

Living Mulches For Organic Farming Systems

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SUMMARY. An important aspect of organic farming is to minimize the detrimental impact of human intervention to the surrounding environment by adopting a natural protocol in system management. Traditionally, organic farming has focused on the elimination of synthetic fertilizers and pesticides and a reliance on biological cycles that contribute to improving soil health in terms of fertility and pest management. Organic production systems are ecologically and economically sustainable when practices designed to build soil organic matter, fertility, and structure also mitigate soil erosion and nutrient runoff. We found no research conducted under traditional organic farming conditions, comparing bareground monoculture systems to systems incorporating the use of living mulches. We will be focusing on living mulch studies conducted under conventional methodology that can be extrapolated to beneficial uses in an organic system. This article discusses how organic farmers can use living mulches to reduce erosion, runoff, and leaching and also demonstrate the potential of living mulch systems as comprehensive integrated pest management plans that allow for an overall reduction in pesticide applications. The pesticide reducing potential of the living mulch system is examined to gain insight on application within organic agriculture.

Soil erosion has been widely recognized as a serious problem in the U.S. since the days of the Dust Bowl. The Dust Bowl was a decade-long drought in the southern Great Plains of the continental U.S. during the 1930s. Drought conditions along with land management practices such as single crop wheat farming, dust mulching, mechanization, and cultivating fallow land, led to severe wind erosion (Lockeretz, 1978). This erosion created expansive dust storms, which gave rise to the name the Dust Bowl. Wheat (*Triticum aestivum* L.) yields dropped as much as 32% and corn (*Zea mays* L.) yields by as much as 50% (Warrick, 1984). In 1931, the Texas legislature passed a law recognizing erosion of soil as the greatest menace to the agricultural lands of the state (Rockie, 1931). On 27 Apr. 1935, the 74th U.S. Congress passed Public Law 46, establishing the Soil Conservation Service as a part of the USDA (Hayes, 1982).

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Jasa and Dickey (1991) proved that plant residues are one of the most effective controls against soil erosion. A surface mulch layer of plant residues protects against raindrop impact and decreases runoff velocity on the soil surface. Conservation tillage is used to preserve plant residues on the soil surface. It is defined by the USDA Natural Resources Conservation Service as a practice that either maintains at least 30% of the plant residue from the previous crop, or where wind erosion is a major concern, maintains 1121 kg·ha⁻¹ (1000 lb/acre) of plant residue during critical periods [Hawaii Coastal Zone Management Program (HCZMP) 1995].

No-till farming promotes conservation of plant residues at the soil surface and maintains soil structure by eliminating tillage for seed bed preparation and weed control. The only type of implement that enters the ground is the no-till planter, which is a modified planter with a coulter in the front to cut through the residue and open a seeding furrow about 5 to 8 cm (2 to 3 inches) wide (Triplett and Van Doren, 1977). No-till systems have less erosion than chisel and other reduced tillage systems (Pantone et al., 1996). Clausen et al. (1996) compared runoff in two Vermont watersheds with different tillage practices. One watershed was moldboard plowed while the other one was disk harrowed. The reduced tillage disk harrow treatment decreased runoff by 64% and soil erosion by 99%. Hall et al. (1984) compared a no-till corn production system to conventional tillage corn. Their results were similar to Clausen et al. (1996), with the no-till treatments reducing soil losses 97% to 100%.

According to USDA statistics, farmers can lose an estimated \$99/ha (\$40/acre) annually in nutrient losses due to soil erosion. Hofstetter (1998) determined that cover cropping can limit these losses to as little as \$25/ha (\$10/acre). Plant residues act as a surface mulch that reduce the amount of soil exposed to erosive elements (Sojika et al., 1984). Cover crops that are planted following a crop harvest make use of residual nutrients and mitigate leaching through the soil profile (Power and Doran, 1988).

Cover crops are also planted to help alleviate weed infestations within no-till production systems. Teasdale et al. (1991), working in a no-till pro-

duction system, showed that when a cover crop produced more than 300 g·m⁻² (1.0 fl oz/ft²) and had greater than 90% groundcover, weed density was reduced 78% compared to treatments without cover crops. Cover crops are also important in limiting weed growth between crop cycles by competing for light, water, and nutrients (Schonbeck et al., 1991). Teasdale and Mohler (1993) conducted experiments in Beltsville, Md., and Ithaca, N.Y., comparing photosynthetic photon flux densities (PPFD) under mulches of hairy vetch (*Vicia villosa* L.) and rye (*Secale cereale* L.). Recordings were made at monthly intervals. PPFD increased much faster in a hairy vetch residue compared to the rye residue, due to the faster rate of decomposition. The decomposition rate of a cover crop plays a vital role in the persistence of a surface residue that can provide weed control.

