contrast to prefabricated plastic films, hydromulch is applied as a water-based slurry that contains tackifiers, binders, fibrous materials, and, when necessary, agricultural residue fillers. Once the slurry dries, it forms a protective layer. The evolution, composition, functional mechanisms, agronomic uses, environmental advantages, and present constraints of hydromulch technology are all examined in this paper. According to the research now in publication, hydromulch can prevent weed growth, lower soil-water evaporation, alter soil temperature, prevent soil erosion, and promote crop establishment and yield. However, feedstock, formulation, thickness, application rate, environmental factors, crop type, and weed spectrum all affect how successful it is. Its potential to sustain crop productivity while lowering reliance on persistent plastic mulch is demonstrated by recent studies in strawberry, blueberry, artichoke, and other horticultural systems. By transforming low-value biomass into beneficial agricultural inputs, the usage of recycled paper, wood fibres, hemp hurds, and agricultural leftovers enhances its potential for a circular economy. However, there are still significant obstacles to broader implementation, such as inconsistent formulation, limited field durability, application-engineering requirements, variable weed suppression, economic competitiveness, and inadequate long-term environmental assessment. Standardized material characterization, crop and weed-specific formulations, precision application, life-cycle assessment, and long-term soil impacts should be the main focus of future research. All things considered, hydromulch is a promising multipurpose technology for circular, low-plastic, and resource-efficient agricultural production systems.

KEYWORDS: Hydromulch; Biodegradable mulch; Weed suppression; Soil-water conservation; Circular agriculture

1. INTRODUCTION
Mulching is a well-known soil management technique that enhances crop establishment, production, and resource efficiency by altering the soil microenvironment. Mulch materials can affect soil temperature, evaporation, weed emergence, erosion, nutrient dynamics, and crop growth by establishing a physical contact between soil and atmosphere. Due to its capacity to suppress weeds, retain soil moisture, and alter the crop microclimate, conventional polyethylene (PE) mulch has grown in importance within intensive horticulture production (Amare and Desta, 2021; Kader et al., 2017; Li et al., 2018). However, growing worries about end-of-life management, the buildup of plastic leftovers, and the challenges of recycling contaminated agricultural films coexist with the agronomic benefits of plastic mulch (Kasirajan and Ngouajio, 2012; Liu et al., 2014; Goldberger et al., 2019; Madrid et al., 2022a).
Nowadays, a lot of plastic mulch is used in agriculture, most of it for single-season applications. Because PE persists in agricultural environments, insufficient clearance may lead to the accumulation of macro and microplastics. After decades of plastic-film mulching, long-term field evidence has shown significant plastic deposition (Li et al., 2022). Contamination with soil and organic residues further complicates recycling, making collection and processing difficult from an economic standpoint (Levitan and Barros, 2003; Sarpong et al., 2024). Alternative mulch technologies that can preserve the agronomic benefits of soil covering while lowering reliance on persistent plastics have gained attention as a result of these worries.
Although biodegradable mulch films are one way to address this issue, their application may still be limited by factors such as material composition, cost, degrading behavior, and organic certification criteria (Miles et al., 2017;

Madrid et al., 2022b). An alternative strategy is Hydromulch. Hydromulch is often made as a water-based slurry with fibrous or particle elements and applied directly to the soil's surface rather than being produced as a prefabricated film. The residual material creates a continuous or semi-continuous layer of soil cover after water is lost during application. According to recent research, hydromulch is a sprayable, biobased, and soil-biodegradable substitute for plastic mulch. Paper-based formulations typically include water, recycled cellulose fiber, tackifiers or binding agents, and, occasionally, fillers made from agricultural residue (Weiss et al., 2026).

Hydroseeding and soil-protection techniques are the foundation of the fundamental idea of applying fibrous materials in slurry form. The use of water-applied seed, fertilizer, and fibre materials for vegetation establishment on disturbed soils and highway slopes was the subject of early hydroseeding studies (Blaser and Ward, 1958; Blaser et al., 1961; Blaser and Woodruff, 1968; Czapowskyj and Writer, 1970). While Barham (1980) reported enhanced nursery-grown sweetgum production linked to hydromulching, Adams and Blaser (1979) looked more closely at vegetation management in highway corridors. The technical viability of transferring fibrous materials in water and evenly distributing them across soil surfaces was demonstrated by these early uses.

