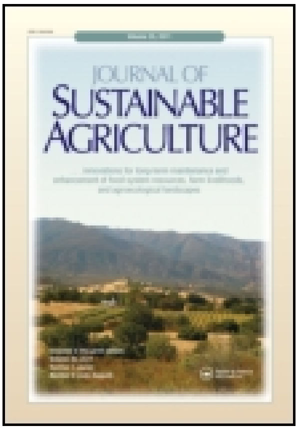

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Miguel A. Altieri [a] , Marcos A. Lana [b] , Henrique V. Bittencourt [c] , André S. Kieling [d] , Jucinei J. Comin [d] & Paulo E. Lovato [d]

[a] College of Natural Resources, University of California, Berkeley, California, USA

[b] Leibniz Centre for Agricultural Landscape Research, CLARIS-LPB, Müncheberg, Germany

[c] Eures de Agronomía, Universidade Federal da Fronteira Sul, Laranjeiras do Sul, PR, Brazil

[d] Centro de Ciências Agrárias, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil

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Enhancing Crop Productivity via Weed Suppression in Organic No-Till Cropping Systems in Santa Catarina, Brazil

MIGUEL A. ALTIERI,[1] MARCOS A. LANA,[2] HENRIQUE V. BITTENCOURT,[3] ANDRÉ S. KIELING,[4] JUCINEI J. COMIN,[4] and PAULO E. LOVATO[4]
[1] *College of Natural Resources, University of California, Berkeley, Berkeley, California, USA*
[2] *Leibniz Centre for Agricultural Landscape Research, CLARIS-LPB, Müncheberg, Germany*
[3] *Eures de Agronomía, Universidade Federal da Fronteira Sul, Laranjeiras do Sul, PR, Brazil*
[4] *Centro de Ciências Agrárias, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil*

In Santa Catarina, southern Brazil, family farmers modified the conventional no-till system by flattening cover crop mixtures on the soil surface as a strategy to reduce soil erosion and lower fluctuations in soil moisture and temperature, improve soil quality, and enhance weed suppression and crop performance. During 2007 and 2008, we conducted three experiments aimed at understanding the processes and mechanisms at play in successful organic conservation tillage systems (OCT), especially the underpinnings of ecological weed suppression, a key advantage of OCT systems over conventional no-till systems. Our results, as well as farmers observations, suggest that cover crops can enhance weed suppression and hence crop productivity through physical interference and allelopathy and also a host of effects on soil quality, fertility, and soil moisture that we did not measure. Results from the three trials indicate that the best cover crop mixture should include a significant proportion of rye, vetch, and fodder radish as these mixtures produce large biomass, and are readily killed by rolling forming a thick mulch sufficient to provide effective weed control in the subsequent vegetable crop.

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Address correspondence to Miguel A. Altieri, ESPM, 137 Mulford Hall, University of California, Berkeley, CA 94720, USA. E-mail: agroeco3@berkeley.edu

KEYWORDS agroecology, cover crops, mulch, allelopathy, weed suppression

INTRODUCTION

In Santa Catarina, southern Brazil, family farmers live on hillsides where soils are subjected to intense erosion if soil cover is not managed adequately. The government programs promoting conservation tillage have not been very successful reaching these farmers due mainly to the high costs of machinery and inputs, among which herbicides may comprise 25% of the costs of production (Wildner-do Prado et al. 2004). Instead, many hillside family farmers practicing annual cropping, using inventive self-reliance, modifying the conventional no-till system by initially leaving plant residues on the soil surface. The noticeable reductions in soil erosion and lower fluctuations in soil moisture and temperature led farmers to repeatedly apply fresh biomass on top of the soil, which further improved soil quality and crop performance. For more than two decades, several researchers and extension agents from the state government and local universities joined forces with farmers experimenting on green manure/cover crops and their incorporation into conservation tillage systems. Both farmers and researchers report that using cover crops minimize soil erosion and weed growth and exhibit positive effects on soil physical, chemical, and biological properties (Petersen et al. 1999). This is how an innovative organic minimum tillage system (OCT) emerged.

