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Contribution of Cover Crops to Weed Management in Sustainable Agricultural Systems

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Research Question

Cover crops have become a viable option for sustainable agriculture because of contributions to soil fertility and improved crop performance. The contribution of cover crops to weed management is not clearly defined. Ideally, weed control could be improved if a manageable cover crop could replace an unmanageable weed population in the agroecosystem. This paper summarizes present knowledge of weed control by cover crops in order to define appropriate cover crop management in sustainable agricultural systems.

Study Description

This paper focuses on cover crop use in no-tillage production systems. No-tillage systems are emphasized because of greater opportunity for cover crops to interact with weed germination and establishment at the surface of soils. Two major types of cover crops are addressed: winter annual and living mulches. Winter annual cover crops are seeded every year in late summer or fall and terminated before planting the following spring. Living mulches are perennials or self-seeding annuals that grow during part or all of the cropping season and naturally re-establish annually.

Applied Questions

Does residue from winter annual cover crops control weeds?

Residue from winter annual cover crops can provide early-season weed suppression but not full-season weed control. Early-season weed suppression is increased by increasing residue biomass. Small-seeded annual weed species with a light requirement for germination are most sensitive to cover crop residues. Weed control is not complete, however, at natural residue amounts, probably because of heterogeneity in the residue layers. Emerged weeds compensate for lower weed numbers with greater growth per plant so weed biomass later in the season is not influenced as much as early-season weed emergence.

Can living mulches suppress weeds but avoid crop competition?

Any living mulch competitive enough to suppress weeds will also be competitive enough to interfere with crop growth and yield. Therefore, research on living mulches has focused on regulating the living mulch enough to prevent competition with the crop but permit sufficient recovery of the mulch for subsequent years. Approaches to regulation have included nonlethal herbicide rates, banded herbicides, strip tillage, mowing, and relay planting.

Are herbicides necessary for weed control when using cover crops?

Most successful management sytems for cover crops require herbicides to control weeds emerging through cover crop residue or to regulate living mulches. Given present cover crops and management systems, complete elimination of herbicides is not a realistic objective.

Can cover crops permit a reduction in herbicide use?

Winter annual cover crops could permit reduction of herbicide inputs and a shift toward total postemergence herbicide programs for many crops. The early weed suppression provided by cover crop residue should permit crops to become

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established before weed emergence. Postemergence herbicides could be used to control later-emerging weeds for crops with viable postemergence alternatives. This approach would contribute to sustainable agriculture by replacing preemergence herbicides, which are most frequently detected in ground and surface waters, with postemergence herbicides, which are often used at lower rates and are less persistent.

What is the role of cover crops in sustainable agriculture?

The major contribution of cover crops to agricultural systems is probably long-term soil protection and fertility enhancement, particularly on erodible land. Erosion prevention and soil stabilization is probably the highest priority for maintaining a sustainable agriculture on these sites. In this situation, herbicides should be regarded as a tool for preserving soil resources rather than an input to be eliminated.

Contribution of Cover Crops to Weed Management in Sustainable Agricultural Systems

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Cover crops have become a viable option for sustainable agriculture because of contributions to soil fertility and improved crop performance. This paper focuses on weed control and summarizes present knowledge of the contribution of cover crops to managing weeds in sustainable agricultural systems. Residue from winter annual cover crops provides early-season weed suppression but not full-season weed control. Living mulches that are effective at controlling weeds also will require management to prevent excess competition with the cash crop. Elimination of herbicides is not a realistic objective for using cover crops. Rather, herbicides should be considered a tool for managing cover crops and optimizing their potential for improving soils and sustaining agricultural production.

COVER CROPS have become a viable option for sustainable agriculture because of contributions to soil fertility and improved crop performance (Smith et al., 1987). Specific contributions include erosion control, reduced runoff, improved infiltration, soil moisture retention, improved soil tilth, nutrient enhancement, and weed control. This paper focuses on weed control and summarizes present knowledge of the contribution of cover crops to managing weeds in sustainable agricultural systems. No-tillage systems are emphasized because of greater opportunity for cover crops to interact with weed germination and establishment at the surface of soils. A comprehensive literature review has been published elsewhere (Teasdale, 1996).

The principle goal of using cover crops for weed control is replacing an unmanageable weed population with a manageable cover crop. This is accomplished by adjusting the phenology of the cover crop to preempt the niche occupied by weed populations. Two major types of cover crops are addressed in this paper: winter annuals and living mulches. The objective of using a winter annual cover crop for weed management is the production of sufficient residue to create an unfavorable environment for weed germination and establishment. The objective of using a living mulch is displacement of weeds by competition from an established cover crop.