Afterward, the idea shifted from vegetation establishment and erosion control to agricultural weed control. Runham et al. (1998) assessed paper mulch for weed control across multiple seasons, whereas Anderson et al. (1995) looked into recycled paper mulch as an alternative to plastic film for vegetable production. Similar results were shown by Smith et al. (1998) about the possibility of recycled waste paper for non-chemical weed control. An essential connection between hydromulch-type materials and sustainable weed management was made by Granatstein et al. (2002), who studied spray-on mulch for in-row weed management in organically grown crops.

The creation of hydramulch formulas created especially as biodegradable liquid paper mulches was a significant breakthrough. In their evaluation of hydramulch in vegetable production, Warnick et al. (2006a, 2006b) showed that it suppressed broadleaf weeds and grasses, but purple nutsedge was still challenging to manage. Additionally, their research showed that hydromulch changed soil moisture and temperature in comparison to PE mulch, demonstrating that its benefits go beyond weed suppression. More recently, Durado et al. (2024) investigated hydromulches made from paper, wood fibers, and hemp hurds with organic tackifiers, demonstrating the increasing sophistication of hydromulch formulation.

The agronomic evidence has also grown, with hydromulch being assessed for soil-water evaporation (Verdú et al., 2020), soil temperature and evaporative fluxes (O'Brien et al., 2018), artichoke production during drought (Muñoz et al., 2021), strawberry production (Ahmad et al., 2024; Weiss et al., 2025a; Torres-Moya et al., 2025), and weed management in perennial crops. However, compared to traditional plastic mulch, hydromulch is still in its early stages of development. Feedstock, formulation, thickness, application rate, environmental factors, crop type, and weed spectrum all have a significant impact on its performance. Weiss et al., (2026) synthesis highlights that weed-control uniformity, field durability, feedstock and application costs, and engineering needs continue to be significant obstacles to commercialization. Thus, the development of hydromulch, its composition and materials, its methods of action, its agronomic uses, its potential for the environment and the circular economy, and its ongoing difficulties are all critically examined in this review. The shift from recycled paper-based materials to multipurpose biodegradable hydromulches intended for contemporary sustainable agriculture is given special attention.

2. Evolution and Concept of Hydromulch

Hydromulch's development is a reflection of soil-cover technology as a whole. Before the widespread use of synthetic films, farmers mostly protected their soil using agricultural leftovers, straw, paper, and other organic materials. Although the thickness, durability, and application consistency of these materials were frequently variable, they were successful. A more uniform soil-cover system and a significant increase in horticultural production were made possible by the use of PE films (Kader et al., 2017; Kasirajan and Ngouajio, 2012).

However, the creation of substitute materials was encouraged by limitations of traditional plastic. Hydroseeding, which involves spraying seed, water, fertilizer, and fibrous materials into damaged soil surfaces, is closely linked to the historical method of hydromulch. Early research on vegetation establishment on highway landscapes was conducted by Blaser and Ward (1958), Blaser et al. (1961), and Blaser and Woodruff (1968). Hydroseeding research was expanded to anthracite coal-mine wastes by Czapowskyj and Writer (1970), demonstrating its usefulness in challenging soil conditions. The technological principle of slurry-based application was established by these investigations.

Later on, hydromulching was linked to soil protection and nursery output. According to Barham (1980), hydromulching increased the yield of sweetgum grown in nurseries, indicating that a surface layer produced by a material applied with water could affect plant establishment. The technology then progressively made its way into agricultural systems, especially as worries about chemical weed control and the disposal of plastic mulch grew.

The fibrous nature, accessibility, and biodegradability of recycled paper have made it a desirable feedstock. Recycled paper mulch was studied by Anderson et al. (1995) as a substitute for plastic film in the cultivation of vegetables. Smith et al. (1998) looked at recycled waste paper as a non-chemical weed-management resource, while Runham et al. (1998) assessed paper mulch across four growing seasons. Later, Haapala et al. (2014) examined the viability of using paper mulches in agricultural production and highlighted their potential as substitutes for traditional plastic materials.

There were a number of useful benefits to switching from solid paper mulch to sprayable hydromulch. Materials can be deposited over uneven soil surfaces and possibly around established plants by using slurry application.

Additionally, it may enable the incorporation of several materials into a single treatment and promote mechanized application. Granatstein et al. (2002) examined spray-on mulch for row crops cultivated organically, offering preliminary proof of its potential for controlling in-row weeds.

