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Cover crop technology – a way towards conservation agriculture: A review

VIBHA SINGHAL[1]*, JYOTIRMOY GHOSH[2] and DINESH JINGER[3]

ICAR-Indian Institute of Soil and Water Conservation, Dehradun, Uttarakhand, India

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ABSTRACT

There is transformation of agriculture from traditional to contemporary to fulfill the growing demand of food grains by mushrooming human population in the past few decades. Contemporary agriculture is completely dependent on external inputs of synthetic fertilizers and pesticides. Though it increased agricultural yield by many folds, but contributed to environmental degradation significantly including greenhouse forcing. The relevance of conservation agriculture emerged in response to the questions raised on health, environment and sustainability issues. Interest in conservation agriculture revived the traditional practices of cover cropping for soil conservation in the recent past. It is a form of reduced tillage improving soil physico-chemical and biological properties, claiming protection against insect-pests besides suppressing weeds effectively. In the present scenario, the role of cover crops extended to soil carbon sequestration thus combating global warming. Mean annual carbon sequestration potential of cover crop was found to be 0.32 ± 0.08 Mg ha^{-1} yr^{-1} to an average maximum increase of 16.7 Mg ha^{-1}. Cover crops control weeds through competition, allelopathy, and/or physical effects due to surface residue, thereby interfering with growth, development and reproduction of weed. Cover crops suppress diseases by extending the length of a crop rotation, improving soil structure, providing a physical barrier and enhancing suppressive effects of soil life therefore disrupting disease cycle phases. Species in the brassicaceae family, such as mustards have been widely known fumigants as they suppress fungal diseases. Despite so many advantages, the issue of competitiveness between cover crop and main crop for resources cannot be ignored and bypassed. Strategic planning, management and manipulation of cover crops system are essential and decisive to reduce competition with the main crop for resources. Though cover crop systems have been in use for centuries, yet environmental concerns raised due to revolutionary inorganic agriculture have paved the way for more exploration and refinement in their use.

Key words: Competition, Conservation agriculture, Cover crop, Soil erosion

Contemporary agricultural revolution based on extensive use of chemicals provided the farmers with a definitive technology package for higher yields.Though intensive agriculture increased agricultural yield, but contributed significantly to environmental issues including global warming (Singhal *et al.* 2017). Farmers throughout the world are increasingly being caught in a vicious spiral of unsustainability related to depletion and degradation of land and water resources, increasing labor and input costs, and decreasing profit margins (Cherr *et al.* 2006). In view of the above mentioned concerns, agriculture is required to provide more diverse ecological services and make more efficient use of natural/renewable resources. Within this context, improved integration of cover cropping system in present agriculture practices may become the cornerstone of sustainable agro-ecosystems. Cover crops help in carbon sequestration by combating soil erosion which is the major land degradation process responsible for emission of carbon. By the inclusion of winter cover crops in annual crop rotations, soil C sequestration potential was estimated to be 40 Tg C yr^{-1} (Sperow 2003) and 20 ±12 g C m^2 yr^{-1} (West and Post 2002). In another study conducted in southeastern USA, soil organic C sequestration rate was estimated to be 0.28 + 0.44 Mg C ha^{-1} yr^{-1}without cover cropping and 0.53 + 0.45Mg C ha^{-1} yr^{-1}with cover cropping (Franzluebbers 2005). Cover crops can also engineer the rhizosphere by altering the microbial population due to availability of diverse energy sources. The functional diversity of bacterial communities from rhizosphere of different cover crops causes various plant growth-promoting properties such as activating nutrients in soils, producing numerous plant growth regulators, protecting against phytopathogens, improving soil structure, sequestering toxic heavy metals and degrading xenobiotic compounds (like pesticides). Cover cropping is a viable and cost effective approach/stategy for weed control and disease suppression. Cover crops have been used to manage weeds in several crops, including corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), soybean

*Corresponding author e-mail : singhalvibha76@gmail.com, [1]ICAR-Indian Institute of Soil and Water Conservation, Dehradun, Uttarakhand; [2]ICAR-Indian Institute of Resins and Gums, Namkum, Ranchi, Jharkhand; [3]ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Vasad, Anand, Gujarat.

and southern pea (*Vigna unguiculata* (L.) Walp). Some well-established allelopathic cover crops known for weed suppression are *Secale cereale* (rye), *Vicia villosa* (hairy vetch), *Trifolium pratense* (red clover), *Sorghum bicolor* (sorghum sudangrass), and species in the brassicaceae family, particularly mustards (Kruidhof 2008). Cover crops suppress diseases by extending the length of a crop rotation, improving soil structure, providing a physical barrier and enhancing suppressive effects of soil life therefore disrupting disease cycle phases (Stone 2012). However, perceived risks and complexity of cover crop-based systems may prevent their initial adoption and long-term use. Hence, the development of functional cover-crop-based systems will require extensive knowledge base on every aspect for more integrated and system-based approach, rather than reinstating traditional production practices.

Agro-ecological potential of cover cropping

Soil carbon sequestration: Soil organic matter (SOM) concentration is necessary to reduce agricultural emissions of greenhouse gases (GHG). It has been indicated that soil organic carbon (SOC) sequestration is credited to those management systems which reduces soil disturbance and erosion, maximize crop residues retained in soil, and improve nutrient and water use efficiencies of crop production systems. SOC level can be strongly influenced by selecting appropriate cropping systems which enhance crop productivity and increase residue input levels. Adoption of reduced or no-till methods, using organic manures or biosolids, growing cover crops, and using nitrogen (N) fertilizer are practices which promote SOC sequestration in agricultural soils (Lal 2001). Leguminous crops are often very good cover crops.They have better canopy and foliage coverage and hence provide better protection to cultivated land against soil and water erosion than ordinary cultivated crops (Jinger and Kakade 2019). The major land degradation processresponsible for emission of carbon (C) is soil erosion. Soil erosion accelerates the depletion of soil C as SOM is concentrated on the soil surface. Globally, 201 Gt of soil is lost to erosion, corresponding to 0.8 to 1.2 Gt of emitted C per year. Africa, Asia, and South America emit between 0.60 and 0.92 Gt of C per year through soil erosion. Cover crops can have favorable effects on soil chemical, physical, and biological properties that combat erosion and promote sustainability. Cover crops enhance soil protection by vegetative cover, improve soil productivity, soil structure, nutrient use efficiency and water stable aggregates, hence help in building up of SOC concentration (Lal 2003). Strategic planning to increase SOC through cover crops requires thorough knowledge of the quality and quantity of plant biomass produced by them and its rate of decomposition in soil. Puget and Drinkwater (2001) studied the distribution of incorporated 13C labeled hairy vetch residues and found that more root-derived than shoot derived C remained in the soil after one corn growing season showing, that root litter was greatly responsible for the short-term soil structural improvements from green manure.The root/shoot contribution of C is a major consideration in designing cover crop harvest options so that organic matter levels could be optimized. Conservation tillage along with cover cropping makes a perfect and complete system for conservation agricultural systems. The rate of C sequestration by various cover crops in different cropping system is compiled in Table 1. Soil organic C sequestration estimated with the EPIC v. 3060 model was (a) -0.03 Mg C ha^{-1} yr^{-1}under conventional tillage cotton, (b) 0.39 Mg C ha^{-1} yr^{-1} under no-tillage cotton with wheat cover crop, (c) 0.49 Mg C ha^{-1} yr^{-1}under no-tillage cotton-corn rotation with wheat cover crop, and (d) 0.50 Mg C ha^{-1} yr^{-1} under no-tillage cotton-corn rotation with wheat cover crop for 10 years following Bermuda grass pasture for 5 years (Abrahamson *et al.* 2009). Meta-analysis conducted by Poeplau and Don (2015) showed mean annual C sequestration potential of cover crop to be 0.32 ± 0.08 Mg ha^{-1} yr^{-1} to an average maximum increase of 16.7 Mg ha^{-1}. Rye, hairy vetch, clovers and pigeonpea are potential cover crop for C sequestration. Pigeon pea (*Cajanus cajan* L. Millsp.) + maize with N fertilization sequestered 1.42 Mg C ha^{-1} yr^{-1}, whereas hairy vetch as cover crop in different systems sequester C ranging from 0.52 to 0.9 Mg C ha^{-1} yr^{-1}.

Rhizosphere manipulation through cover crops: Due to root exudates and rhizodeposits, the soil in vicinity of the root system is a live complex of microbial abundance and activity. Earlier the root system was thought to provide support and uptake of nutrients and water only but indeed it is a centre for numerous underground interactions. Rhizosphere can be engineered with the help of suitable selection of cover crops as different plant species markedly influences both the quantity and composition of soil microbial community and the population dynamics of introduced rhizobacteria. The variation in the biochemical composition of plant species and the subsequent organic compounds availability to microbes may modify the composition of microbial communities (Zak *et al.* 2003). Recent studies have reported plant species-dependent changes in microbial communities of either the root rhizosphere or bulk soil. Vetch and rye cover cropping increase soil microbial biomass and alter microbial community structure in a vegetable cropping system, attributed to a combination of rhizosphere exudation, nutrients released from decomposing roots, and nutrients leached into the soil from above-ground cover crop (Buyer 2010). In another 1-year study, both rye and oats (*Avena sativa* L. cv. Hercules) increased mycorrhizal colonization of sweet corn with the combination of both cover crops being the best performer (Kabir and Koide 2002). Cover crops might provide the degradable carbons and energy sources needed to increase rhizosphere microbial metabolic capacities and diversities. Rhizosphere manipulation by cover crops can be beneficial to the associated or succeeding main crop. The functional diversity of bacterial communities from rhizosphere of different cover crops showed various plant growth-promoting properties at different levels as listed in Table 2. PGPRs (Plant growth promoting rhizobacteria)

Table 1 Role of cover crops in soil carbon sequestration

Location	Cover crop cropping system	Change in C Stock (Mg C ha^{-1} yr^{-1})	Depth (cm)	Duration (years)	Reference
Southeastern China	Ryegrass (*Lolium perenne*) under China fir (*Cunninghamia lanceolata*)	0.36 + 0.40	-	7	Zhang and Fang (2007)
Brazil	*Desmodium ovalifolium* into *Brachiaria*	1.17	-	9	Tarre*et al.* (2001)
	Oat (*Avena strigosa* Scherb)-common vetch-corn-cowpea compared with oat-corn on sandy clay loam	0.82 (no till) 0.62 (plow till)	30	9	Bayer *et al.* (2000)
	Cajanus cajan-maize	0.9	0–20	12	Bayer *et al.* (2001)
Southern Brazil	Lablab (*Lablab purpureum* L. Sweet) + maize	0.83	0–17.5	17	Diekow *et al.* (2005)
	Pigeon pea (*Cajanus cajan* L. Millsp.) +maize with N fertilization	1.42	0-107.5	17	
	Mucuna spp. + Maize	0.68	0- 20	8	Bayer *et al.* (2009)
	Pigeon pea (*Cajanus cajan* L. Millsp.) and velvet beans (*Stizolobium cinereum* Piper & Tracy) in no tillage maize cropping systems	0.38–0.59	-	7–19	Amado *et al.* (2006)
Central Brazil	No tillage (NT) with cover crop (*Crotalaria*) compared to disc tillage (DT).	0.35	0–10	5	Metay *et al.* (2006)
India	Sesbania in rice-wheat rotation	0.09 + 0.03		12	Singh *et al.* (2006)
Albama, USA	Cotton-winter rye compared to cotton fallow on silt loam	5.4	30	2	Nyakatawa *et al.* (2001)
	Hairy vetch in tomato-silage corn on sandy loam	0.9	20	6	
Georgia, USA	Rye in tomato-eggplant (*Solanum melongena* L.) on fine sandy loam	0.63	20	5	Sainju *et al.* (2002)
	Hairy vetch in tomato-eggplant (*Solanum melongena* L.) on fine sandy loam	0.52	20	5	
	Crimson clover in tomato-eggplant (*Solanum melongena* L.) on fine sandy loam	0.5	20	5	

enhance plant growth through activating nutrients in soils, producing numerous plant growth regulators, protecting against phytopathogens, improving soil structure, sequestering toxic heavy metals and degrading xenobiotic compounds (like pesticides) (Ahemad and Kibret 2014).

Herbicide fate: Cover crop and its residues cause changes in physico-chemical and biological parameters of soil.Transformation of herbicides in soil happens through microbial metabolism mostly; thus modifying the soil environment as well as microbial populations by reduced tillage and/or cover crops. Cover crops affect herbicide fate, i.e. retention, degradation and transport in soil (Alletto *et al.*2010). Tillage and herbicide-desiccated ryegrass cover crop influenced the potential for fluometuron degradation.Accumulation of metabolite and modification of nonextractable components by incorporation of the tri-fluoromethylphenyl ring label was observed in no—tillage (NT) and conservation tillage (CT) soils underneath ryegrass residues at 0–2 cm soil depth, where the most speedy fluometuron degradation was observed. Rapid accumulation of fluometuron into non-extractable components parallel with greater microbial counts and activities of soil enzyme was found in NT and CT surface soils from ryegrass plots in comparison to respective soils with no cover crop. The addition of organic amendments to a Dundee silt loam enhanced the degradation rate of fluometuron and cyanazine, with ryegrass residues being more stimulatory than either cornmeal or poultry litter. In other study the residues of rye-grass and vetch-oat cover crop above soil decreased 14C glyphosate mineralization, altered degradation pattern and enhanced immobilization by non-extractable residue (NER) formation compared to a bare soil. The potentially mobile fraction of available 14C-glyphosate was greater in the mulch compartment (from 3.5% for white mustard to 9.7% for vetch-and-oat) than in soils (0.12 ± 0.0 in average for all treatments). The composition of soil organic matter varies according to the nature of cover crop residue. Residues of rye tend to form less aliphatic and more aromatic humic acids compared to mix of vetch/rye residues, which could influence pesticide behavior and efficacy in soil (Ding *et*

Table 2 Functional diversity of PGPRs in the rhizosphere of different cover crops

Crop	PGPR (Plant growth promoting rhizobacteria)	Function	Reference
Pearl millet (*Pennisetum glaucum*)	Diazotrophs (*Azospirillum, Azotobacter, Klebsiella*)	Nitrogen fixing	Tiwari *et al.* (2003)
	Non diazotrophic Pseudomonas	High *invitro* acetylene reduction activity and Production of indole acetic acid (IAA)	
	A. calcoaceticus	IAA, Phosphate solubilization, zinc oxide and siderophore production	Rokhbakhsh-Zamin *et al.* (2011)
Wheat (*Triticum aestivum*)	*Klebsiella pneumoniae*	IAA production	Sachdev *et al.* (2009)
	Bacillus sp., *Pseudomonas* sp	Phosphate solubilization, siderophore and IAAproduction	Joshi and Bhatt (2011)
Mandua (*Eleusine coracana*)	*P. fluorescens*	Potent in inhibiting growth of phytopathogenic fungi (*F. oxysporum* and *P. aphanidermatum*)	
Rapeseed (*Brassica napus*)	*Agrobacterium, Burkholderia, Enterobacter* and *Pseudomonas*	Indolic compounds and siderophores production, solubilize phosphate, and some could also fix nitrogen	Farina *et al.* (2012)
Chinese cabbage (*Brassica campestris*)	*Pseudomonas* and *Agrobacterium* belonging to alpha- and gamma-Proteobacteria groups	Producing IAA and ACC deaminase activity, phosphate solubilization	Ahemad and Khan (2012)
Indian mustard (*Brassica juncea*)	*Variovorax paradoxus, Rhodococcus sp.* and *Flavobacterium sp*	Indoles and siderophores production, cadmium tolerance	Belimov *et al.* (2005)
Lupin (*Lupinus albescens*)	*Enterobacter* and *Serratia*	Production of siderophores and indolic compounds	Giongo *et al.* (2010)
Chickpea (*Cicer arietinum*)	*Bacillus, Pseudomonas, Azotobacter* and *Rhizobium*	Production of IAA, ammonia (NH_3), Heavy metal tolerance	Joseph *et al.* (2007)
Willow primrose (*Ludwigia octovalvis*)	*Arthrobacter globiformis*	Arsenate resistance	Titah *et al.* (2011)

al. 2006). On the basis of studies conducted earlier, it was found that hairy vetch (*Vicia villosa* Roth) residues had a higher retention for chlorimuron than rye (*Secale cereale* L.) residues and a higher retention for fluometuron than wheat (*Triticum aestivum* L.) residues (Gaston *et al*. 2001). This greater sorption by vetch than rye or wheat residues may be related to differences in physical state that offered a greater surface area for herbicide sorption in the case of the vetch and in composition of the residues that contained less cellulose and more amino acids. Fluluometuron retention in cover crop residues and rapid dissipation were attributed to strong herbicide affinity to cover crop residues and herbicide co-metabolism as cover crop residues decomposes. Fresh residues of cover crops limited S-metolachlor leaching and enhanced S-metolachlor dissipation through greater NER formation compared to decomposed residues. Application of S-metolachlor on fresh or slightly decomposed mulch could be a way to reduce its pollution in the environment. Adsorption of the pesticides differed significantly according to (i) the type of pesticide, (ii) the nature of cover crop, (iii) decomposition level of the cover crop and the cover crop × decomposition time interaction. Epoxiconazole was the most adsorbed molecule compared to S-metolachlor and glyphosate, Adsorption of the three pesticides increased with decomposition time (up to sevenfold for glyphosate on oat), and was negatively correlated with C/N ratio and positively with the lignin fraction of the residue in decomposition. The mulch increases soil surface roughness, thus reducing runoff (Selim *et al*. 2003). However, the mulch effectiveness in controlling runoff and erosion depends on the nature and quantity of plant residues. For quantities of residues increasing from 0 to 1.5 t ha^{-1} either remaining on the soil surface in no-tillage or mixed in the ploughed horizon in conventional tillage, runoff was reduced by 96 and 40%, respectively.Therefore cover crop residues help in controlling water pollution due to pesticides by reducing their run off.

Cover crops as alternative weed control strategy

Herbicide use and labor cost for weed control can be reduced with well planned cover cropping systems and mulch crops, thus, provide farmers with an organic cost-effective approach for weed control, which is a major deciding factor to be considered by farmers while adoption of such technologies (Gutiererez Rojas *et al.* 2004). Cover crops reduces weeds through competition for resources, disturbance of niche, and release of phytotoxins from both root exudates and decomposing residues, thereby interfering with growth, development and reproduction of weeds. The key characteristics of cover crops responsible for weed suppression are plant density, initial growth rate, aboveground biomass, leaf area duration, persistence of residues and time of planting of a subsequent crop (Kruidhof 2008). Some well established allelopathic cover crops are *Secale cereale* (rye), *Vicia villosa* (hairy vetch), *Trifolium pratense* (red clover), *Sorghum bicolor* (sorghum-sudangrass), and species in the brassicaceae family, particularly mustards (Haramoto and Gallandt 2005). Many studies have confirmed the weed suppressing ability of living mulches in different cropping systems. The suppression of weeds by different cover crops through allelopathy is listed in Table 3. Best combination of species to use cover crop as live mulch for providing high forage yields and lower weed densities includes alfalfa, kura clover, and reed canarygrass (Singer *et al.* 2005). Annual cover crops such as *Mucuna* may also be used to control perennial weeds, provided that they effectively shade out these weeds just prior to weeds starting replenishing their storage organs (e.g. rhizomes) with assimilates (Teasdale *et al.* 2007).The mulch crop mixtures with complementary canopy characteristics (e.g. rye and clover) and differential root traits (e.g. fibrous vs deep tap roots) will exhibit better cover-crop performance and thus, more effective weed control (Linares *et al.* 2008).

Disease management: Cover crops suppress diseases by disrupting disease cycle phases such as dispersal, host infection, disease development, propagation, population buildup, and survival of the pathogen, in a number of ways. The mulch crops reduce pathogen dispersal via splashing, water runoff, and/or wind-borne processes (Cantonwine *et al.* 2007). The incidence and severity of soil-borne diseases can be reduced by crops residues via inducing inherent soil suppressiveness, whereas massive use of inorganic fertilizers may cause nutrient imbalances and lower pest resistance (Altieri and Nicholls 2003). Disease suppression in some cover crop based cropping systems has been summarized in Table 4. When designing covercrop systems specifically for disease management, information on effectiveness of these crops in hosting or suppressing pathogens is prerequisite. In some cases, the cover crops can be a host for the pathogen but will not develop any disease symptoms itself. In case, they are not properly decomposed, population of pathogen such as *Pythium* spp. increases, causing severe epidemics (Manici *et al.* 2004). Cover crops promote disease suppression by favoring certain groups of soil microbial communities due to interactive effects of root exudates and root affinity of different crops on beneficial organisms (Mazzola 2004). The mulch crop can also interrupt disease cycles and reduce fungal and bacterial populations (Everts 2002), and parasitic nematodes (Vargas-Ayala *et al.* 2000) as the impact of the mulch crop on the pathogen will depend upon the nature and life cycle requirements of the pathogen. Species in the brassicaceae family, such as mustards have been widely known fumigants as they suppress fungal disease populations through the release of naturally occurring toxic chemicals

Table 3 Allelochemicals present in different cover crops

Cover crop	Allelochemical	Plant Part	Reference
Wheat (*Triticum aestivum* L.)	Hydroxamic acids and simplephenolic compounds	Root exudate	Gavazzi *et al.* (2010)
Cucumber (*Cucumis sativus* L.)	Benzoic and cinnamic acids	Root exudates	Yu *et al.* (2003)
Brassica spp.	Glucosinolates	Roots and shoots	Bangarwa *et al.* (2011)
Sweet vernalgrass (*Anthoxanthum odoratum* L.)	Coumarins		Razavi (2011)
Sorghum (*Sorghum bicolor* L.)	Sorgoleone strigolactones and orobanchol, resorcinolic lipids and Secalonic	Root exudate	Czarnota *et al.* (2003)
Hairy vetch (*Vicia villosa*)	Cyanamide	Leaves and stems	Kamo *et al.* (2003)
Barley (*Hordeum vulgare*)	Phenolic compounds, and two alkaloids, gramine and hordenine	Leaf, stem, root, root exudate	Kremer and Hammouda (2009)
Annual wormwood (*Artemisia annua*)	Artemisinin, a sesquiterpenoid lactone with herbicidalactivity	Leaves, flower and roots	Jessing *et al.* (2013)
Sunn hemp (*Crotalaria juncea*)	Monocrotaline	seeds	Jourand *et al.* (2004)
Tall fescue (*Festuca arundinacea*)	Pyrrolizidine alkaloids, flavonolglycosides and flavonols.	Root exudates and extracts, above ground biomass	Bertoldi *et al.* (2012)
Mexican sunflower (*Tithonia diversifolia*)	Sesquiterpene lactones Tagitinin-A, Tagitinin-C, Tagitinin-F and Tagitinin-D	Shoot	Musyimi *et al.* (2012)
Mungbean [*Vigna radiata* (L.) Wilczek]	Glucosylflavonoids, vitexin & isovitexnia, isovitexin	Seed coat and in leach from germinating seed	Lertmongkol (2011)
Velvetbean (*Mucuna pruriens* L.)	3-(3',4'-dihydroxyphenyl)-l-alanine (l-DOPA)	Roots	Nishihara *et al.* (2005)

Table 4 Disease suppression in cover crop based cropping systems

Cover crop	Disease suppression	Reference
Marigold (*Tagetes patula*)	Early blight disease caused by *Alternaria solani* in potato	Gomes-Rodríguez *et al.* (2003)
Greenleaf (*Desmodium intortum*) and silverleaf (*D. uncinatum*)	Effective control of S. *hermonthica* (Del.) Benth. infestation	Khan *et al*. (2000)
Canola and rapeseed (*Brassica napus*)	Rhizoctonia canker, black scurf, and common scab in potato cropping systems	Larkin *et al.* (2010)
Indian mustard (*B. juncea*)	Reductions in powdery scab (caused by *Spongospora subterranea*) and common scab (*Streptomyces scabiei*) in potato cropping systems	Larkin & Griffin (2007)
Hairy vetch (*Vicia villosa*)	Controls development of early blight epidemic on tomato foliage	Mills *et al.* (2002)
	Control Fusarium wilt (*Fusarium oxysporum* f. sp *niveum*) in watermelon	Zhou and Everts (2007)
Hairy vetch and rye (*Secale cereale*)	Decrease in powdery mildew (*Podosphaera xanthii*), plectosporium bight (*Plectosporium tabacinum*) and black rot (*Didymella bryoniae*) in pumpkin compared to conventionally tilled pumpkin	Everts (2002)
Broccoli (*B. oleracea* var. *italica*)	Reduction in viable sclerotium density of *S. cepivorum*, lower white rot incidence and increase in garlic yield.	Ulacio-Osorio *et al.* (2006)

during the degradation of glucosinolade compounds in their plant cell tissues (Lazzeri and Manici 2001). