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Contribution of Cover Crops and Reduced Tillage Systems for Weed Management in Organic Vegetable Production

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ABSTRACT

In recent years, organic vegetable production systems have become an increasingly important segment of agriculture; and weed control is a principal concern for organic vegetable growers. In the absence of herbicides, tillage and cultivation are the most commonly used tools by vegetable growers for managing weeds in organic systems; however, intensive tillage may have adverse effects on soil and environmental health. In recent times, to reduce intensive soil tillage and achieve successful weed management, integration of cover crops with conservation tillage (reduced or no-tillage) is emerging as an innovative alternative production practice in organic farming. Research over the globe has shown that cover crops can be used to control weeds in vegetable fields, and also play an important role in improving productivity of subsequent crops by improving soil physical, chemical, and biological properties. In agronomic crops, the benefits of cover crops in conjugation with reduced tillage on weed management are well documented but, such information is scarcely available for vegetables grown in organic production systems. This review focuses on different types of cover crop species and conservation tillage systems for weed management in organic vegetable production.

Keywords: cover crops, conservation tillage, weed control, sustainability, organic production

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Introduction

Over the past two decades, organic production and consumption of vegetables have increased drastically around the world. In U.S., organic production has been estimated to be growing at about 20 to 25 percent per year during the last one-decade. In the recent (2011) U.S. Department of Agriculture (USDA) statistics, 5.4 million acres are under organic production, with 147,446 acres under organic vegetables. Consumers purchase organic foods due to lower pesticide residues and perceived health benefits in terms of phytonutrients and certain vitamins (Baker *et al.* 2002). Moreover, the detrimental environmental and health impacts related to intensive use of chemicals and over-fertilization in conventional vegetable production (Venterea *et al.* 2000) have encouraged many producers to explore organic methods. In organic vegetable production systems, where there is no use of chemicals, weed control is documented as the most important hurdle (Hutchinson *et al.* 2000), because there are very few effective weed control options (Clark *et al.* 1999, Walz 1999). Tillage and mechanical cultivation are the main tools used by the organic vegetable growers for weed control (Ateş 2007). However, these methods are very time consuming and expensive; therefore, these are not always environment friendly or economical (Ngouajio *et al.* 1997). Furthermore, repeated tilling of the soil is unsustainable and degrades the soil structure, which increases surface runoff and soil erosion. It can also lead to a decline in organic matter and nutrient content (Bosco *et al.* 2015, Hatfield *et al.* 1998); and also reduce water holding capacity (Zibilske *et al.* 2007). Because of the adverse effects of tillage and intensive use of chemicals on soil and environment health, the integration of different weed control measures and reduced tillage practices could be the best method to achieve sustainability of agroecosystems (Bajwa 2014, Price *et al.* 2011).

In recent times, the use of conservation management production systems such as cover crops and reduced tillage or no tillage have become more widespread for sustainable agriculture because of their contributions to improve soil health, promote nutrient availability, reduce weed pressure, increase microbial diversity, and increases the soil resilience against drought and other extreme environmental factors (Doran and Zeiss, 2000). But, the adoption of conservation tillage and cover crops in vegetable production system has been very limited, mainly due to lack of information in this area. This paper reviews the impact of cover crops and reduced tillage on weed management in organic vegetable production systems. In order to improve weed management options in organic systems, more research is needed to investigate alternative methods for effective weed control.