An essential phase in this process was portrayed by Warnick et al. (2006a, 2006b). Their hydramulch was made of a slurry that included newspaper and cotton waste, a unique glue, and gypsum as a filler. Although purple nutsedge was able to pierce the material, field tests revealed that hydramulch could inhibit broadleaf weeds and grasses. While soil moisture responses varied with rainfall, the temperature of the soil beneath hydramulch was lower than that under PE mulch.

The goal of hydromulch's further development was to enhance its physical characteristics. Given the significance of adherence and cohesiveness in the dry layer, Vaughn et al. (2012) looked into tackifiers that might replace guar gum. Later, Claramunt et al. (2020) showed that hydromulch performance might be maximised by mechanically characterising mixes of recycled paper pulp and lignocellulosic materials. This work changed the focus of the research to materials engineering.

Subsequently, hydromulch research went beyond weed suppression. O'Brien et al. (2018) studied evaporative fluxes and soil-temperature dynamics after hydromulch application. In controlled environments, Verdú et al. (2020) showed effects on soil-water evaporation. Hydromulch was investigated as an erosion-control strategy by Ricks et al. (2020). These investigations showed that hydromulch can affect various soil processes.

More recently, circular-economy formulations have been incorporated into the technology. While López-Marín et al. (2021) looked at hydromulch's economic feasibility in artichokes, Mas et al. (2021) studied whether it might suppress perennial weeds. Hydromulching under drought stress and its relationship with arbuscular mycorrhiza were investigated by Romero-Muñoz et al. (2022a, 2022b). Afterwards, Durado et al. (2024) created biodegradable composite hydromulches with organic tackifiers, paper, wood fibres, and hemp hurds.

Recent studies show that field-scale validation is becoming more prevalent. Cirujeda et al. (2024) investigated hydromulch formulations in perennial crops using circular economy principles. In organically managed strawberry systems, Ahmad et al. (2024) showed weed control and fruit production maintenance. While Weiss et al. (2025b) showed that hydromulch inhibited dicot weeds more successfully than monocot weeds in established blueberries, Weiss et al. (2025a) observed maintenance of strawberry yield, fruit quality, and plant nutrition across differing conditions. Additionally, Torres-Moya et al. (2025) found that in organic strawberry farming, yield protection was on par with plastic mulch.

As a result, hydromulch has undergone a series of technological developments:

Hydroseeding and erosion control → paper-based soil protection → spray-on weed-control mulch → engineered biodegradable hydromulch → multifunctional circular-economy soil-cover technology.

This historical development is significant because it shows that hydromulch is more than just a novel paper mulch composition. Instead, it is a new way to distribute biodegradable materials and possibly other agricultural inputs to soil surfaces. According to Weiss et al. (2026), hydromulch application technologies may someday be able to integrate more soil amendments due to their multifunctionality, which could result in fewer field operations.

3. Materials, Composition and Formulation of Hydromulches

The formulation of hydromulch essentially determines its performance. Hydromulch can be made from a variety of fibres, fillers, binders, and additives, in contrast to PE mulch, which is produced as a somewhat uniform film. One of its main benefits is this adaptability, which is also one of the main reasons why experimental outcomes vary. Many hydromulches have traditionally been made of paper and cellulose fibres. After drying, the fibrous structures found in recycled newspaper, paper pulp, and cotton waste can create a cohesive surface (Anderson et al., 1995; Warnick et al., 2006b). They are appealing feedstocks due to their accessibility and biodegradability, and recycling offers the chance to redirect waste materials toward agricultural uses. Another significant resource is lignocellulosic agricultural leftovers. In their evaluation of recycled paper pulp mixtures with other lignocellulosic materials, Claramunt et al. (2020) showed that material composition had a significant impact on mechanical properties. This method was expanded upon by Durado et al. (2024), who tested hemp hurds, paper, and wood fibres in composite hydromulches. Their findings showed that while guar gum and psyllium husk were promising organic tackifiers, paper-based materials could have advantageous mechanical properties.

From the standpoint of the circular economy, using agricultural leftovers is especially crucial. Hydromulch development can turn industrial fibres and crop residues into useful agricultural products rather than treating them as waste. This strategy may connect crop production, soil conservation, and waste management. However, raw fibres might not offer sufficient adhesion or stress resistance on their own. As a result, binders and tackifiers are crucial parts. In their evaluation of guar gum substitutes, Vaughn et al. (2012) showed how crucial tackifying chemicals are to preserving hydromulch cohesiveness. Guar gum's high binding qualities and biological origin have made it one of the most promising materials.