Contrary to conventional no-till systems, these novel OCT systems do not depend on herbicides for weed control. Instead they rely on the use of mixtures of summer and winter cover crops which leave a thick residue mulch layer, on which after the cover crops are rolled, traditional grain crops (corn, beans, wheat, onions, tomatoes, etc.) are directly sowed or planted. These crops usually exhibit low weed interference during the growing season, thus, reaching agronomically acceptable yield levels. Depending on the cover crop or cover crop combination used, residues have the potential to suppress weeds, but weed responses to residue depends on the type, quantity, and thickness of residue applied, the time remaining as an effective mulch, cover crops used and biology of particular weed species involved (Fayad 2004). Farmers have reported that the emergence of certain weeds declines monotonically as mulch rate (residue amount and thickness) increases. Some weed species develop shallow root systems in the litter layer-soil interface which makes them easier to control (Petersen et al. 1999).

Despite much research and on-farm experimentation and availability of cover crop germplasm for summer and winter cycles, for different rotations and cropping systems as well as heterogeneous soils, adoption of conservation systems is uneven and fragmentary across different regions in Santa Catarina state. One reason is that very little research has been conducted to understand the ecological underpinnings of these systems; in particular processes involved in weed suppression and that determine optimal soil fertility and crop productivity (Lana 2007). From agroecological experience with other alternative systems (Altieri 2002), it is known that simply copying the cover crop mixtures used by successful farmers does not work for widely diffusing the technology. Agroecological performance is linked to processes optimized by OCT systems and not to specific species or techniques. Weed suppression and optimal soil fertility are emergent properties of the whole system. The synergy associated to OCT makes it difficult to evaluate individual practices (i.e., one or two cover species mixes) effectively, because experimental tests of individual practices or subsets of practices are unlikely to reveal the true potential of a complex OCT system (Altieri 1995). Our goal was to understand the processes and mechanisms at play in successful systems, such as the underpinnings of ecological weed suppression, a key advantage of OCT systems over conventional ones. To advance in such knowledge we conducted three experiments in the state convinced that the elucidation of the mechanisms at play will provide principles and guidelines to thousands of farmers interested in transitioning towards OCT systems.

WHAT IS KNOWN ABOUT ORGANIC CONSERVATION TILLAGE SYSTEMS

Agronomic Aspects

Soil erosion resulting from soil tillage prompted researchers and farmers to look for alternatives and to reverse the process of soil degradation by focusing on reduced tillage. This led to movements promoting conservation—or even zero-tillage. Over the last two decades, the technologies were perfected and adapted for nearly all farm sizes, soil and crop types, and climatic zones, and, by 2000, 13.5 million hectares in Brazil were under minimum tillage (Christoffoleti et al. 2007). Promoters of conservation tillage (CT) methods affirm that the technology is sustainable because it conserves soils; enhances soil quality by improving structure, water infiltration, and biological activity; saves energy and labor; captures CO2; etc. Despite the alleged benefits CT promotes, systems are mostly based on monocultures that exhibit heavy reliance on herbicides and have lately constituted the main entry point for transgenic corn and soybean. In addition, in Brazil CT is a technology adopted mainly by large farmers as the costs associated by the required mechanization and herbicides creates economies of scale excluding most small-scale and family farmers (Petersen et al. 1999).

In Santa Catarina, the state's agricultural extension agency has for years been involved in efforts aimed at implementing and disseminating no-tillage systems appropriate to family farmers. Through time they have carefully selected the most adapted cover crop species and mixtures and defined agronomic management for no-till systems (Monegat 1999). More than 100 species as well as varieties of winter and summer cover crops are available for use by farmers including winter and summer cover crops (Derpsch and Calegari 1992).

Most small-scale farmers use draft animals or mini-tractors for traction. Local manufacturers produce a variety of conservation tillage machinery for this market, and its availability has permitted the spread of reduced tillage in the region (Bittencourt 2008). In some parts of the state, highly successful conservation tillage systems, and complex multi-year rotations with conservation tillage systems, have become well established for certain key crops such as maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), tobacco (*Tabacum nicotianum* Berchtold & Opiz.), and onions (*Allium cepa* L.). Usually, numerous local variations of a given cropping system include different elements such as minimum or zero tillage, animal or mechanical traction, or variations in the cover crop species composition and sequencing of the rotation (Monegat 1991). Apparently, adoption of this technology by farmers is enhanced due to the fact that it reduces labor requirements and soil cultural operations, minimizes soil erosion and weed growth, and, finally, as soil quality improves, so do crop performance and financial returns (Kieling 2007).