Cover crops

A cover crop is a transition crop between two production systems. It is an important component of sustainable production systems because it provides the agro-ecosystem with several benefits (Sarrantonio *et al.* 2003), such as suppressing weeds (Teasdale *et al.* 2000), improving soil fertility (Decker *et al.* 1994), sequestering soil carbon (Sainju *et al.* 2002), providing habitat for beneficial insects, and increasing soil water infiltration and storage (Dabney *et al.* 2001, Munawar *et al.* 1990). Weed control is one of the most important benefits cover crops can provide in organic vegetable production systems (Brandsæter *et al.* 1999, Ngouajio *et al.* 2003). In the previous studies, it has been shown that in vegetable production systems organic soil amendments have the potential to reduce weed pressure (Liebman *et al.* 2000, Roe *et al.* 1993). Introducing cover crops in the fallow period between two main crops can prevent growth and development of weeds and, also inhibit seed production of weeds through competition. Undoubtedly, cover crops fill gaps between the two main crops that would otherwise be occupied by weeds. Thus, the primary goal of using cover crops for weed control is to replace an unmanageable weed population with a manageable cover crops (Teasdale 1996). Cover crops have both long and short-term weed control effects (Bàrberi 2002), due to direct competition or through other types of interference, primarily allelopathy (Brennan *et al.* 2005, Creamer *et al.* 1996). Allelopathy has been defined as "any direct or indirect harmful effect produced in one plant through toxic biochemicals released into the environment by another" (Rice 1974). These allelochemicals are released from plants through root exudation, leaching, volatilization, and from plant residue on decomposition (Weir *et al.* 2004). In cover crops a number of allelochemicals such as phenolic acids, coumarins, and glucosinolates that suppress weeds have been identified previously (Norsworthy 2003, Petersen *et al.* 2001, Vyvyan 2002). In organic bell pepper, approximately 79% of large crabgrass (*Digitaria sanguinalis* L. Scop.) and 48% of Palmer amaranth (*Amaranthus palmeri* S. Wats.) control has been reported by using *Brassicaceae* cover crops (Norsworthy *et al.* 2007). Hutchinson and McGiffen (2000) observed that by using cowpea [*Vigna unguiculata* (L.) Walp] as a surface mulch, weed emergence was reduced in pepper crop (*Capsicum annuum* L.). Apart from allelopathic effects, the residue of cover crop can also have an adverse effect on weed germination and emergence through other mechanisms. Crop residues left on the soil surface can have an inhibitory effect on weed germination by decreasing soil temperature and reducing light penetration (Teasdale *et al.* 1993). The choice of the most suitable cover crop depends on several factors such as weather, soil type and as well as the growers preference (Zibilske *et al.* 2009). Likewise, the effect of cover crops on weed populations depends on species, time and weather (Herrero *et al.* 2001). As cover crops are providing multiple benefits, therefore, these can be used as part of an integrated weed management program in organic vegetable systems (Isik *et al.* 2009).

Types of cover crops

Cover crops can be annual, biennial, or perennial plant species that serve a variety of purposes. Grasses, cereals, legumes, and brassica cover crops are most extensively used in vegetable production system for multiple beneficial purposes such as weed control, nitrogen source, improve soil fertility and quality, and manage soil erosion (Isik, Kaya, Ngouajio and Mennan 2009, Peoples *et al.* 1995, Wang *et al.* 2008).

Grasses/Cereals

Most commonly used annual grass cover crops include the annual cereals such as rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), buckwheat (*Fagopyrum sagittatum* Gilib), and black oats (*Avena strigosa* Schreb.); annual or perennial forage grasses such as Italian ryegrass (*Lolium perenne* L.), and warm-season grasses such as sorghum-sudangrass (*Sorghum bicolor* L.). Graminacious species are commonly used as a fall and winter cover crops because of their extra biomass production, winter hardiness, relatively high carbon to nitrogen ratio, allelopathic effect on weeds, and slow residue decomposition (Hoffman *et al.* 1993, Wilkins *et al.* 1996). Cereals such as rye and barley have an approximately 33:1 carbon to nitrogen ratio (Creamer, Bennett, Stinner, Cardina and Regnier 1996). All these factors help in suppressing weeds for longer period of time.

In the previous field and green house studies, it has been shown that the decomposing residue of small grain cover crops such as wheat, oats, rye, and barley have an allelopathic effect, which means they can chemically suppress the germination and growth of various weed (Barnes *et al.* 1983, Bond *et al.* 2001, Brainard *et al.* 2004, Campiglia *et al.* 2010, Golisz *et al.* 2007, Iqbal *et al.* 2003, Liebl *et al.* 1983, Macías *et al.* 2004, Putnam 1979, Putnam *et al.* 1983, Radicetti *et al.* 2013, Samedani 2006), also by blocking light (Teasdale and Mohler 2000), and competing for nutrients and water (Liebman and Davis 2000), which are important factor for the germination of weed seed and emergence of seedlings (Ballaré *et al.* 2000).

Several studies have demonstrated that annual cereals have tendency to inhibit both the growth and of density several weed species such as common lambsquarters (*Chenopodium album* L.), barnyardgrass (*Echinochloa crusgalli* L.), giant foxtail (*Setaria faberi* Hernn.), velvetleaf (*Abutilon theophrasti* Medicus), and smooth pigweed (*Amaranthus hybridus* L.) (Burgos *et al.* 1996, Przepiorkowski *et al.* 1994). In pepper crop, oat residue have decreased plant density of different weed species and reduced nearly 97% of aboveground weed biomass as compared to weedy fallow (Radicetti *et al.* 2013). Also, reports have described the strong weed-suppressive ability of buckwheat (Creamer *et al.* 2000, Iqbal, Hiradate, Noda, Isojima and Fujii 2003). In green bean crop, the emergence of pigweed (*Amaranthus retroflexus* L.) and common lambquarters have been reduced by freshly incorporated buckwheat (Haramoto *et al.* 2005). Mohler *et al.* (1995) reported that the presence of rye residue decreased the seed production of common purslane (*Portulaca oleraceae* L.) in one year in sweet corn. Also, in the previous studies, it has been reported that nearly 80% of common annual weeds were controlled by dense stand of winter rye residue (Liebl *et al.* 1992, Teasdale *et al.* 1991, Walters *et al.* 2008).

Legumes

Leguminous crops are often very good cover crops. Commonly used legume cover crops include winter annual legumes, such as crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia villosa* Roth.), Austrian winter pea [*Pisum sativum* L. ssp. *arvense* (L.) Poir.], subterranean clover (*Trifolium subterraneum* L.) etc. and summer annual legumes include berseem clover (*Trifolium alexandrinum* L.), soybean (*Glycine max* L.), velvetbean (*Mucuna pruriens* L.), sunn hemp (*Crotalaria juncea* L.), jack bean (*Canavalia ensiformis* L.), and cowpea (*Vigna unguiculata* L.). Biennial and perennial legumes include alfalfa (*Medicago sativa* L.), crown vetch (*Securigera varia* L.), red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), and sweet clover (*Melilotus officinalis* L.). Legume cover crops are planted alone or in combination with grass cover crops to minimize soil erosion (Wall *et al.* 1991), to maintain soil organic matter (Frye *et al.* 1988), and to reduce weed density and biomass (Hooker *et al.* 2008, Teasdale 1996). Legume cover crops also have ability to fix nitrogen from the atmosphere and add it to the soil (Nascente *et al.* 2015, Sarrantonio and Gallandt 2003). Some previous studies have shown that hairy vetch, crimson clover and subterranean clover have reduced weed density and growth of early season weeds (Johnson *et al.* 1993, Yenish *et al.* 1996). Several studies have shown that hairy vetch is suitable to be used as a cover crop for weed management in vegetable production systems (Abdul-Baki *et al.* 2002, Sainju *et al.* 2001, Teasdale *et al.* 1997). Liebman *et al.* (2002) noted that red clover residue can reduce the density and growth of wild mustard in common bean. Additionally, red clover residue also provide a favorable environment to some insects such as crickets or carabid beetles, which can increase weed seed mortality (Davis *et al.* 2003). Furthermore, some species of legume cover crops have allelopathic effect that inhibit the growth of many weeds (Collins *et al.* 2007). The decomposing above-ground residue of hairy vetch releases phytotoxins that inhibit germination and emergence of weeds (Campiglia *et al.* 2010, Radicetti, Mancinelli and Campiglia 2013). Similarly, crimson clover inhibits weed seed germination through allelopathy, and also due to thick ground cover, its residues is capable of reducing weed density by blocking light (Brennan *et al.* 2009). In humid areas, velvetbean has suppressed some weed species due to allelopathic effect. In corn, velvetbean cover crop controlled cogongrass (*Imperata cylidrica* (L.) same as that of herbicides (Udensi *et al.* 1999). Likewise, Caamal-Maldonado *et al.* (2001) reported that smothering effect of velvetbean can provide good control of field sandbur (*Cenchrus insertus* M.A. Curtis), spiny amaranth (*Amaranthus spinosus* L.), and bitterweed (*Parthenium hysterophorus* L.). Also, forage alfalfa produces allelochemicals that suppress growth of several common weed species including pigweed, commom lambquarters and large crabgrass (Chung *et al.* 1995).