Cover crops contribute biomass, which can maintain or increase organic carbon in the soil (Sainju and Singh, 1997). A green manure is a cover crop that is plowed under to add organic carbon and nitrogen to the soil (Abdul-Baki and Teasdale, 1993). The main crop in a production cycle contributes very little to soil organic matter when the harvest consists of removing most of the crop dry weight. With a cover crop, 100% of the dry matter is left in the field. Legume cover crops can yield anywhere from 1 to 9 Mg·ha⁻¹ (0.4 to 4.0 tons/acre) of biomass, while nonlegume crops can contribute 2 to 7 Mg·ha⁻¹ (0.9 to 3.1 tons/acre) (Sainju and Singh, 1997).

New requirements were set by the U.S. Congress in 1990 for states that have federally approved coastal zone management (CZM) programs, which are designed to protect coastal waters from nonpoint pollution. These plans are approved by the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA). A large portion of the CZM plan deals with agriculture. Management measures include erosion and sediment control, nutrient leaching and runoff control, pesticide reduction, and irrigation water quality and use (HCZMP, 1995).

Soil is a major source of nonpoint source pollution from an organic farm. The Natural Resource Conservation Service (NRCS) lists 22 management practices for erosion control and eight

could be directly applied to the living mulch system. The numbers following these practice are the NRCS practices (HCZMP, 1995) and include conservation cover (327), conservation cropping sequence (328), conservation tillage (329), contour farming (330), cover and green manure crop (340), field border (386), filter strips (393), and grasses and legumes in rotation (411).

It is important to recognize that choosing just one will not make for a successful nonpoint pollution control program and a farmer should design a best management practice (BMP) that will integrate several methods. The living mulch system allows an organic farmer to comply with federal standards while obtaining the benefits contributory to a sustainable system.

Living mulch

A living mulch is a cover crop that maintains a mulch layer all season long. A cover crop can suppress early season weed seed germination, but has very little effect late in the season due to break down of the residue (Hartwig 1989, Weston 1990). Suppressing the living mulch allows for regrowth that can maintain a mulch layer during the entire crop cycle (Elkins et al., 1979). In a review, Paine and Harrison (1993) cited four characteristics that are deemed important for a living mulch species; 1) rapid establishment of the living mulch is needed to provide early weed control and to prevent soil erosion, 2) adequate wear tolerance and persistence is needed for entrance into the field, 3) tolerance to drought and low fertility, and 4) low maintenance budget associated with mowing intervals, fertilizer needs, thatch removal, or chemical mowing.

A successful living mulch system provides balance between competition against weeds and accessibility for the cash crop with respect to light, water, and nutrients. In southern Illinois, Elkins et al. (1983) discovered, in a no-till corn and soybean (*Glycine max* L.) experiment using a grass living mulch, that maintaining 60% of the grass living mulch resulted in yields comparable to a conventional cultivation treatment for both crops. In a living mulch system, as mulch dry matter increases there is often a decrease in yield for the cash crop (Nicholson and Wein, 1983; Paine et al., 1995; Welker and Glenn, 1985). In

a screening of living mulch candidates, Nicholson and Wein (1983) selected five turfgrasses and three dwarf white clover (*Trifolium repens* L.) cultivars as treatments in a living mulch experiment growing sweet corn and cabbage (*Brassica oleracea* L. Group Capitata). These mulches were selected for use without any mulch suppression and without a plant-free crop strip. As mulch dry weight increased vegetable yield parameters decreased. Welker and Glenn (1985) planted peach (*Prunus persica* L.) trees in an unirrigated tall fescue (*Festuca arundinacea* L.) living mulch and compared the difference in tree growth among different sizes of vegetation-free squares below the trees. These squares ranged from 0.6 to 3.6 m² (6.5 to 38.8 ft²). Tree growth increased as the vegetation-free area increased. Perennial ryegrass (*Lolium perenne* L.) and dutch white clover living mulches in an asparagus (*Asparagus officinalis* L.) production system controlled weeds better in the unsuppressed mulch treatments, but yields of asparagus were 50% to 75% the yield of the unmulched controls (Paine et al., 1995).

The timing of living mulch suppression is crucial in obtaining good weed control and adequate crop yields. In a corn production study, early suppression (2 weeks before crop planting) of a crimson clover (*Trifolium incarnatum* L.) mulch decreased weed control, which resulted in low yields (Kumwenda et al., 1993). Grubinger and Minotti (1990) looked at sweet corn production in a white clover living mulch with treatments consisting of suppressing the clover mulch via rototilling at 2, 4, and 6 weeks after emergence. Suppression of the mulch 2 weeks after emergence produced the best corn yields. The optimum time for suppression of the living mulch is during the critical growth period of the main crop. A proper living mulch system should exert maximum competition for resources over weeds before the crop is planted. After the crop is planted, the living mulch is suppressed to allow for optimum crop productivity and contribute to the suppression of weeds. At the end of the cropping cycle the living mulch reasserts its role as the dominant weed controlling species.

Managing competition between living mulch and the cash crop is a major concern for farmers. One of the

best ways to reduce competition against the cash crop is to increase crop accessibility to light, nutrients, and water (Wiles and Crabtree, 1989). This is not always economically, nor environmentally responsible. However, the use of drip irrigation will further minimize competition from the living mulch by providing moisture and nutrients directly to the cash crop. Living mulch species that require a large input of resources are considered less desirable (Ogg and Dawson, 1984). Many growth characteristics must be considered to reduce resource competition. Screening for living mulches involves collection of analytical data as well as visual observation to identify certain desirable characteristics. One important feature is rapid germination and establishment to exclude weeds (Nicholson and Wein, 1983). Growth habit has emerged as a significant attribute in identifying a suitable living sod. Living mulch with a low stature will reduce the competition for light. Nonrhizomateous spread is also desired to further minimize competition by keeping the mulch from growing into the crop row (Newenhouse and Dana, 1989).

A living mulch system not only protects soil from erosive factors, but also preserves soil structure due to a reduction in soil compaction. This can be accounted for by minimized contact of tractor implements to the soil. A perennial root system is beneficial to the improvement of soil, where old roots decay leaving behind channels, while new roots create channels, forming pore spaces for better soil aeration and water infiltration (Russell, 1971). Bacteria living on this perennial root system produce polysaccharides and gums that bind to the channels, which also promotes soil aggregate formation (Russell, 1971).

A living mulch system can provide a comprehensive integrated pest management scheme, with potential for eliminating synthetic pesticides. A living mulch production system can eliminate preemergence herbicide applications (DeFrank, 1990). The living mulch not only provides for the effective management of weeds, but also plays a role in the management of arthropod and nematode plant parasites. The main component of this system relies on interplant presence, which alters the biotic and abiotic conditions within the microenvironment

due to an increase in floral diversity and ecological complexity.

Costello and Altieri (1994) looked at cabbage production in a living mulch system. A perennial legume living mulch reduced cabbage aphid (*Brevicoryne brassicae* L.) numbers compared to a cabbage monoculture. They concluded that the lower numbers in the living mulch plots were due to the lower light intensities reflected off of the living mulch. This reduction in arthropod pests can be translated into further reduction in overall pesticide use in a conventional production system and increased potential as a pest prevention measure within an organic production system.

Planting a nonhost cover crop species can reduce plant parasitic nematode populations compared to production cycles with a noncrop or weedy fallow period (Ko and Schmitt, 1996; Sipes and Arakaki, 1997; Viaene and Abawi, 1998). Valenzuela and DeFrank (1994) found 250% greater counts of plant parasitic nematodes in a monoculture eggplant production system compared to eggplant (*Solanum melongena* L.) production in a rhodesgrass (*Chloris gayana* Kunth.) living mulch system. Vrain et al. (1996) found the use of nonhost or resistant intercrops in raspberry (*Rubus idaeus* L.) production to lower plant parasitic nematodes in the between row space, but with no effect on the nematode populations within the adjacent raspberry rhizosphere. Spatial manipulation of the rhizosphere with the use of a nonhost living mulch species in the between row space can have an impact on the population locality and density of plant parasitic nematodes, allowing for directed measures of control.

A key component to a successful organic farming operation is the improvement and maintenance of soil health and stability. The conventional organic approach to improving or maintaining soil health is through repeated incorporation of compost, green manure, and animal manure by mechanical cultivation. However, a living mulch system with reduced tillage can also improve soil physical characteristics. These improvements include increased soil organic carbon, total soil nitrogen, moisture retention, and microbial biomass (Analele and Bishnoi, 1992; Carter, 1991 and 1992; Fausey and Lal, 1992; Sojka et al., 1991; Wood and Edwards, 1992). Welker