Do Prado et al. (2004) describes many strategies on how to incorporate green manures into prevalent production systems, management of the biomass, cultural operations, seeding times, the variety of equipment used by farmers, and the production of seeds of the various green manure-cover crop species. Managing the cover crops generally requires flattening the biomass with a roll chopper (*rolo-faca* in Portuguese), which, in the case of legumes, is done after full flowering, as at this stage they provide the most biomass and nutrients to the soil. Most farmers observe a waiting period after the cover crops have been flattened and before the subsequent crop is planted varying from species to species depending on the C/N ratio of the mulch. For legumes or oilseed radish the waiting period is 1–2 weeks, while winter cereals may require 3–4 weeks (do Prado et al. 2004). Most research has shown that by rolling down the cover crop instead of mowing it, the cover crop takes longer to decompose and becomes a weed-suppressing mulch, in many cases reducing or totally eliminating the use of herbicides. Kliewer et al. (1998) reported soybean yields after black oat yield of 2600 kg/ha without using any herbicides at all. Weed biomass measurements 96 days after seeding soybeans yielded 93 kg/ha of dry matter after black oats, against 7390 kg/ha after fallow and yields of soybeans reached a low 780 kg/ha.

Using a rotation where long and short term cover crops are seeded as soon as possible after harvesting the previous crop, or after rolling down cover crops with a knife roller, it may be possible not to use herbicides in no-tillage for as much as three years in a row. A common problem however is cover crop regrowth which causes competition with the main crop. Another problem is that the mulching effects of the rolled-down cover crop may not last long enough to suppress weeds before the main crop canopy develops to exert shading suppressive effects.

EFFECTS OF COVER CROP MULCHES ON WEED COMMUNITY DYNAMICS

Plant residues left on the soil surface after cover crops that have been flattened can have several effects on weed germination and growth. The physical barrier caused by the plant residues covering the soil surface, can exert an important weed suppression effect by simply serving as a physical barrier to normal plant growth and development, or by intercepting solar radiation and diminishing the thermal and hydric soil flux. These physical effects can directly affect weed species that have some mechanism of dormancy control or that for germination are dependent upon sunlight, temperature, and water content in the soil (Christofoletti et al. 2007).

One of the basic requirements for most weed seeds to germinate is exposure to sunlight, but the amount needed to induce weed seeds to germinate penetrates only a few centimeters in the topsoil layer. In addition to reducing the light intensity, the plant residue covering the soil surface affects light quality, by acting as a filter. Plant residues that shade the soil surface filter light and reduce the ratio of red: far red light compared to full sunlight, can reduce or even inhibit germination of weed species that need full sunlight to germinate (Teasdale and Mohler 1993).

The presence of plant residue covering the soil surface can also affect soil temperature. Generally plant residue on the soil surface diminishes the thermal amplitude of the upper soil layers during the day, so that weed seeds that are sensitive to temperature alternation for germination would be affected. Although there is a lack of information on the germination behavior of several weed species, in regard to temperature, it is known that effect of plant residue covering the soil surface on soil temperature certainly contributes to the reduction in weed seed germination (Liebman et al. 2001).

Research suggests that residues from cover crops must be present in very high amounts to provide a high level of physical suppression of annual weeds. When grown as cover crops, the combination of grass and legumes enhanced biomass production and therefore mulch thickness which in most cases led to higher weed suppression. Mohler and Teasdale (2000) showed that greater than 75% inhibition of weed emergence is consistently achieved only when mulch biomass exceeds 8000 kg/ha and mulch thickness exceeds 10 cm. Many cover crop mixtures including legumes and grasses (e.g., rye and hairy vetch) can achieve such high biomass levels if grown to maturity (Derpsch and Calegari 1992).

