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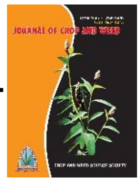

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Review Article

Significance of living mulch for sustainable crop production- A review

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ABSTRACT

Living mulch in agriculture is a cover crop that is seeded beneath or in between two other crops. Its goal is to perform the roles of mulch, such as managing soil temperature and controlling weeds. Legumes can be used as living mulch to reduce the need for fertilizer, in addition to fixing nitrogen. Consequently, an attempt has been made to get a greater knowledge of the significance of living mulch and its management for sustainable crop production by reviewing the work done by scientists on a related subject. Main benefits of cover crops in agro ecosystems includes control of soil erosion, improved soil structure and water holding capacity improves soil physical properties, increase the amount of organic matter in the soil, weed control and fix atmospheric nitrogen by legume cover crops besides living mulches can prevent water runoff. The fundamental problem with living mulch is that it often suppresses the main crops. This section's objective is to describe management techniques that may boost the probability of beneficial results in living mulch systems. Some of the management tactics are described under- kind of living mulch, planting pattern and density, irrigation and nutrient inputs and mechanical control. The identification of low-input chemical control techniques, the improvement of alternatives for organic systems, the improvement of the list of efficient living mulch species, and the adoption of a more comprehensive strategy for managing living mulch are all general research topics.

***Keywords*:** Cover crops, living mulch, soil erosion, soil moisture retention and weed control

Living mulch refers to a practice in agriculture and gardening where certain plants, typically low-growing and spreading, are intentionally grown alongside main crops to provide ground cover and offer various benefits. Instead of using traditional, non-living mulch materials like straw or plastic, living mulch involves the use of living plants to cover the soil between rows or around individual plants. This technique has several advantages like moisture conservation, nutrient cycling, soil erosion prevention, weed suppression, pest management, microclimate modifications, The cover crops are either assimilated into the soil or eliminated using herbicides, living mulches continue to grow alongside the primary crops for a considerable amount of time.It has been discovered that some live mulches boost populations of agricultural pests' natural adversaries (Hartwig and Ammon .2002). In addition to fixing nitrogen, legumes can be utilized as living mulch to lessen the requirement for fertilizer. Hence, a review of various researchers' work on the subject has been undertaken in order to acquire a deeper understanding of the importance of living mulch and how to manage it for sustainable crop production.

A. *Advantages of living mulches*

The primary advantages of cover crops in agro-ecosystems is reduction of soil erosion, nitrogen fixation and nutrient recycling and increase in organic matter content, weed control and insect control (Daryanto *et al.*, 2018).

1. **Soil erosion control:** According to Borrelli *et al.* (2020), soil erosion is a serious worldwide issue that threatens freshwater, land, and oceans. It also poses a serious risk to food security and ecosystems, with long-term and extensive effects as the rate of soil loss occurs forty times faster than the rate of soil renewal and sustainability. The main advantage of using living mulch is that it prevents soil erosion by capturing rainwater and reducing runoff water. Thus, the infiltration into the soil is increased.

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Additionally, it minimizes soil compaction brought on by heavy rains by controlling wind erosion through the earth's thick mantle, which shields the soil from separation. Besides, the roots of the living mulch help bind the soil together, reducing the risk of erosion caused by wind and water. This is particularly beneficial on sloping terrain. Vetch (*Vicia sativa*), bird's foot trefoil (*Lotus corniculatus*), and other forms of mulch can be used successfully under wet ground.

2. **Improves soil structure and retention of soil moisture:** The soil aggregate stability and soil structure both improve on account of increase in organic matter as a result of living mulch decomposition. It also makes the soil more capable of holding onto moisture. Consequently, less frequent irrigation is required, which lowers the cost of farming. Rahman (2022) conducted an experiment in maize using cowpea as living mulch (CPLM) and found that the soil moisture at various growth stages of the crop improved compared to the control treatment. Similar findings of increase in soil moisture as a result of living mulch compared to control treatments has also been suggested by Wiggans *et al.*, 2012; Trail *et al.*, 2016; and Qu *et al.*, 2019. Sharma *et al.* (2010) reported that live mulching with sunnhemp or Leucaena biomass increased crop productivity by 6.8–8.8% and the soil moisture content at maize harvest by 1.15–1.57% compared to no mulching. When both mulching materials were used together, the soil moisture content (+2.08–2.29%) and grain yield (15.1%) were improved more than when they were applied separately.