WINTER ANNUAL COVER CROPS

Winter annual cover crops are planted in late summer or fall, become established before winter, and produce most biomass during early spring before planting a summer crop. Typically, cover crops are terminated or senesce close to planting, leaving a layer of residue on the soil surface. Many legume or cereal species can be used in coastal or southern areas (Holderbaum et al., 1990). Hairy vetch (*Vicia villosa* Roth) is the most winter hardy legume and can be grown in most areas of the USA except the northernmost states. Rye (*Secale cereale* L.) is the most winter hardy cereal species and will overwinter anywhere in the USA. Winter annual cover crops are best adapted to areas where there is a sufficient establishment period in the fall and soil moisture is not limiting in the spring.

Weed Control by Cover Crop Residue

Several features of weed control by surface residue from winter annual cover crops have been identified:

Weed control increases with increasing residue biomass. Weed biomass and/or density decreased as biomass of wheat (*Triticum aestivum* L. emend. Thell.)(Crutchfield et al., 1985; Wicks et al., 1994), rye (Mohler and Teasdale, 1993), hairy vetch (Mohler and Teasdale, 1993), or old field (Carson and Peterson, 1990) residue increased. Residue biomass was more important in determining weed suppression than residue type. At equivalent residue biomass levels, hairy vetch and rye equally suppressed weed density (Mohler and Teasdale, 1993; Teasdale and Mohler, 1992).

Weed control is species specific. Cover crop residue selectively suppressed emergence of some weed species more than others. Early research showed that establishment of small-seeded vegetable crops was inhibited more than large-seeded crops by residues of various grass species (Putnam and DeFrank, 1983). Velvetleaf (*Abutilon theophrasti* Medicus), a relatively large-seeded, light-insensitive weed species, was influenced less than small- seeded, light-sensitive species such as common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and various annual grasses (Table 1). Litter in old-field communities reduced the density of annual species more than perennial species (Monk and Gabrielson, 1985; Carson and Peterson, 1990; Facelli and Pickett, 1991). Emergence of the perennial weed species curly dock (*Rumex crispus* L.) and dandelion (*Taraxacum officinale* Weber in Wiggers) were unaffected by natural residue rates in contrast to annual species (Table 1). Generally, small-seeded annual species having a light requirement for germination appear to be most sensitive to surface residue.

Weed control is incomplete. Total weed density was reduced by approximately 50 to 75% by naturally occurring cover crop residue levels (Crutchfield et al., 1985; Mohler and Teasdale, 1993). Natural residue levels are assumed to be approximately 3000 lb/acre in this paper but may vary considerably depending on species, location, and planting and termination dates (Smith et al., 1987). Annual grass species required residue levels 1.5 to 2 times natural levels

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Abbreviation: PPFD, photosynthetic photon flux density.

Table 1. Influence of hairy vetch residue on emergence of selected weed species in 1990 at Ithaca, NY, and Beltsville, MD (based on Mohler and Teasdale, 1993).

Weed species	Species characteristics†	% reduction of emergence at natural residue level‡	Residue level§ required for >90% reduction in emergence
		%	
Velvetleaf	Annual, broadleaf, –	26	>4X
Redroot pigweed	Annual, broadleaf, +	68	4X
Common lambsquarters	Annual, broadleaf, +	66	4X
Common chickweed	Annual, broadleaf, +	37	4X
Barnyardgrass	Annual, grass, +	40	1.5X
Witchgrass	Annual, grass, +	58	2X
Giant green foxtail	Annual, grass, +	78	1.5X
Curly dock	Perennial, broadleaf, +	0	4X
Dandelion	Perennial, broadleaf, +	0	4X

† – or + = absence or presence of a light requirement for germination.
‡ Natural rate equalled 2580 lb/acre at Ithaca and 2850 lb/acre at Beltsville.
§ Multiplier times natural rate.

Table 2. Influence of cover crop residue on factors influencing weed germination and emergence.