Brassicas

Common brassicas cover crops include mustard (*Sinapis alba* L.), rapeseed (*Brassica napus* L.), canola (*Brassica napus* L.), wild radish (*Raphanus raphanistrum* L.), black mustard (*Brassica nigra* L.), and white/yellow mustard (*Brassica alba* L.). Brassica cover crops have distinct attributes from cereals and legumes that includes their allelopathic affect, rapid fall growth, nutrient scavenging ability, great biomass production, and their capacity to serve as a biofumigant. In recent years, all brassica species have received great interest because of their multiple benefits to agroecosystems (Fahey *et al.* 2001, Haramoto *et al.* 2004). All members of the *Brassicaceae* family contain chemical such as glucosinolates. Glucosinolates are not phytotoxic themselves, but as the plant cells are ruptured, they are enzymatically hydrolyzed to form biologically active compounds, isothiocyanates and thiocyanates, that are harmful to a variety of soil micro fauna (Borek *et al.* 1998, Elberson *et al.* 1996), and weeds (Haramoto and Gallandt 2004, Morra *et al.* 2002, Norsworthy *et al.* 2005). Isothiocyanates are generally regarded as the most toxic of the glucosinolate breakdown products, and are well-known to inhibit seed germination (Petersen, Belz, Walker and Hurle 2001), reduce seedling emergence (Al-Khatib *et al.* 1997), and cause stunted seedling growth (Wolf *et al.* 1984). In previous studies, Haramoto and Gallandt (2005) found that soil incorporation of mustard cover crops provided 23–34% reduction and delay in emergence of various weeds. Aqueous extracts of wild radish (*Raphanus raphanistrum* L.) residues inhibited germination of pitted morning glory (*Ipomoea lacunosa* L.), prickly sida (*Sida spinosa* L.), sicklepod (*Senna obtusifolia* L.), and yellow nutsedge (*Cyperus esculentus* L.) (Norsworthy 2003). Field-grown rapeseed and mustard cover crops have also decreased early season weed emergence in green pea (*Pisum sativum* L.) (Al-Khatib, Libbey and Boydston 1997). Similarly, a blend of brown and yellow mustard reduced large crabgrass emergence 4 weeks after planting by 73% in southern pea [*Vigna unguiculata* (L.) Walp] (Norsworthy, Brandenberger, Burgos and Riley 2005). Kumar *et al.* (2009) found that yellow mustard residue suppressed hairy galinsoga [*Galinsoga ciliata* (Raf.) Blake] emergence, biomass production and seed production by more than 50% as compared to bare soil in pea, snap bean, lettuce and Swiss chard crops. Likewise, Shuler *et al.* (2005) reported that residue of brown mustard is effective in reducing weeds in the following snap bean crop. Among mustard cover crops, yellow mustard has potential to suppress weeds due to its high glucosinolates content; and also it is inexpensive and easily available (Haramoto *et al.* 2005, Kumar, Brainard and Bellinder 2009).

Reduced tillage

Organic vegetable production systems rely extensively on tillage to prepare seedbeds, bury plant residues, and control weeds. However, repeated tillage is very expensive and may have adverse effects on soil and environment health. In recent times, the use of conservation tillage (reduced tillage or no-tillage) have increased because of their capacity to suppress annual weeds and improve soil health (Price, Balkcom, Culpepper, Kelton, Nichols and Schomberg 2011). One major goal of conservation tillage systems is to increase accumulation of crop residue at the soil surface that helps in reducing soil erosion, increasing soil water infiltration, improving soil health, and suppressing weeds. Reduced tillage is another term that has been used as a synonym (Roberts *et al.* 1999) or considered to be a variation of conservation tillage (Rapp *et al.* 2004). Reduced tillage is defined as “a tillage system in which the total number of tillage operations preparatory for seed planting is reduced from that normally used on that particular field or soil (America 2008)." Terms such as no-tillage, zero tillage, ridge tillage, or strip tillage are different types of reduced tillage. In no-till systems, the soil is not disturbed at all prior to planting, plant residue is maintained year-round and crops are planted in narrow slots with a specialized no-till planter. Strip tillage, is a hybrid of no-tillage and conventional tillage, where disturbance of soil is limited to tilled strips on no more than 30% of the surface, where crops are grown. In ridge tillage systems, pre-formed ridges are scraped, crops planted on the bared ridge bases and ridges are rebuilt after planting (ASAE 1993). Reduce tillage helps in the accumulation of plant residues at the soil surface, that helps in inhibiting weed seed germination by shading and blocking light. Previous research on conservation tillage has revealed that reduced tillage is more promising approach for production of several vegetables (Buchanan *et al.* 2016, Doss *et al.* 1981, Knavel 1981, Robinson 1985).