3. **Improves soil physical properties:** Studies have reported a reduction in soil bulk density of intercropping or living mulch systems (Sharma *et al.* 2010; Gitari *et al.* 2019). Rahman *et al.* (2022) conducting an experiment on cowpea living mulch planted on the same day and two weeks after maize sowing, reported that with cowpea living mulch (CPLM), the soil temperature was considerably cooler during the vegetative, tasseling, and harvest growth stages of maize than it was under the control treatment. When compared to CPLM planted two weeks after maize, the soil temperature of the CPLM with maize planted on the same day decreased at all stages of the crop's growth. They explained that the cowpea's canopy cover lowers the amount of sunlight that reaches the soil's surface directly, which influences the temperature of the soil. They also reported that the soil bulk density at tasseling and harvest growth of maize decreased with cowpea living mulch. They further reported that cowpea living mulch greatly boosted the soil's organic carbon (OC).The soil total nitrogen for cowpea living mulch was 17–40% higher than that of the control treatment. The available soil phosphorus for the cowpea living mulch increased to the extent of 40–107% compared with the control. Similarly, the microbial biomass nitrogen (MBN) of the CPLM increased by 45–142% relative to that of the control treatment. The soil microbial quotient (SMQ) of the cowpea living mulch increased by 21–45 relative to that of the control treatment. Living mulch has also been proven to boost the number of organisms that act as some crop pests' natural enemies. Living mulch treatments exhibiting greater natural enemy populations than synthetic mulch and bare-ground treatments have also been reported by Frank and Liburd (2005). Romaneckas *et al.* 2012; Qian *et al.* 2015; Gattullo *et al.* 2020) have also supported that use of living mulch in cropping systems improve soil OC relative to non-mulch systems. The significant response to soil total nitrogen could be due to the biological nitrogen fixation activity due to legume living mulch which added an external source of nitrogen into the soil.

4. **Increase the amount of organic matter in the soil:** Living mulch increases soil organic matter all year - round by incorporating its leftovers into the soil through shedding and defoliation. It concentrates at the soil's surface, greatly improving the soil's tilth and preserving soil permeability and air circulation, as well as preserving the soil's overall condition and production. According to Gitari *et al.* (2019), the living mulch canopy covers the soil surface, lessening the effect of rainfall on the soil surface. It also increases biomass production, which breaks down to build biopore channels and lessens soil compaction. There is ample evidence supporting the benefits of living mulch with regard to soil erosion, soil structure, soil organic matter, etc. According to Martin *et al.* in 2020 and Autret *et al.* 2016, assessed the impact of various arable cropping strategies on the soil organic matter content in a long-term cropping system, specifically for living mulch in cereal production. They observed that, in comparison to the traditional farming system, which produced +78 kg C ha-1 year-1 of soil organic carbon storage, the conservation agriculture-based cropping system significantly boosted soil organic carbon storage in the top 0.3 meters of soil between 1998 and 2014. The benefits of living mulch for soil erosion, soil

structure, soil organic matter, etc., particularly in cereal-based farming system are well documented (Martin *et al.* in 2020).Autret *et al.* (2016) evaluated the effects of several arable cropping strategies on the soil organic matter content in a long-term cropping system. They discovered that, compared to the traditional farming systems, the conservation agriculture-based cropping strategy significantly enhanced soil organic carbon storage.

5. **Weed control:** Weeds can also grow and germinate in the absence of competition. Living mulch provides efficient weed control for the primary crop cultivated. Through its dense surface coating, it either prevents weed growth or slows it down. Natural levels of normal cover crop residues can be expected to limit weed emergence by 75 to 90%. Weed suppression by cover crop residue increases with increasing residue quantities. In accordance with the pace of residue decomposition, weed suppression will decrease during the crop duration. The most suppressive residues are those with many layers and little vacant interior space. Common lambsquarters and pigweeds, annual species with small seeds and light germination requirements, are susceptible to surface cover, but annual weeds with large seeds and perennial weeds are comparatively insensitive. According to research (Brophy *et al.*, 1987), white clover may effectively suppress weeds on par with commercial herbicides. On the other hand, plants like clover, ryegrass, etc. have an allelopathic action that prevents the growth of weeds. Living mulch like covered crops adds nutrients to the soil when they are plowed under, reducing the need for chemical fertilizer on the main crop. The biomass, which varies over time and is influenced by rainfall and other factors, determines how much of a contribution is made. Living mulch has two methods for weed control. They control weeds by competition when they are sown before weed establishment (Hartwig, 1977). Living mulches have the ability to control weeds in some settings because of their allelopathic qualities. To manage weeds in sweet maize (*Zea mays* var. *rugosa*) and snap beans (*Phaseolus vulgaris*), for instance, winter rye (*Secale cereale*), ryegrasses (*Lolium* spp.), and subterranean clover (*Trifolium subterraneum*) can all be employed as allelopathic plants (De Gregorio and Ashley, 1986). Fernando and Shrestha (2023) cited several studies indicating that a combination of cover crop species is better than a single species for effective weed control and that planting timing is critical for maximizing biomass from cover crops. This means that managing weeds with cover crops alone might not be successful; instead, it should be done in conjunction with other strategies. Cover crops, however, are an essential component of the tools for integrated weed management.

6. **Fix Atmospheric Nitrogen by Legume Cover Crops:** Legume-living mulch as a cover crop has several significant impacts on the cycle of nutrients during crop production. They fix atmospheric N2 and may add nitrogen to the soil and crops, recycle nutrients, and change the availability of nutrients in the soil. According to reports (Lehman *et al.*, 2000), legumes have greater foliar nitrogen concentrations overall, ranging from 20 to 45 mg g-^{1}. Leguminous live mulch can reduce the requirement for synthetic nitrogen fertilizers by fixing atmospheric nitrogen. Some of this nitrogen is also released through the breakdown of legume plant leftovers for use by future crops. *Sesbania*, hairy vetch, clover, and other plants are examples of living mulches that fix nitrogen. On the other hand, this decrease in the use of synthetic nitrogen fertilizer lowers the risk of groundwater nitrate pollution. The rate of soil nutrient turnover increases with biomass. Due to extensive tillage, bare soil can result in soil erosion, nutrient losses, and pesticide off-site movement. According to Hartwig and Ammon, 2002, a percentage of the nitrogen that may be fixed by legume cover crops will be made accessible for crops with a high nitrogen requirement, such as maize. The use of ground coverings in locations where soil nitrogen is already a problem may offer a sink to capture part of this excess nitrogen and keep it until the following growing season.

7. **Living mulch can prevent water run-off:** Water run – off can be reduced by planting living mulch as cover crops as it retains rain water in soils besides preventing soil erosion. The rain water flows freely from barren fields as no obstruction / resistance is offered in the absence of vegetation. For vineyards, orchards and popular agronomic crops like corn, minor grains and forages, ground cover cropping systems have been developed. The study conducted by Machiwal *et al.*, 2021, revealed that intercropping cereal and legumes reduces the negative effects of rainfall on soil erosion and crop yield. They further clarified that cultivated fallow (108.03 49.95 kg $ha^{-1}yr^{-1}$) and unplowed fallow (78.95 28.42 kg $ha^{-1}yr^{-1}$) have the highest soil loss rates. Green gram is effective in reducing soil loss when grown as a sole crop (event-wise soil loss ranges from 0.54 to 33.94 kg ha^{-1}), as well as when grown in intercrop arrangements with sorghum and pearl

millet (event-wise soil loss ranges from 0.60 to 23.37 kg ha^{-1}).

B. *Management of living mulch*

The fundamental problem with living mulches is that it often suppresses the main crops. Most living mulches that are effective in suppressing weeds are also effective at suppressing crops. Crop suppression is mainly caused by resource competition (Liebman *et al.*, 2001; Teasdale 1998), though allelopathy may also be involved (Walters and Young 2008). Living mulches may result in unacceptably low yields if they compete with the main crops excessively. In an extreme case, Eberlein *et al.* (1992) observed that under non-irrigated conditions, unsuppressed lucerne (*Medicago sativa* L.) living mulch might result in corn yield losses larger than 96%. This section's objective is to describe management techniques that may boost the probability of beneficial results in living mulch systems. Even though there aren't many generalizations that can be made about all living mulch systems, the aim to spot any new patterns in the management literature and bring attention to any remaining knowledge gaps.