Other residues that do not reach the desired thickness may exert effects via chemical effect of residue mulches through the process of allelopathy (Putnam, DeFrank, and Barnes 1983). Depending on the type, certain plant residues can release allelopathic compounds that may suppress weed germination and growth (Wu et al. 1999). This inhibition is caused by phytotoxic substances that are passively liberated through decomposition of plant residues. Phytotoxins leaching from the surface layer of organic matter diffuse only a short distance from the soil (2–3 cm where about 90% or more of the weed seed bank remains), forming an allelopathic zone . Weed seeds that germinate within such zone frequently are poisoned (Liebman et al. 2001). There is a long list of cover crop species that have phytotoxic effects. In Santa Catarina, many farmers have observed that if they include cruciferous species in the cover crop mix, weed emergence is lower. Cruciferous plants contain glucosinolate compounds that hydrolyze to isothiocyanates, which, in turn, have potent inhibitory effects on plant growth and germination (Boydston and Hang 1995).

Weed community dynamics in CT and OCT systems can be greatly influenced by the crop fertilization strategy used by farmers. Organic systems rely upon the use of organic fertilizers that typically release nutrients (especially N) at a slower rate compared with mineral fertilizers (Magdoff and van Es 2000). Nutrient release rate is largely dependent on the C:N ratio of the source, soil properties, climatic conditions, and incorporation method, which, together, determine the mineralization rate of the organic matter incorporated in the soil (Liebman et al. 2001). Faster nutrient release, typical of chemically fertilized CT systems, is often advantageous to weeds, which are usually able to take up nutrients in earlier growth stages more quickly and more efficiently than crops, and this effect seems to turn into a competitive advantage for certain weeds. Weeds usually exhibit stronger height and leaf area responses to chemical fertilizer than do crops, increasing the weeds' ability to shade the crops (Liebman et al. 2001). Slower nutrient release from organic sources does not usually result in increased weed competitive ability; it may however favor the occurrence of late-season weed emergence flushes that may contribute to seedbank replenishment and consequently to higher weed seedling recruitment in subsequent years.

Undoubtedly, many factors and processes (mulch thickness, physical interference, nutrient and moisture levels, phtyotoxins) linked to OCT systems affect weed dynamics (Figure 1) although questions still remain

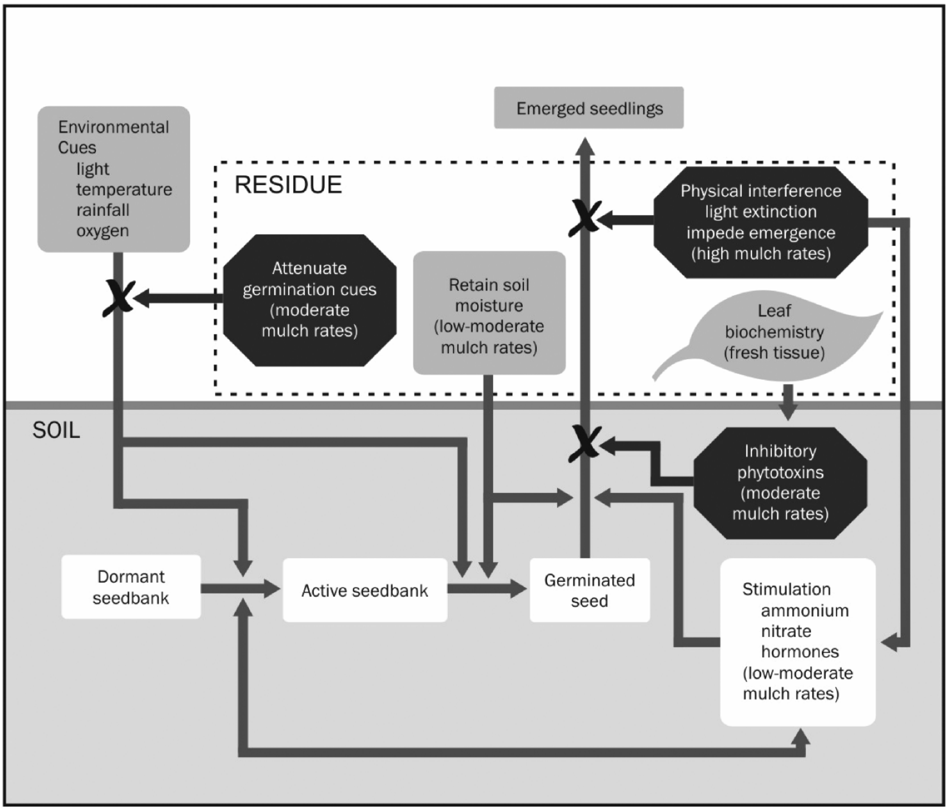

FIGURE 1 Effects of cover crop mulch thickness on weed suppression (after Monegat 1991).

unresolved on the ecology of weeds and the mechanisms that underlie weed suppression in OCT systems.

AGROECOLOGICAL EXPERIMENTS IN SANTA CATARINA

To enhance our understanding on the weed suppressive effects and mechanisms underlying such suppression in Santa Catarina OCT systems, from 2006 to 2008 our research group conducted three experiments using combinations of various winter cover crops in rotation with either tomatoes (Itopuranga region) or beans (Campos Novos region) in plots displayed in randomized block designs with cover crop treatments replicated three times each. Specific details on experimental designs, treatments, methods used in these studies can be found in Lana (2007), Kieling (2007), and Bittencourt (2008). Data were subjected to analysis of variance using a randomized complete block model.

RESULTS

Bean Trials

EXPERIMENT 1

The goal of this research was to assess the potential of the most common cover crop mixture used by farmers in the region of Campos Novos (vetch (*Vicia villosa*), fodder radish (*Raphanus oleiferus*), and rye (*Secale cereale*) compared to rye alone and a fallow system, in reducing winter and summer weed populations and increasing bean yields. Using methods described by Lana (2007), ground cover by cover crops and weeds, weed and cover crop biomass, weed species diversity as well as bean yields grown after the cover crops were flattened were measured. Mulch degradation was also monitored using three 25 × 25 cm litter bags with 2 mm mesh in each plot and placed between the mulch and the soil surface to determine the degradation rate of the various mulches (Lana 2007).

At 112 days after cover crop sowing, the vetch + fodder, radish + rye, vetch + fodder radish, and vetch + rye combinations reached significantly higher biomass production (5.39, 5.35, and 5.03 Mg ha^{-1} of dry matter per hectare respectively) compared to the other treatments (Table 1). At this date, the percentage of soil cover by the mixtures reached 95%. The lowest biomass of winter weeds was observed in the vetch + fodder, radish + rye treatment (0.26 t/ha), although the rye + vetch also exhibited high weed suppressive potential (0.46 t/ha of weed biomass) followed by the radish + vetch mixture (1.1 Mg ha^{-1}). The highest weed biomass values were exhibited by the rye monoculture (2.01 Mg ha^{-1}), rye + radish mixture (2.52 Mg ha^{-1}), and the fallow treatment, which reached significantly higher biomass value (5.41 Mg ha^{-1}). The decomposition rates of these residues were affected by the combination of cover crops, increasing with the presence of vetch a plant with higher N content than oats. Vetch had a C/N ratio of 14.8, decomposing faster than black oats which produces more biomass and takes longer to degrade as it has a C/N ratio of 40.3. When in a mixture the proportion of vetch is increased from 49% to 68% and the black

TABLE 1 Dry Biomass of Winter Cover Crops (Mg ha^{-1}) in Three Times After Sowing (Lana 2001)

Treatment	35 days	87 days	112 days
Rye + vetch	0.417^{a}	2.00^{b}	$5.03^{a,b}$
Fodder radish + vetch	$0.359^{a,b}$	$1.44^{b,c}$	5.35^{a}
Rye + fodder radish	0.242^{b}	1.10^{c}	3.89^{c}
Rye + fodder radish + vetch	0.389^{a}	2.15^{a}	5.39^{a}
Rye	$0.292^{a,b}$	$1.42^{b,c}$	4.71^{b}

Means followed by same letter in columns do not differ statistically (DMS-Fischer test, $p \leq .05$).

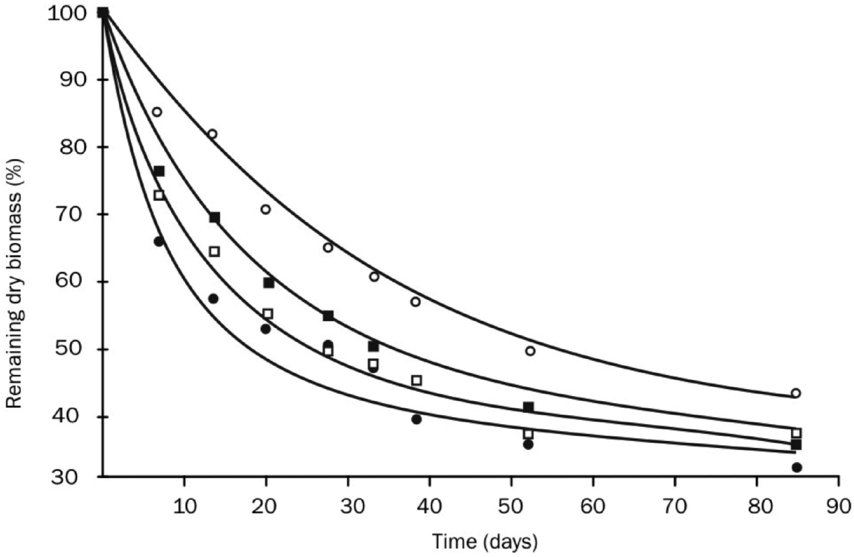

FIGURE 2 Percentage of cover crop mulch (dry biomass) remaining throughout the growing season (after Lana 1991).

oat proportion is reduced from 51% to 32%, the C/N ratio drops from 20.6 to 18.1, thus, residues decompose faster enhancing N release (Figure 2).

Due to a prolonged drought, beans were planted late in the season and thus yields estimated in March were low in comparison to yields usually obtained when beans are timely planted in late spring. Not surprisingly, bean yields in the fallow plots exhibited poor yields (<300 kg/ha) as these plots had the highest summer weed biomass values (3.8 t/ha at 100 days) thus competition was very acute. The vetch + radish and rye + radish plots also exhibited low bean yields (350 kg/ha and 310 kg/ha, respectively, not significantly different from the fallow plots) reaching higher summer weed biomass values (on average 3.0 t/ha) than the other cover crop treatments. According to an analysis of variance (ANOVA), bean yields were significantly higher in plots where beans followed the rye+radish+vetch (820 kg/ha) and the rye+vetch (630 kg/ha) mixtures and the rye monoculture (760 kg/ha) than the fallow plots. These plots exhibited lower summer weed biomass values than fallow plots (less than 2.0 Mg ha^{-1}) at 100 days after bean sowing.

EXPERIMENT 2

This experiment was also conducted in Campos Novos, in the same area as the previous work, and the main objective was to determine the suppressive effect of winter cover crops commonly used by bean family farmers in the region. The effects of various combinations of rye (*Secale cereale*), black oats (*Avena strigosa*), ryegrass (*Lolium multiflorum*), vetch (*Vicia sativa*), and fodder radish (*Raphanus sativus*) on soil cover, cover crop, and weed biomass, biomass of summer and yields of common beans were evaluated (Bittencourt, 2008).

The mixtures of rye + vetch, rye + vetch + fodder, radish and black oats + vetch exhibited the highest percentages of soil cover (on average 95%), while cover crop biomass production was highest in the black oat + vetch + fodder radish mixture (5.64 Mg ha^{-1}), followed by the rye and *Lolium* + rye treatments (Table 2). All treatments exhibited lower weed biomass values than the fallow plots where weed biomass reached 2.6 Mg ha^{-1} 28 days after bean sowing. Although not statistically significantly different from other cover crop treatments, the highest weed suppression effect at 28 days after bean emergence was observed in the plots following rye (1.47 Mg ha^{-1} of weed biomass), black oats (1.46 Mg ha^{-1}) and *Lolium* (1.43 Mg ha^{-1}) (Table 3). Dominant weeds that produced the highest biomass levels included *Brachiaria plantaginea, Ipomoea grandifolia, Bidens pilosa,* and *Euphorbia heterophylla.*

TABLE 2 Means and Standard Errors of Dry Biomass Values of Various Winter Cover Crops (Mg ha^{-1}) Before Flattening (Bittencourt 2008)

Rye	$5.08 \pm 0.61^{a,b}$
Ryegrass	3.13 ± 0.56^{d}
Black oat	$4.11 \pm 0.15^{b,c,d}$
Rye + ryegrass	$5.01 \pm 0.58^{a,b}$
Rye + vetch	$4.66 \pm 0.16^{a,b,c}$
Black oat + vetch	$3.66 \pm 0.42^{c,d}$
Black oat + vecth + fodder radish	5.64 ± 0.54^{a}
Rye + vetch + fodder radish	$4.43 \pm 0.51^{a,b,c}$
Fallow	2.91 ± 0.46^{d}

Different letters mean significant differences between treatments by Fisher LSD test ($p \leq .05$).

TABLE 3 Total Weed Dry Biomass (Mg ha^{-1}) 14, 21 and 28 Days After Bean Emergence With Different Winter Cover Crops (Bittencourt 2008)

	Days after emergence		
Winter cover crop	14	21	28
Rye	$0.63^{a,b}$	$1.35^{a,b}$	1.47^{a}
Ryegrass	0.97^{bc}	$1.34^{a,b}$	1.43^{a}
Black oat	$0.51^{a,b}$	$1.10^{a,b}$	1.46^{a}
Rye + ryegrass	$0.63^{a,b}$	$1.12^{a,b}$	1.67^{ab}
Rye + vetch	0.44^{a}	0.96^{a}	1.47^{a}
Black oat + vetch	$0.56^{a,b}$	$1.29^{a,b}$	$1.64^{a,b}$
Black oat + vecth + fodder radish	$0.66^{a,bc}$	$1.50^{a,bc}$	$1.92^{a,b,c}$
Rye + vetch + fodder radish	$0.78^{a,b}$	$1.75^{b,c}$	$2.36^{b,c}$
Fallow	1.12^{c}	2.09^{c}	2.62^{c}

Means in the same column with different letters are significantly different (Fisher LSD, $p < .05$).

Bean yields in all plots with cover crops were significantly higher than in plots following winter fallow. The best bean yields were obtained in plots following *Lolium* (1.95 Mg ha^{-1}), rye (1.45 Mg ha^{-1}), and black oats (1.73 Mg ha^{-1}) which proved to be the most weed suppressive cover crop. With the exception of the fodder radish + black oats + vetch combination, which had yield lower than *Lolium* and higher than fallow, yields in beans following all other mixtures exhibited average yields around 1.5 Mg ha^{-1}, reaching 1.75 Mg ha^{-1} after the rye + vetch mixture. Due to the lower seed costs, US$25/ha and US$27/ha, respectively, ryegrass and black oats cover crops produced higher revenues as farmers using these species alone or in mixture yielded greatest returns per unit of money invested. Similar results were also observed by Kliewer et al. (1998).

Tomato Trial

The main objective of this research conducted in Itopuranga was to evaluate the effects of different winter cover crops in a no-tillage tomato production undergoing an agroecological transition process. The treatments consisted of seven combinations of winter cover crops-black oats (*Avena strigosa*), vetch (*Vicia villosa*), and fodder radish (*Raphanus sativus*) compared with a control (fallow) treatment. Weed and cover crops biomass, soil physical and chemical characteristics and tomatoes yields were evaluated (Kieling 2007).

The cover crops that produced the highest biomass were in descending order: black oats + vetch, black oats, fodder radish + vetch, and fodder radish + black oats. In comparison to the control plot, weed biomass (average total biomass collected in three dates) reached lowest values in the black oats + vetch and black oats + vetch + fodder radish plots, followed by the vetch + fodder radish, black oats + fodder radish and black oats plot (Table 4).

Cumulative tomato yields were estimated by totaling commercial fruit weight obtained in eight consecutive harvests in each plot. The vetch + fodder radish and the black oat plots exhibited the highest cumulative yields with values of 82.6, 78.2, and 76.1 Mg ha^{-1}, respectively. The control plot exhibited higher yields (74.3 Mg ha^{-1}) than the fodder radish, black oats + fodder radish and vetch plots. Surprisingly the vetch + fodder radish + black oats showed the lowest yields (69.0 Mg ha^{-1}) although weed biomass in such plots was very low (795 kg/ha).