To change physical attributes, fillers may also be used. For instance, to enhance texture and aggregation, gypsum was added to early hydramulch formulations (Warnick et al., 2006b). Nevertheless, hydromulch performance is not always enhanced by the addition of fillers. Weiss et al. (2026) observed that while wheat straw had potential for enhancing material characteristics, numerous filler materials decreased mechanical strength. Therefore, the formulation needs to strike a balance between several conflicting properties:

- Slurry pumpability

- Consistent application;
- Adherence to the soil;
- Resistance to precipitation;
- Mechanical power;
- The ability to suppress weeds;
- Compatibility with crops;
- Rate of decay;
- Safety of the environment;
- Financial viability.

There is a significant difference between field performance and laboratory material performance. When subjected to frequent rainfall, irrigation, wind, microbiological activity, and soil movement, a hydromulch may exhibit excellent tensile or puncture resistance. Therefore, field evaluation should come after formulation screening. This gap has started to be addressed in recent work. In their investigation of the rain-fastness and puncture resistance of biodegradable horticulture hydromulches, Durado et al. (2025) emphasised the significance of durability in practical field settings. Rainfall can weaken or redistribute the mulch before weeds have been sufficiently inhibited, so this is crucial.

Environmental toxins must also be taken into account when choosing feedstock. Concerning pollutants or chemical additives may be present in recycled paper and cardboard. For instance, Langberg et al. (2024) looked into the recycling of cardboard, paper, and related per- and polyfluoroalkyl substances (PFAS) in Norway. Such a study shows why feedstock characterisation and contaminant screening should be included in hydromulch production, even if it does not prove that every recycled-paper hydromulch poses a PFAS danger. Therefore, functional design—where feedstocks are chosen based on their necessary agronomic role rather than just their availability—should be the direction of hydromulch formulation in the future. A formulation for erosion management or long-duration perennial crops may be very different from one for short-duration weed suppression. The Table 1. Illustrates that the overall and concise version of materials used in hydromulch formulation and their functions.

Table 1. Materials used in hydromulch formulation and their functions

Hydromulch component	Examples of materials	Major function in formulation	Significance	Author citation
Cellulosic fibres	Recycled paper, newsprint, cardboard, paper pulp	Provides the main structural framework and, once dried, creates the mulch layer.	Good mechanical strength and weed barrier qualities have been demonstrated by paper-based hydromulches.	Claramunt et al. (2020); Durado et al. (2024)
Wood fibre/pulps	Wood fibre, wood pulp	Adds to the structure of mulch and provides lignocellulosic biomass.	Can be utilized as a source of renewable fibre, but formulations made with wood fibre might not be as strong mechanically as those made with papers	Durado et al. (2024)
Hemp hurds	Hemp hurd fibres	Alternative biomass feedstock and lignocellulosic filler	Offers a possible feedstock made from industrial and agricultural residues, but large amounts could weaken mechanical strength.	Durado et al. (2024)
Agricultural residues	Wheat straw, rice hulls/rice husk, mushroom-production substrate	Water-resource recovery and filler/reinforcement.	Can promote circular-economy formulations and alter mechanical and physical properties.	Claramunt et al. (2020); Cirujeda et al. (2024)
Tackifiers/ binders	Guar gum	Increases mechanical strength, soil adhesion and fibre cohesion.	Higher concentrations of guar gum can enhance mechanical performance; it has shown significant improvements in tensile and puncture resistance.	Vaughn et al. (2013); Durado et al. (2024)
Tackifiers/ binders	Psyllium husk	Enhances the hydromulch layer's cohesiveness and adherence.	Potential as an organic trackifier for hydromulches made of paper has been demonstrated	Durado et al. (2024); Ahmad et al. (2024)
Alternative organic tackifier	Camelina meal	Provides cohesive and binding qualities while making use of an	Examined as a substitute organic trackifier in formulations for biodegradable hydromulch.	Durado et al. (2024)

		agricultural byproduct.		
Mineral/agglomerating agents	Gypsum	Improves the mulch matrix's mechanical integrity and aggregation; examined as a substitute organic tackifier in formulations for biodegradable hydromulch.	Gypsum, wheat straw and paper pulp were combined to create a hydromulch blend that was mechanically robust.	Claramunt et al. (2020)
Other agglomerating agents	Rice bran, white glue, sodium silicate	Boost the fibre's bonding and aggregation.	Tested as additives to enhance recycled-paper hydromulches mechanical properties.	Claramunt et al. (2020
Water	Water-based carrier	Creates a pumpable slurry for spray application from dry materials.	Permits even application across the soil's surface; the slurry creates a continuous mulch layer as it dries.	Ahmad et al. (2024)