C. *Types of living mulches*

Living mulches that are annual or perennial should be chosen to meet different criteria and offer various benefits. Rapid establishment is a common requirement for living mulches (Buhler *et al.*, 1998; De Haan *et al.*, 1994). Legumes (Fabaceae), grasses (Poaceae), brassicas (Brassicaceae), and other broadleaf plant families (*Plantago major*) constitute the majority of cover crops. According to Koudahe *et al.* (2022), the best plant species to utilize as a cover crop will vary depending on the cover's function, the soil's quality, and its location and climate. Scavo *et al.* (2022) suggested that the selection of cover crops is based on factors such ease of establishment, soil coverage, ability to control weeds and pests, disease resistance, low competition with the main crop, and ease of termination. Despite the fact that annual species can also minimize tillage by eliminating the requirement for inter-row cultivation during the growing season, Leoni *et al.* (2020) determined that perennial living mulches are particularly well suited for no-till or low-tillage systems. Perennial living mulches could be more challenging to eradicate once they've taken root. For instance, Cardina and Hartwig (1980) discovered that crownvetch living mulch increased its herbicide tolerance over time. Annual living mulches provide the producer with more control over planting and termination dates, in addition to being easier to suppress than established perennial living mulches. Annual living mulches can be removed before seed is set to stop weeds from emerging next year, even if they are sometimes supposed to grow themselves (Teasdale, 1996). Living mulches should typically be able to grow quickly at first. They should be capable of competing with weeds and recovering quickly from field management activities. The main crop canopy shouldn't be hampered by a manageable, short-stature growing habit. For pest control and functional variety, producers should select living mulch species and primary crops from several families. Rosa *et al.* (2021) suggested that rye (*Secale cereale*) is one of the most popular cover crops produced in maize (*Zea mays*) and soybean (*Glycine max*) cropping systems due to its high biomass, propensity to outcompete weeds, low cost, and winter hardiness. Sullivan *et al.* (1991) claimed that legumes like hairy vetch (*Vicia villosa*) and balansa clover (*Trifolium michelianum*) are effective at fixing nitrogen (N) and increasing the bioavailability of N in soils, while grasses and Brassicaceae cover crops are known for nutrient absorption (Tribouillois, 2015) . Turk (2003) and Gavazzi (2010) highlighted the allelopathic effect of brassicas and rye on weeds. Brassica plants, like Siberian kale (*Brassica napus*) and purple top turnips (*B. rapa*), were found to lessen soil compaction through the development of their taproot systems, according to a study by Chen *et al.* (2014).

D. *Planting pattern and density*

A living mulch's ability to control weeds and perform other functions, as well as how it competes with the main crop, are all influenced by its density. Pouryousef *et al.* 2015 reported that there are three different results from experiments on the seeding rate of living mulch. First, when resources are scarce, crop productivity may decrease with an increase in living mulch density. This result represents a lot of mulch-crop competition at a lot of live mulch density. If weed pressure is anticipated to be high, on the other hand, crop production can rise with live mulch density (Kaneko *et al.*, 2011). The pattern and technique of planting living mulch may affect both the dynamics of competition and the yield of the primary crop, much like planting density does. According to Vrabel *et al.* (1980), legumes and maize competed excessively when planted together, but there was no yield loss if the legumes were sown in 0.45 m^{-1} strips between the corn rows. Buhler *et al.* (1998) discovered that when sava medic (*Medicago scutellata* Mill cv. Sava) was allowed to mature, the planting method (band between rows, band across rows or broadcast) had minimal impact on gigantic foxtail (*Setaria faberi* Herrm.) control or maize yield. Nagarajan *et al.,* (2020) reported that crop geometry affects the quantity at all phases of crop development; a spacing of 45 cm X 15 cm had higher light interception, while Pearlmillet in paired row sowing 30/90 × 15 cm had lower light interception. According to the aforementioned findings, the main crop and intercrop may both grow well when sown in paired rows of 30/90 × 15 cm since the intercrops receive more sun energy. A study (Sanders *et al.*, 2017) suggested growing maize in 90-cm rows on top of 20-cm herbicide bands applied to white clover mulch, taking into account possible mineralizable nitrogen, clover persistence, and corn grain production. Extension guidelines suggest that as an established legume living mulch may impede planter operation and seed placement, maize and soybean planting rates should be increased by 10% (Singer and Pedersen, 2005). It may not be necessary to use higher planting rates if grass or legumes and live mulch are planted later.