and Glenn (1988) looked at the soil properties of different peach tree planting systems, comparing no-till groundcover treatments versus a bareground cultivated treatment and a bareground herbicide treatment. The no-till plots prevented or reduced soil organic matter depletion, increased water infiltration rate and soil aggregate stability. These are attributes associated with the maintenance of organic matter in the soil (Oades, 1984; Russell, 1971). Welker and Glenn (1988) also showed an increase in soil CO₂ concentration in the sod no-till treatments, which they attributed to increased microbial activity associated with breakdown of the sod root system. Merwin and Stiles (1994) compared groundcover management practices (GMP) in an apple (*Malus domestica* Borkh.) orchard system. Six years into the experiment, soil water retention in the bareground treatment plots decreased on a per unit volume basis, due to a decrease in the micropore fraction of the soil profile. Under dry conditions, water sorptivity was also decreased in the bareground plots compared to the mulch treatments, due to the dense surface crust formed on the bare soil. After 5 years, the two bareground treatments showed a decrease in soil organic matter compared to the rest of the treatments, which maintained or increased in soil organic matter levels. Living mulch systems contribute to soil health sustainability with the presence of a perennial root rhizosphere. A rhizosphere is the soil profile with in the root zone. Plant roots release organic substrates, including carbohydrates, amino acids, organic acids, enzymes and vitamins (Lynch, 1982). Microbial populations include bacteria, fungi, yeast, and protozoa, and are directly influenced by the presence of a root system (Lynch, 1982). Microbial diversity increases when multiple plant species are grown in mixture (Newman et al., 1979). Soil microbial diversity has been shown to promote plant growth and disease resistance (Shen, 1997). An increase in rhizosphere microflora is accompanied by heightened faunal activity, especially with groups that graze on microflora or roots (Paul and Clark, 1989), such as microbivorous nematodes (nonplant parasitic bacterial and fungal feeder nematodes). Leary (1999) recorded an increase in microbivorous nematode populations in buffelgrass

(*Cenchrusciliaris*L.) living mulch treatments compared to the bareground monoculture treatment, which may have been attributed to an increase in rhizosphere volume and diversity and also an increase in soil moisture. A positive correlation has been reported between organic carbon and nematode density (Dwivedi et al., 1988, 1989), while an increase in soil moisture has been shown to enhance root and fungal growth, resulting in an increase of fungal feeding nematodes (Steinberger and Loboda, 1991). Taylor and Rodriguez-Kabana (1999) have demonstrated in peanut (*Arachis hypogaea* L.) production an influence of microbivorous nematodes on the suppression of root-knot nematodes. However, it is unclear what role microbivorous nematodes play in suppressing plant parasites. A higher microbivorous nematode population in the living mulch system can indicate a more complex soil and rhizosphere microbial population compared to a monoculture system. A normal rhizosphere structure does not include pathogens and may resist their invasion if it remains stable (Lynch, 1982). Disease resistance can be attributed to allelopathy, spatial competition within an ecological niche, and parasitism (Shen, 1997).

Many studies are characterized by treatments using either a legume or a grass as the living mulch. Selection is dependent on the crop being grown and the purpose for using a living mulch system. In corn production, where nitrogen is in high demand (Hartwig, 1990; Welker and Glenn, 1985), a leguminous crop is desirable and shows promise in controlling weeds as well (Enache and Ilnicki, 1990; Hartwig, 1989). However, maintaining a legume living mulch can be difficult, with a severe loss of stand after chemical suppression (Elkins et al., 1983).

Even though there may be a reduction in competition for nitrogen with a legume, there may be an increase in competition for moisture. The taproot system of a legume can reach down to soil levels used by the main crop (Mohler, 1995). Toenjes et al. (1956) found that chewing's fescue (*Festuca rubra* L.) and kentucky bluegrass (*Poa pratensis* L.) predominately absorb water within the first 20 cm (7.9 inches) of the soil surface, whereas white clover depleted water down to

100 cm (39.4 inches). He also found that grasses generally used less water than legumes.

Desirable attributes of a grass as a living mulch species include early high density and a low growth habit that is not rhizomateous. A tillering or bunch-type grass is ideal for management of competitive effects (Nicholson and Wein, 1983). In a living mulch screening study, Nicholson and Wien (1983) found differences in the mulch dry weight and weed control between grasses and legumes. The grasses in general provided better weed control.

Research needs for organic living mulch systems

An important factor in the management of living sods is the method of suppression. Two methods that have been extensively reported in the literature are mechanical mowing and chemical suppression with sublethal doses of selective herbicides. Even though chemical suppression is not a viable option for an organic farmer, current research has shown it to be the most promising strategy (Costello and Altieri, 1994; Elkins et al., 1983; Graham and Crabtree, 1987; Valenzuela and DeFrank, 1994; Wiles and Crabtree, 1989). Leary (1999) looked at long-term production of eggplant in a buffelgrass living mulch system comparing different rates of chemical suppression. There was no significant linear trend in yield response of the eggplant, with an increase in suppression of the living mulch. They concluded that the lowest rate of suppression was adequate in obtaining commercially acceptable yields and that further research should be conducted to determine yield response in a buffelgrass living mulch system without any suppression.