Factor	Influence of cover crop residue on factor	Resulting influence on weed emergence
Light		
Quantity	Reduction	Reduction
Quality	None	None
Soil temperature		
Maximum	Reduction	Delay
Minimum	Slight increase	None
Amplitude	Reduction	Reduction
Soil moisture	Increase	Reduction if saturated soil Increase if droughty soil
Allelopathy	Present	Reduction if sufficient toxin concentration
Physical impedence	Present	Reduction if sufficiently dense

to reduce weed densities by greater than 90%, whereas most other species required residue levels 4 times natural levels for 90% reduction (Table 1). Despite emergence reductions by residue, the number of emerged weed seedlings usually is sufficient to compete effectively with crops and reduce yields when no herbicides are applied (Wicks et al., 1994). Weed biomass may be influenced less by residue than weed density because weeds often compensate for reduced density by producing greater biomass per plant (Carson and Peterson, 1990; Facelli and Pickett, 1991). In general, cover crop residue can be expected to provide early-season weed suppression but not full-season weed control.

Factors Controlling Weed Germination and Establishment

Cover crop residue influences many factors that control weed germination and establishment (Table 2). Most of these factors are related to modifications of the radiation environment by an organic surface mulch. Interception and reflection of short-wave radiation by mulch elements reduces the quantity of light available to activate phytochrome-mediated germination, reduces heat absorption by soil during the day, and reduces evaporative soil water loss.

Light. Transmittance of photosynthetic photon flux density (PPFD) declines according to an exponential decay function of residue biomass (Facelli and Pickett, 1991; Teasdale and Mohler, 1993). Similar decay functions describe both weed density and light transmittance (Teasdale and Mohler, 1992), suggesting that light transmittance may be a good indicator of the capacity of mulches to suppress weed emergence. This is not unreasonable since most weed species require light to activate phytochrome-mediated germination. Other factors discussed below also are confounded with light transmittance and may contribute to inhibition of weed seed germination.

Mulch structure influences light transmittance through residue. Teasdale and Mohler (1993) showed that hairy vetch and rye residue had very similar light extinction coefficients. Facelli and Pickett (1991) demonstrated that oak (*Quercus alba* L.) leaves had a greater and goldenrod (*Solidago* spp.) had a lower extinction coefficient than that observed for hairy vetch or rye residue by Teasdale and Mohler (1993). This suggests that light extinction is greatest for residue consisting of large leafy material, intermediate for residue consisting of fine stems, such as hairy vetch or rye, and lowest for residue consisting of larger stems such as goldenrod. If light transmittance is a good indicator of weed suppression by residue, then cover crops having a greater proportion of large leafy elements and fewer stems should be best adapted for controlling weeds.

Light transmittance through cover crop residue is highly heterogeneous, despite the appearance of uniform soil coverage (Teasdale and Mohler, 1993). Natural rates of hairy vetch or rye residue (approximately 3000 lb/acre) had 17 to 25% of sites under the residue transmitting greater than 50% of incoming PPFD. Twice the natural residue rate permitted 16 to 25% of sites to transmit greater than 10% of incoming PPFD. The spatial heterogeneity of residue may explain why complete weed control is not obtained.

Light quality is influenced minimally by desiccated cover crop residue. Transmittance increased slightly as wavelength increased from 400 to 1100 nm (Teasdale and Mohler, 1993). The red to far-red ratio was not altered sufficiently to influence phytochrome-mediated germination.

Soil temperature. Residue on the soil surface reduces maximum soil temperature and may slightly increase minimum soil temperature compared with bare soil (Bristow, 1988; Teasdale and Mohler, 1993). Natural residue levels reduced maximum soil temperatures by 4 to 9°F (2 to 5°C) and raised minimum soil temperatures by 1 to 2°F (1°C). This degree of reduction in maximum soil temperature was not sufficient to prevent weed seed germination but probably accounted for the delay of germination observed for many species (Mohler and Teasdale, 1993). Reduction of soil temperature amplitude probably was sufficient to prevent germination of species with a temperature amplitude requirement to break dormancy, such as common lambsquarters and barnyardgrass [*Echinochloa crus- galli* (L.) Beauv.].

Soil moisture. Residue on the soil surface increases soil moisture by increasing infiltration (McVay et al., 1989) and by decreasing evaporative moisture loss (Bristow, 1988). Under saturated soil conditions, residue could slow evaporation and reduce germination of species inhibited by excess soil moisture. Under droughty conditions, retention of soil moisture could enhance weed germination and seedling survival. This would explain the increase in density of selected species observed at low residue levels compared with bare soil (Mohler and Teasdale, 1993).