E. *Irrigation and nutrient inputs*

Mulch-crop competition usually occurs highest in regard to belowground resources because the majority of living mulches have low growth rates (Hartwig and Ammon 2002). Therefore, adding below-ground resources may lessen competition and reduce the amount of yield decreases brought on by living mulch as non-legume living mulch frequently decreases the amount of nitrogen available to the primary crop. It might be beneficial to boost nutrient nitrogen because non-legume-living mulches frequently restrict the availability of nitrogen to the primary crop. But the addition of nitrogen also tends to increase weed biomass several times more. However, a number of studies have demonstrated that legume-living mulches may actually require less nitrogen fertilizer than is typically the case for a monoculture crop. A partial kill of the legume improves the probability of this desired outcome since fixed nitrogen is released from legume tissues only after they die (Zemenchik *et al.*, 2000). Similar to competition for nutrients, competition for water is a major way in which live mulch may reduce crop yields. Graham and Crabtree (1987) revealed that yield decreases caused by a living mulch of perennial ryegrass (*Lolium perenne* L.) were mostly caused by water-use competition and that these reductions could be averted by watering and chemically suppressing the mulch. Irrigation may be less successful when crop productivity is not constrained by live mulch's ability to absorb water.

F. *Mechanical control*

Living mulch can be managed mechanically or chemically for a number of purposes. Strips of pre-existing ground cover must frequently be eliminated to allow for the planting and establishment of the primary crop. Management techniques can also support weed control efforts and/or reduce the intensity of mulch-crop competition. Herbicides were frequently seen as necessary in early investigations on living mulches (Teasdale, 1996). However, the popularity of mechanical management techniques has grown as a result of movements towards organic farming and reducing the use of herbicides. Although these methods are frequently successful, they may not completely eliminate weeds that are growing in crop rows in living mulch stands. Living mulches can sometimes make it more difficult to suppress weeds because it reduces the option of mechanical equipment that can be used. Planting competitive main crops and live mulch is therefore recommended. A previous recommendation supported this outcome, suggesting the use of mechanical and chemical techniques for row establishment in mixed-species living mulch. Strip tillage occasionally outperforms chemical treatments when only one technique is applied. Mechanical techniques may enhance crop nitrogen uptake. Boosting the crop's nitrogen availability is suggested by spreading legume clippings to the crop row after mowing. The effectiveness of this method is unknown (Thériault *et al.,* 2009), but removing clippings from the system may not be advisable. Varco *et al.* (1991) discovered that nitrogen levels at 0 to 10 cm soil depth were lower in a cut-and-remove treatment than in a cut-and-return treatment after 14 days. Further research could result in the creation of techniques that minimize disturbance to the soil and damage to the living mulches while balancing crop output, weed control, and soil fertility. Nowadays, combining mechanical control with other tactics, like chemical management, or using relatively aggressive procedures, like stripping tillage instead of mowing, are the most efficient approaches to reduce competition against main crops.