4. Mechanisms and Functional Properties of Hydromulch

Hydromulch mostly works by physically altering the surface of the soil. Its effects result from the creation of a transient layer that modifies the flow of gases, light, water, and heat between the soil and atmosphere. Weeds, soil moisture, temperature, erosion, and crop growth can all be influenced by the interplay of these systems. The function that has been investigated the most is weed suppression. The hydromulch layer forms a physical barrier that emerging weed seedlings must pass over once it has dried. Degradation rate, mechanical strength, thickness, and continuity all affect how effective this barrier is. Although purple nutsedge might pierce the material, Warnick et al. (2006b) showed that thicker hydramulch coatings typically produced stronger suppression of broadleaf weeds and grasses.

This species-specific reaction is crucial. Perennial and monocot weeds may be able to pierce soil-cover layers due to their unique emerging structures or increased mechanical strength. Weiss et al. (2025b) later observed higher suppression of dicot than monocot weeds in established blueberries, whereas Mas et al. (2021) particularly examined whether hydromulch may prevent emergence of perennial weeds. These results show that weed community composition must be taken into account in addition to total weed biomass when evaluating hydromulch.

Soil evaporation can also be influenced by hydromulch. While Verdú et al. (2020) investigated the decrease in soil-water evaporation under controlled settings, O'Brien et al. (2018) showed that hydromulch altered soil temperature and evaporative fluxes. Although its impact varies depending on thickness, porosity, and continuity, the dry layer increases resistance to direct water loss from the soil surface.

In times of drought, the moisture effect can be very significant. According to Romero-Muñoz et al. (2022a), ecological hydromulching enhanced escarole growth under drought stress and linked this reaction to hormone modulation. Romero-Muñoz et al. (2022b) also showed interactions between hydromulching and arbuscular mycorrhiza in escarole, indicating that biological mechanisms influencing nutrient uptake and plant growth may interact with hydromulch-mediated changes in the soil environment.

Additionally, hydromulch alters the temperature of the soil. While O'Brien et al. (2018) reported changes in soil-temperature dynamics after hydromulch application, Warnick et al. (2006b) found lower soil temperatures beneath hydromulch than under PE mulch. Climate and surface factors determine the direction of the temperature effect. Therefore, it is not necessary to anticipate that hydromulch will warm soil in the same way as dark PE film. In crops where considerable soil warming is undesirable, the distinction between hydromulch and PE mulch may be helpful from an agronomic standpoint. On the other hand, crops that need quick early-season soil warming might not benefit as much from hydromulch. This highlights how crucial it is to match mulch properties with crop and environmental requirements.

Erosion reduction is another essential process. The physical surface layer that hydromulch offers can lessen the impact of direct raindrops and soil particle separation. In laboratory-scale erosion studies, Ricks et al. (2020) assessed hydromulches and showed their potential for use in erosion control. Therefore, the technology is useful outside of intensive horticulture, especially for disturbed landscapes and exposed soils.

One way to illustrate how these systems interact is as follows:

Hydromulch application → surface-cover creation → altered radiation, water, and heat exchange + physical weed barrier + decreased soil exposure → altered soil microenvironment → better circumstances for crop establishment and resource use.

Even if hydromulch's main function is to reduce weeds, this integrated mechanism explains why it could have an impact on crop growth.

5. Agronomic Applications and Effects on Crop Production

Although hydromulch has been tested for a variety of agricultural uses, the evidence is stronger for crop establishment, weed control, and soil-water conservation. More recent studies have extended the technology to drought-stressed production, organic horticulture, and perennial crops.

5.1. Weed Management

Hydromulch's physical barrier can significantly lower the emergence of weeds. Its ability to reduce grasses and broadleaf weeds was demonstrated in early research by Warnick et al. (2006b). The potential of paper-based materials for non-chemical weed management was further shown by Anderson et al. (1995), Runham et al. (1998), and Smith et al. (1998). In this situation, hydromulch's compatibility with organic agriculture is its main benefit. Synthetic herbicide use is restricted for organic farmers, and they frequently need rigorous mechanical or manual weed management. Thus, spray-on mulch was taken into consideration by Granatstein et al. (2002) as a possible in-row weed-management technique for organically cultivated crops.

But not everyone uses weed suppression. The literature frequently highlights purple nutsedge as a significant drawback (Warnick et al., 2006b). Additionally, Mas et al. (2021) showed that perennial weeds continue to be a problem. Recent studies have reaffirmed the significance of the weed functional category. In established blueberries, dicot weeds were more strongly suppressed than monocots, according to Weiss et al. (2025b). According to these results, hydromulch should be used in conjunction with other weed control techniques. It may be most useful in environments where there are few pesticide alternatives and the dominant weed flora is vulnerable to physical exclusion.

5.2. Soil-water conservation and drought management

Another significant use is water conservation. Hydromulch can reduce evaporative losses by limiting the soil surface's direct exposure. O'Brien et al. (2018) showed evidence of changed evaporative fluxes under hydromulch, but Verdú et al. (2020) showed this impact under controlled settings. Research conducted in drought conditions demonstrates the agronomic significance of this function. Romero-Muñoz et al. (2022b) discovered that combining hydromulching with arbuscular mycorrhiza enhanced growth and productivity, while Romero-Muñoz et al. (2022a) showed increased escarole growth under drought stress. According to Romero-Muñoz et al. (2024), hydromulching improved soil characteristics and plant hormone balance, which in turn raised the production and quality of drought-stressed artichokes.

According to these studies, hydromulch can affect crop drought response in both physiological and physical ways. However, not all formulations should be presumed to conserve water. The hydromulch's permeability, thickness, deterioration, and local climate all affect the outcome.

5.3. Crop growth and productivity

The key consideration in deciding whether hydromulch can supplement or replace current mulch systems is crop productivity. Early research mostly concentrated on weed suppression and establishment, while more recent studies have offered direct yield comparisons. Cline et al. (2011) examined the effects of spray-on mulch on tree establishment, early yield, and soil physical characteristics in heavily watered apple orchards. Hydromulching as a substitute for plastic film in artichokes was then investigated by López-Marín et al. (2021) along with an economic analysis.

The cultivation of strawberries has become a particularly significant research system. In organically managed strawberry systems, hydromulches were shown by Ahmad et al. (2024) to reduce weeds while preserving fruit yield. While Torres-Moya et al. (2025) observed yield protection comparable to plastic mulch in organic strawberry cultivation, Weiss et al. (2025a) reported maintenance of strawberry yield, fruit quality, and plant nutrition across differing conditions. These studies are important because they expand the body of knowledge to include commercial-scale horticultural systems rather than just laboratory or greenhouse trials. However, additional multi-location testing is required because performance is still reliant on formulation and environment.

5.4. Perennial crops

Perennial crops present a particularly interesting application because conventional plastic mulch can be difficult to install, remove and manage around established plants. In the vicinity of perennial crops, hydromulch may be sprayed directly onto soil surfaces.

Cirujeda et al. (2024) assessed hydromulch formulations with a circular economy for controlling weeds in perennial crops. Weiss et al. (2025b) evaluated hydromulch in established blueberries, while Mas et al. (2021) examined perennial weed suppression. All of these investigations point to hydromulch's potential in systems where frequent mechanical weed control is costly or where plastic film is inconvenient.

5.5. Soil protection and erosion control

Additionally, hydromulch may be used as a method for soil conservation. While the historical hydroseeding literature indicates that slurry-applied fibre materials have long been utilized to create plants and protect disturbed soil (Blaser and Ward, 1958; Blaser et al., 1961; Czapowskyj and Writer, 1970), Ricks et al. (2020) demonstrated its potential for erosion control. Therefore, hydromulch has the potential to bridge land-reclamation and agricultural uses, especially in situations where temporary surface protection is needed before vegetation grows.

6. Environmental Sustainability, Biodegradation and Circular-Economy Potential

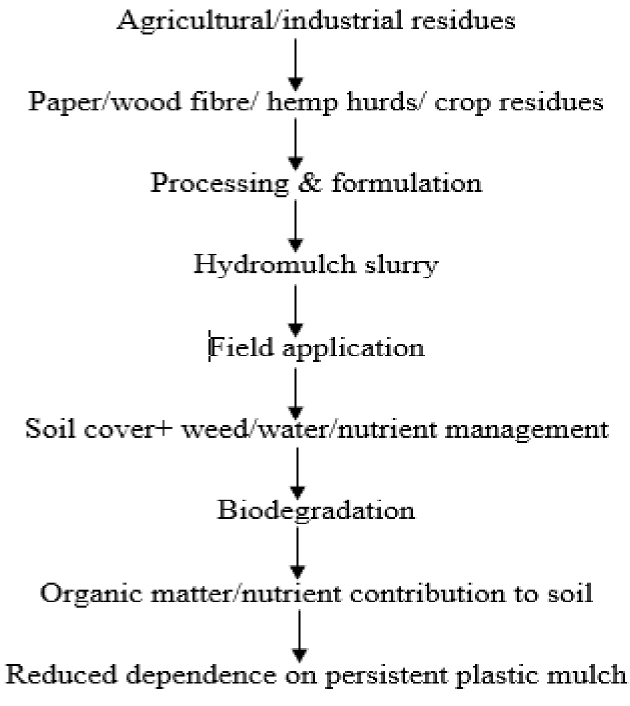
Hydromulch's ability to replace persistent plastic mulch with biodegradable, biobased materials is its main environmental justification. Although conventional PE mulch offers many agronomic benefits, it poses serious end-of-life issues. While Li et al. (2022) offered proof of long-term macro- and microplastic buildup in agricultural soils, Liu et al. (2014) detailed the shift from the "white revolution" of plastic mulch to worries about plastic pollution. End-of-life care is still challenging. PE mulch's recyclable value is diminished by soil and organic material contamination (Levitan and Barros, 2003). Madrid et al. (2022a) highlighted the intricacy of agricultural mulch-film disposal while reviewing potential end-of-life management paths. In a similar vein, Sarpong et al. (2024) examined the opportunities and constraints associated with recycling agricultural plastic mulch in the US.

These issues have led to the development of biodegradable mulch technology. While Miles et al. (2017) evaluated the viability of biodegradable plastic mulch for organic and sustainable agriculture, Kasirajan and Ngouajio (2012) examined polyethylene and biodegradable mulches. Madrid et al. (2022b) looked at factors influencing the deterioration of soil-biodegradable polymers, whereas Moreno et al. (2017) studied the deterioration patterns of biodegradable mulches in field settings. In contrast to these materials, hydromulch can have feedstocks that are mostly fibrous and biobased. Opportunities to convert waste streams into agricultural inputs include paper, wood fibre, hemp hurds, and agricultural residues (Claramunt et al., 2020; Durado et al., 2024). This opens up a possible circular economy pathway where low-value biomass is converted into a crop-producing substance and then degraded back into the soil.

The idea of the circular economy is especially pertinent to agricultural residues. For perennial crops, Cirujeda et al. (2024) specifically assessed hydromulch formulations based on circular economy concepts. These strategies have the potential to lessen reliance on virgin raw materials while generating new applications for wastes that are available locally. But being biodegradable does not always imply being safe for the environment. The environmental impact is influenced by feedstock production, transportation, processing, additives, and application. Contaminants must also be carefully taken into account when using recycled paper. The necessity of evaluating PFAS connected to paper and cardboard recycling streams was emphasized by Langberg et al. (2024). Consequently, one of the most important aspects of hydromulch safety is feedstock quality.

Hydromulch may also offer other ecosystem functions. While hydromulch degradation may add organic carbon to soil depending on material composition and decomposition conditions, Milne et al. (2015) highlighted the many advantages of soil carbon management. However, the extent and durability of this effect are still not adequately measured. Therefore, evaluations of sustainability should go beyond biodegradability. Future comparisons ought to include: Sourcing feedstock, producing energy, transportation, application, agronomic performance, degradation, soil effects, and end-of-life results. Before hydromulch can be scientifically categorized as more sustainable than rival mulch systems, such a life-cycle study is necessary. The Figure 1. illustrates the circular economy pathway of the hydromulches.

Figure 1. Circular-economy pathway of hydromulch



7. Challenges, Research Gaps and Future Perspectives

Even though hydromulch research is growing quickly, the technology is still in its early stages. According to a recent assessment by Weiss et al. (2026), hydromulch shows promise but needs a lot more investigation before it can be widely commercialized. Formulation uniformity is the first significant obstacle. Hydromulch lacks a single standardized composition, in contrast to PE film. Comparing research is challenging due to variations in fibre source, particle size, tackifier, filler, slurry concentration, and application rate. Therefore, it is crucial to develop standardized agronomic and physical characterization techniques.

Durability in field settings is the second problem. When weeds are most competitive, a hydromulch must stay intact but later deteriorate. Weed suppression fails if it breaks down too soon, and the technology's environmental benefit may be compromised if it lasts too long. In order to highlight the significance of field durability, Durado et al. (2025) carefully examined rain-fastness and puncture resistance. Weed-spectrum limitation is the third problem. Many broadleaf weeds have been effectively suppressed by hydromulch, but certain monocots and perennial weeds have shown less success. Together, Warnick et al. (2006b), Mas et al. (2021), and Weiss et al. (2025b) show this restriction. Therefore, rather than assuming universal weed control, future formulations should be created according to target weed communities.

Crop compatibility is the fourth difficulty. In direct-seeded systems, a covering thick enough to stop weeds from emerging may also hinder crop emergence. Therefore, when deciding on application rate and thickness, the crop establishment method should be taken into account. Application engineering is the fifth challenge. Equipment for mixing, pumping, and spraying hydromulch is needed. To prevent nozzle clogging and uneven application, the slurry must be sufficiently homogeneous. Application consistency could be just as significant at the field scale as material composition. Economic competitiveness is the sixth obstacle. While Weiss et al. (2026) noted feedstock and application costs as significant commercialization constraints, López-Marín et al. (2021) specifically looked at economic viability in artichokes. The financial benefit of hydromulch will rely not only on the cost of the materials but also on the savings from less manual weeding, herbicide use, and plastic removal and disposal.

Long-term environmental assessment is the eighth difficulty. Soil organic matter, microbial activity, nutrient cycling, and pollutant exposure may all be impacted by repeated applications. Compared to ordinary plastic and biodegradable plastic mulches, these impacts are currently better understood. Standardized life-cycle assessment is the eighth difficulty. Future comparisons should use uniform functional units, preferably cost and environmental consequences per hectare and per unit of crop output, to assess hydromulch versus PE mulch, biodegradable plastic mulch, paper mulch, and organic mulches.

The creation of multifunctional hydromulches is a particularly interesting avenue. Hydromulch may include suitable fertilizers, soil amendments, microbial inoculants, or other elements because it is supplied as a slurry. According to Weiss et al. (2026), this multifunctionality presents a significant future possibility. Hydromulch may be combined with precision application technologies to increase consistency and minimize material consumption. Crop-specific application maps may minimize treatment between rows while focusing on the soil surface surrounding plants. These methods could increase the technology's economic viability. All things considered, hydromulch's future depends on more than just substituting biodegradable paper for plastic film. Instead, it involves creating a well-thought-out, multipurpose, residue-derived soil-cover system that concurrently tackles waste management, water conservation, soil preservation, weed control, and environmental sustainability.

8. CONCLUSION

From the concepts of hydroseeding and paper-based soil protection, hydromulch is an emerging class of sprayable soil-cover technologies that has developed into increasingly complex biodegradable compositions. The necessity to preserve the agronomic advantages of soil covering while lessening the environmental impact of persistent plastic mulch has propelled its development. Hydromulch can suppress weeds, change the temperature of the soil, lower evaporative water loss, prevent soil erosion, and increase crop yield, according to the evidence that is currently available. Recent field research on perennial crops, blueberries, strawberries, and artichokes shows that technology has advanced beyond lab testing to useful agricultural applications.

Hydromulch isn't yet a suitable substitute for polyethylene mulch, though. Formulation, thickness, application rate, crop, weed spectrum, and environmental factors all have a significant impact on its efficacy. Achieving sufficient field durability while preserving predictable biodegradation is the key technological problem. Standardized material characterization, crop- and weed-specific formulations, enhanced application engineering, economic optimization, long-term soil assessment, and life-cycle analysis should be the top priorities for future research. The development of circular-economy hydromulches is particularly promising when recycled paper, wood fibers, hemp hurds, and agricultural leftovers are used. Hydromulch may play a significant role in low-plastic and circular agricultural production systems with further interdisciplinary study encompassing agronomy, materials science, soil science, engineering, and environmental evaluation.

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Conflict of Interest

The authors declare no conflicts of interest relevant to this article.

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