DISCUSSION AND CONCLUSIONS

In all three experiments, the residual effect of most cover crops alone or in mixture on the productivity of subsequent crops was positive. Cover crops

TABLE 4 Means of Cover Crops and Weeds Biomass (Mg ha^{-1} of Dry Biomass) for Each Treatment in Two Different Sampling Dates (Mean ± Standard Error)

			Cover crops biomass*	Weed biomass
			May 15, 2005	Nov. 16, 2005
Treatment	Fallow	Control	0.0 ± 0.0^{d}	5057
	Oats		6850 ± 250^{a}	1316
	Vetch		3306 ± 418^{c}	3267
	Fodder radish		5101 ± 203^{b}	1579
	Oats + vetch		7256 ± 365^{a}	838
	Oats + fodder radish		6082 ± 424^{ab}	1205
	Vetch + fodder radish		6598 ± 488^{ab}	1183
	Oats + vetch + fodder radish		5911 ± 1095^{ab}	896

*Means (in the horizontal) not followed by letters do not differ statistically according Student's *t* test with 5% of probability.

significantly reduced weed pressure but varied in their effects depending on whether they were grown alone or in mixtures. In the Itopuranga bean cropping systems the rye + vetch + fodder radish mixture consistently produced the highest biomass and led to significant levels of weed suppression. In the case of such high biomass-producing mixtures, it is possible that the residues acted as a physical barrier blocking sunlight inhibiting germination of many weed species. However, the presence of either black oats or rye in the mixture affected weed germination and growth presumably via alleolpathy. It is well known that rye can significantly suppress weeds under field conditions and this has been attributed to the allelochemicals it releases including B-phenyllactic acid and B-hydroxybutiric acid and various benzoxazolinone compounds (Barnes and Putnam 1987). Most oat (Avena spp) species have the capacity to exude scopoletin (6-methoxy-7-hydroxy coumarin), a chemical identified as phytotoxic towards several plant species (Putnam and Tang 1996). Glucosinolate compounds contained within crucifer cover crops such as fodder radish can also contribute to weed management by reducing weed density and biomass, but the effect is most dramatic when the cover crops is incorporated into the soil (Wu et al. 1999).

Depending on the C/N ratio of the cover crops, the toxicity of plant residues can decline substantially after several weeks of decomposition. In order to increase crop yield security, many farmers in southern Brazil wait several weeks between residue incorporation and seeding a sensitive crop, while reducing weed establishment before planting. Other farmers sow maize, bean, or soybean seeds deeper than 3 cm because they have observed that germination fails when seeds are sowed superficially. This may be due to the fact that some decomposing residues form an allelopathic toxic layer in the first 2 cm or so of the soil surface as suggested by Liebman et al. (2001). Apparently most phytotoxins leach a short distance from the mulch into the soil. Some famers have also noticed that small-seeded crop species appear to be especially susceptible to allelochemicals, whereas large-seeded species appear to be relatively insensitive, therefore they transplant seedlings of small-seeded crops (onions, tomatoes, etc.) to somewhat reduce susceptibility to allelochemicals. Although cover crop residues and their phytotoxins are associated with weed suppression, the residues may also have positive effects on subsequent crops due to increased soil quality parameters, improved crop nutrition and in some cases suppression of soil-borne pathogens, all factors leading to improved crop yields.

Our results as well as farmers observations suggest that cover crops can enhance weed suppression and hence crop productivity possibly through allelopathy and via a host of effects on soil quality and fertility, soil moisture as suggested in Figure 1. Results from the three trials indicate that the best cover crop mixtures should include a significant proportion of rye, vetch, and fodder radish, as mixtures with these plant species:

- produce large biomass, at least 4 tons of aboveground dry matter per hectare;
- are readily killed by rolling forming a thick mulch sufficient to provide effective weed control in the subsequent vegetable crop;
- do not suppress the vegetable or grain crop through chemical (allelopathic) or microbial effects (i.e., N inmobilization);
- increasing the proportion of vetch in the mixtures decreases the C/N ratio which gives a gradual release of plant available N.

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