The development of an organic living mulch system must be preceded by research into nonchemical methods of suppression, such as mechanical mowing or spray applications of organic paints that when applied to the living mulch will physically block photosynthesis. Maintaining a minimum height stature is crucial in minimizing competition for light. Shankarnarayan et al. (1979) showed that frequent cutting of a buffelgrass pasture decreased root numbers and weights. Manipulating root development can

Table 1. Beneficial soil attributes associated with the a perennial living mulch in an organic farm production system.

Attribute	Benefit
Erosion control	Preserve top soil and comply with federal regulations particularly in coastal zones
Soil structure development and maintenance	Channel and aggregate formation for water infiltration, aeration, and root penetration
Organic matter augmentation and carbon dioxide sequestration	Improved nutrient status and retention
Perennial rhizosphere presence and diversity	Increased and more complex microbial diversity with improved stability

Table 2. Beneficial pest management attributes associated with the a perennial living mulch in an organic farm production system.

Pest	Benefit
Weeds	Spatial competition in the between row space; accessibility of mulch to be directed in to the crop row
Arthropods	Masking of the cash crop; habitat to beneficials; mitigation of pest migration across crop rows due to presence of a nonhost species in the between row space
Nematodes	Manipulation of plant parasite populations through nonhost presence
Diseases	Mitigation of soil splash as a source of disease induction; increased microbial diversity creating a more stable soil system and lower disease inducement

play a part in minimizing competition for moisture and nutrients. The use of biologically derived disease agents that are selectively pathogenic to the living mulch and not the cash crop also has potential as an organic means for suppression. Research in this area would include the preparation of inoculum, methods of application, and the manipulation of microenvironmental conditions for disease proliferation.

Further research must also be continued in selecting desirable living mulch species. This is dependent on the crop being produced and the local climate. In terms of minimizing competition against the cash crop, the selection process should be based on resource requirements and growth habit. A common objective in plant breeding programs is to identify and incorporate attributes such as increased yield production and disease resistance. Identifying beneficial attributes for a living mulch species focuses on similar traits from a different perspective. A living mulch species with high biomass production may be indicative of aggressive competition. A living mulch breeder would be more interested in cultivars that demonstrate a medium to low production rate that is ideal for soil surface protection with minimum competition against the cash crop. A living mulch breeder may also be interested in cultivars that are susceptible to certain diseases. A resistant variety may rule out the use of disease inoculum as a biological suppressant, while a hypersensitive variety may be killed.

Further study is needed to determine the role of living mulch as a habitat for beneficial arthropods. When predator/parasite augmentation is a desired pest management strategy, a suitable habitat for the beneficial should optimize the effectiveness in control of the pest. Tiffany et al. (1998) found buffalo grass (*Buchloe dactyloides* L.) to have very few pests due to a high number of beneficial predators and parasites living in the canopy.

Implementing a living mulch component into an organic farming system

An organic farmer incorporates compost and mulch as a source of nutrition and weed control respectively. The presence of the living mulch in the between row space allows the farmer to concentrate resources within the cash crop row and reduce application up to 60%. If a green manure crop is desired for nutrition supplement, cost of materials are reduced based on direct planting into the crop rows compared to broadcast seeding over the entire field. Incorporation of the green manure crop can be achieved by rotovation or strip tillage. Strip tillage has been proven successful in reduced tillage comparison studies (Hoyt, 1999). The disadvantage to plowing under a green manure is the loss of weed control supplied by the mulch layer on the soil surface. Strip tillage in a living mulch system can be followed by a mowing in the between row space and application of the living mulch

clippings to the cash crop row providing a mulch layer.

Successful use of a living mulch system in organic farming will be attained by developing techniques that enhance the benefits associated with intercrop presence (Table 1 and 2). Potential for successful transition to a living mulch system is high, due to an organic farmer's proactive stance on the development and practice of new and innovative production techniques. Organic farming has generally been viewed as a return to traditional farming practices before the advent of chemical fertilizers and synthetic pesticides. However, advances in organic farming will require an extensive knowledge base in microbial/plant complex interactions within an agroecosystem and the use of modern technologies compatible with natural product enterprises. A living mulch system can improve soil nutrient status and structure, provide arthropod pest management through masking of the cash crop and supplication of a beneficial habitat, provide spatial competition against weed infestation, and support a rhizosphere-enhanced diversity in microbial populations that can suppress soilborne pathogens.

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