Cover cropping is a key component in conservation tillage. Coupling cover crops with conservational tillage systems can improve soil health by minimizing tillage and can also provide weed control through physical and allelopathic/chemical means (Hartwig *et al.* 2002). In conservation tillage systems, Anderson (2010) found 15% reduction in weed seedling density for each 1000 kg ha^{-1} of cover crop residue. In reduced or no-tillage systems, cover crops are grown prior to cash crop establishment, and are terminated without incorporating residue in the soil, thus leaving surface mulch into which the subsequent cash crop can be planted. Many studies have been conducted using reduced tillage and cover crops to reduce weed populations in agronomic crops (Al-Kaisi *et al.* 2004, Brainard *et al.* 2013, Smith *et al.* 2011), and an extensive literature is present. But, there has been limited research conducted on reduced tillage practices in vegetable production systems, however, interest in this practice is expanding. In conventional no-till systems, herbicides are the primary means for killing the cover crops but, in organic systems producers terminate cover crops mechanically by using roller-crimper or flail mower during a particular stage of growth and have very limited options for the control of weeds that comes up through the cover crop mulch. Rye and hairy vetch are the most commonly used cover crops in organic systems that can be effectively killed at flowering (Ashford *et al.* 2003) and early pod stage (Mischler *et al.* 2010), respectively. If sufficient biomass is produced, the rolled cover crop mulch can provide full season annual weed suppression (Silva 2014, Smith, Reberg-Horton, Place, Meijer, Arellano and Mueller 2011) for a cash crop planted through the mulch using no-till methods.

Prior studies on organic no-till methods have shown that cover cropping can reduce weed populations. There has also been considerable variability in vegetable crop yield under reduced tillage in previous organic research (Bottenberg *et al.* 1999, Leavitt *et al.* 2011). Swenson *et al.* (2004) found that no-till and strip-till systems using rye and wheat as living mulch cover crops produced greater marketable tomato (*Solanum lycopersicum* L.) yield than no-till and strip till systems using herbicides. Large seeded vegetable crops such as pumpkins and summer squash have been successfully grown when planted directly in the undisturbed cover crop using no-tillage practice and were effective in suppressing weed population (Hoyt *et al.* 1994, Hoyt 1999, Rapp, Bellinder, Wien and Vermeylen 2004). Similarly, hairy vetch was determined to be the best cover crop for no-till tomato production without compromising yield (Abdul-Baki *et al.* 1996). Schellenberg *et al.* (2009) found that a no-tillage system using flail mowed warm-season legume cover crops Egyptian bean, soybean, sunn hemp, and a mixture of sunn hemp and cowpea had similar yields for spring broccoli (*Brassica oleracea* L. *var. italic*), but reduced yields for fall broccoli, compared with conventional tillage. In recent studies, Jokela (2016) recorded effective early season weed suppression in organic no-tillage and strip-tillage broccoli without any yield losses. When evaluating strip tillage for tomato production, Kornecki *et al.* (2011) found that a rye cover crop was able to produce enough biomass to suppress weeds and maintain yield; thus making it a viable alternative to plastic mulch whereas, crimson clover, did not produce the biomass necessary to suppress weeds and resulted in decreased yields. In contrast, Leavitt et al. (2011) found that rye and hairy vetch cover crops lowered weed density in no-tillage tomato, pepper and zucchini (*Cucurbita pepo var. cylindrica*) but reduced crop yields due to short growing season, reduced nutrient immobilization, plant mortality resulted from insect pressure, and also due to allelopathic interference.

Although reduced tillage has been shown to build soil health and reduce weed populations while maintaining yield, one major negative impact of reduced tillage is that a weed suppression throughout the season cannot be attained with this system. Furthermore, in many organic vegetable production systems reduced tillage is not very effective in controlling perennial weeds (Melander *et al.* 2012, Peigné *et al.* 2007), intensive tillage is likely to be needed to control a perennial weed infestation. For reduced tillage to be a sustainable option for organic growers various weed control strategies such as cover crops, mulches, soil solarization, flaming, and biological means must be suitably integrated to better ensure its success.

CONCLUSION

Weeds are a major limitation for organic vegetable production. A number of cover crops species have potential to suppress weeds through direct crop interference or through allelopathic effects. Research has shown that cover crop termination methods using reduced tillage approaches also have potential to give better weed control as compared to conventionally tilled land. Choosing an appropriate cover crop species, planting time, termination timing and termination methods are very important to maximize cover crop biomass, weed suppression, and crop performance. The efficacy of cover crop also depends on location and residue management practices. Hence, determining, cover crop species and management practices is based on the needs and goals of sustainable production. To date, the use of cover crops in vegetable production system is limited due to economic, biological, and farm operational factors, but educating farmers, and continued research can help in overcoming present hurdles to adoption. Also, limited information is available on benefits of cover cropping for weed control in vegetable systems, therefore, research is needed to determine appropriate cover crop species for greater weed suppression and limited phytotoxicity in vegetable production systems. More research is also needed on perennial weed responses to cover crops and conservation tillage systems.

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