G. *Chemical control*

Similar to mechanical control, chemical control may help live mulch systems achieve a number of objectives, such as better crop establishment, less competition between mulch and crops, and increased weed suppression. In addition, live mulches are appreciated for their capacity to help reduce herbicide rate. Reduced herbicide rates are preferable for the environment and may increase the longevity of sods, but they may not sufficiently lessen competition with the primary crop. However, the use of herbicides tends to reduce the competition that mulch crops have with other plants, which can be detrimental to ground cover, biomass development, and the ability of living mulch to suppress weeds. Sometimes early research on living mulch failed to find herbicide treatments that increased primary crop yields without killing the mulch or drastically reducing ground cover. Subsequent research has focused on finding ways to protect yields without severely killing the mulch. Herbicide selection, dosage, application method, and/or timing may need to be modified to the living mulch system in order to meet these goals. Herbicide applications that vary in location can be used to control the trade-off between protecting the primary crop and sustaining the living mulch. For instance, clearing areas of living mulch with herbicides before crop emergence or planting can lessen interspecific competition. Planting crops resistant to herbicides is an alternative method of weed control. Affeldt *et al.* (2004) found that glyphosate- or glufosinate-resistant maize could be grown in a kura clover living mulch. The preplant applications of glyphosate plus dicamba (1.66 + 0.14 kg *a.i.* ha^{-1}) and postplant banding of dicamba plus clopyralid (0.56 + 0.05 kg *a.i.* ha^{-1}, 25 cm) before the in-season applications of glyphosate (0.83 kg *a.i.* ha^{-1}) or glufosinate (0.37 kg *a.i.* ha^{-1}) between the corn V3 and V5 stages did not affect the kura clover yield when compared to monocrop corn.

H. *Green manure crops as living mulch*

A growing cover crop of annual plants (or other growing plant material) is known as "green manure," and it is put into the soil to enhance or restore fertility and soil texture. Usually, these plants are grown on fallow ground and then buried under the earth before crops are planted. However, there are certain instances where plants are cultivated in one location and the foliage and roots are buried under the soil or utilized as mulch in another location. Legumes constitute the majority of the cover crops used for green manure. While they are growing, the crops cover and preserve the soil as well as add minerals to increase fertility. Per hectare of land, cover crops can add more than 30 t of organic matter and 200 kilogram nitrogen each year. Different legumes intercropped with a cereal-based cropping system include rice-soybeans, pigeon peas, and mung- beans; wheat-lathyrus, lentils and chickpeas and maize-pea, sunhemp, and cowpea. *Sesbania rostrata* is a legume that is used most importantly as a green manure and as a cover crop either as pre-rice or as an inter- or mixed crop with rice. Along with rice, it is sown at a rate of 25 kg per hectare. *Sesbania* is smothered with 2,4-D ester at a rate of 0.50 kg per hectare after 25 to 30 days of growth, or when it is roughly 30 to 40 cm tall. Without having any negative effects on rice yield, this co - culture method can cut the weed population in half. Nascimento *et al.* (2022) studied the effects of three cover crops *Cajanus cajan*, *Crotalaria juncea*, *Urochloa ruziziensis*, *Pennisetum glaucum* and fallow on the growth, yield components, yield and quality of upland rice in a no-tillage system. They discovered that these cover crops had a positive effect on these factors. Upland rice produced more panicles per m^{-2} when *C. cajan* was cultivated as a cover crop with mechanical soil scarification. Without scarification treatments, the number of empty grains rose with the growing of *C. cajan* as a cover crop. Pereira *et al.*, 2016 opined that a possible approach to boost plant biomass productivity and nutrient accumulation in no-tillage systems is management of plant crops, such as cultivation of cover crops or in intercropping systems. By combining cover crops with mechanical tilling of soil, one can increase crop quality, yield, and root growth and penetration in the ensuing seasons while reducing topsoil compaction.

I. *Future scope of living mulch*

Research on the introduction of living mulch along with primary crops has been done but information on research on various aspects exclusively on living mulch/cover crops, particularly under Indian conditions, is lacking. We believe that living mulch should receive more attention in order to diversify weed control programmes, prevent land degradation, and address environmental problems related to intensive farming. Growers who are willing to accept slight production losses in exchange for ecosystem services are particularly suited to using living mulches. Although research on living mulches for more than 50 years has shown that cultural, mechanical and chemical management techniques can boost the yields of major crops and support services like weed control, yet to create system-specific recommendations, additional study is required because best management practices vary between living mulch systems. Identifying low-input chemical control methods, refining organic system alternatives, expanding the list of effective species for living mulch, and implementing an all-encompassing strategy to managing living mulch are all examples of broad study subjects.

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