Allelopathy. The toxicity of extracts of numerous plant species to germination or growth of other plants is well established (Putnam, 1985). Various allelopathic compounds have been isolated and identified (Barnes et al., 1987; Shilling et al., 1986). Toxins released from cover crop residue have been presumed to inhibit weed germination and growth in natural environments (Putnam and DeFrank, 1983; Shilling et al., 1985) but this is difficult to demonstrate in situ. Allelopathic influences of residue are confounded with the physical and nutrient influences addressed above. Putnam and DeFrank (1983) suggested that superior weed suppression by rye residue compared with wood shavings demonstrated that more than physical effects were involved. Blum et al. (1992) provided a comprehensive analysis of soil extraction procedures and bioassays that demonstrated the allelopathic activity of wheat in no-tillage soils. Yenish et al. (1995) showed that disappearance of allelochemicals from rye residue corresponded more closely with the duration of weed suppression by rye than physical disappearance of rye residue. Ultimately, research must demonstrate that sufficient toxin concentration remains in the soil long enough to inhibit weed germination or growth.

Physical impedence. Surface residue probably inhibits the emergence of many weed species by forming a mechanical barrier to the upward growth of seedlings. However, this factor is confounded with the environmental and allelopathic factors discussed above and no research has been conducted to determine the contribution of this factor alone to weed suppression.

Role of Cover Crop Residue in Sustainable Agriculture

Research indicates that cover crops may contribute to weed control in reduced-tillage cropping systems but additional management practices, including herbicides, are required for achieving optimum control. Weed control and crop yield were improved and more consistent when cover crops were supplemented with herbicides in various reduced-tillage systems, including corn (*Zea mays* L.) (Johnson et al., 1993; Teasdale, 1993; Wicks et al., 1994), soybean [*Glycine max* (L.) Merr.] (Liebl et al., 1992), cotton (*Gossypium hirsutum* L.) (Brown and Whitwell, 1985), and potato (*Solanum tuberosum* L.) (Wallace and Bellinder, 1989). At present, elimination of herbicides is not a realistic objective for using cover crops. The contribution of cover crops toward soil improvement and fertility probably is more important than their contribution to weed control.

Cover crops could permit reduction of herbicide inputs and a shift toward total postemergence herbicide programs for crops with effective postemergence options. The early weed suppression provided by cover crop residue would permit many crops to become established before weed emergence. Postemergence herbicides then could control later-emerging weeds until the crop is past the critical period for weed control. This approach potentially could reduce environmental impact by replacing preemergence herbicides, which are most frequently detected in ground and surface waters (National Research Council, 1989), with postemergence herbicides, which are often used at lower rates and are less persistent. Wallace and Bellinder (1992) proposed that cover crops, combined with an as-needed postemergence herbicide program, could enhance sustainable vegetable production.

LIVING MULCH

A living mulch is a cover crop that remains alive for part or all of the cropping season. Species are typically perennials but may be self-seeding annuals. Living mulches offer the advantage of not requiring reseeding each year but have the disadvantage of competing with the crop for available resources. This requires a management program to suppress the living mulch enough to prevent competition but not enough to prevent recovery.

An established living mulch potentially can inhibit germination and emergence of weeds more effectively than desiccated residue (Teasdale and Daughtry, 1993). Chlorophyll in living mulch vegetation intercepts red light and reduces the red to far-red ratio sufficiently to convert phytochrome to an inactive form. Light transmittance and soil temperature amplitude are reduced more by living than by desiccated mulches. In addition, any seedlings that emerge are at a competitive disadvantage against an established living mulch. Opportunities for weed establishment may develop in gaps when the living mulch stand thins.

Living Mulch Regulation

A living mulch that is competitive enough to suppress weeds usually requires regulation to avoid crop suppression. Most research on living mulches has focused on crop response to various management approaches. Many reports demonstrate the difficulty of achieving effective and consistent results. This paper will summarize successful approaches that have been reported.

Non-lethal broadcast herbicide. Eberlein et al. (1992) reported that alfalfa (*Medicago sativa* L.) could be suppressed by a sublethal rate of atrazine but recover from buds on the lower stems. Corn yield was not reduced by suppressed alfalfa when corn was irrigated but leaf area, growth, and yield were reduced without irrigation. Elkins et al. (1983) found that corn yields were not reduced by various perennial grasses and legumes when suppressed at least 50% by selected herbicide treatments. In Pennsylvania, Hartwig (1987) has developed prescriptions using sublethal herbicide applications for establishing and maintaining a crownvetch (*Coronilla varia* L.) living mulch in various field crop rotations.

Banded herbicide. Eberlein et al. (1992) managed alfalfa with a band application of a lethal rate of atrazine. This approach also required irrigation to prevent corn yield loss. Elkins et al. (1983) also included various banded herbicide treatments successfully. Kumwenda et al. (1993) demonstrated that crimson clover (*Trifolium incarnatum* L.) killed in a 60 to 80% band over the corn row did not interfere with yield and permitted adequate reseeding of the clover.

Banded cultivation. Strip tillage of a living mulch has been practiced primarily for horticultural crops. Yields of sweet corn and cabbage (*Brassica oleracea* var. *capitata* L.) planted in a 12-in. (30-cm) band were not reduced by various grass and white clover (*Trifolium repens* L.) mulches as long as mulch biomass was limited (Nicholson and Wien, 1983). A combination of strip tillage plus rototilling between rows did not kill white clover but prevented reduction of sweet corn yields (Grubinger and Minotti, 1990). Costello and Altieri (1994) reported that broccoli (*Brassica oleracea* L. var. *italica)* could be grown successfully in 4-in. (10-cm) cultivated strips in mowed living mulches of various clover species.

Mowing. Mowing, alone, has not been reported to suppress living mulches. This approach may be useful in combination with other practices to avoid shading during crop establishment.

Relay planting. Relay planting is useful in intercropping systems to stagger the critical growth phase of each crop so they do not compete for the same resources during the same time. This approach can be applied to winter annual living mulches, which naturally senesce before crop demand for resources becomes critical. Corn planted into crimson clover (Kumwenda et al., 1993) or subterranean clover (*Trifolium subterranean* L.)(Enache and Ilnicki, 1990) successfully exemplifies this approach. Both of these clover species naturally reestablish from seed each year, thereby behaving as a living mulch despite being annuals.

Contribution of Living Mulches to Sustainable Agriculture

Most living mulches require herbicides to regulate growth and often require as much herbicide as would be required to control weeds in the absence of the mulch. The major contribution of living mulches to agricultural systems is long-term soil protection and fertility enhancement, particularly on erodible land. Erosion prevention and soil stabilization is probably the highest priority for maintaining a sustainable agriculture on these sites. In this situation, herbicides should be regarded as a tool for preserving soil resources rather than an input to be eliminated.

INTEGRATED MANAGEMENT SYSTEMS

Cover crops influence many aspects of cropping sytems including nutrient availability, soil tilth, soil temperature, soil moisture, erosion, leaching, crop establishment, and weed control. This makes component research difficult because the influence of one factor is confounded with that of other factors. On the other hand, cover crops offer opportunities to manipulate many facets of cropping systems through management of a single component. An integrated approach is needed for managing and assessing cover crop performance in cropping systems.

Cover crop influences can be both positive and negative. Some common advantages to growing cover crops are nutrient enhancement (particularly when using a legume cover crop prior to a grain crop), soil nutrient capture, soil moisture retention, and long-term soil stabilization. Some common disadvantages include additional management and expense, interference with crop establishment, soil moisture depletion, cooler soil temperature, and less predictable crop fertilizer requirements. The goal of integrated management should be optimization of the benefits and minimization of the liabilities associated with cover crops.

Increasing the biomass of cover crop residue to increase weed control provides an illustrative example. Greater cover crop biomass could be achieved by growing locally productive species, by permitting cover crops to grow longer before termination, or by growing combinations which produce more biomass than any cover crop alone. However, enhanced residue biomass could have several negative consequences. Crop establishment often is difficult through dense layers of residue (Brown and Whitwell, 1985; Kumwenda et al., 1993; Liebl et al., 1992; Teasdale, 1993). High residue biomass may be achieved at the expense of a high C:N ratio, which could immobilize N (Holderbaum et al., 1990). Greater or longer cover crop growth in spring could lead to excessive soil moisture depletion (Liebl et al., 1992). High residue levels could lower soil temperatures and reduce early crop growth (Fortin and Pierce, 1990). These effects could nullify the weed control benefits of high residue levels and result in a net yield loss. Wicks et al. (1994) found that maximum corn yield was achieved at intermediate rates of wheat residue, despite greater weed suppression by high residue rates.

The success of cover crop management depends on the balance of positive and negative cover crop influences. An accurate assessment must be made of the potential for weed suppression and herbicide reduction relative to other potential benefits such as improved soil fertility. This will determine whether herbicide reduction should be a primary objective of cover crop management or whether herbicides should be used as a tool toward achieving other cover crop benefits. Development of models that accurately predict cover crop influences would aid in simulating cover crop performance under various management and environmental scenarios.

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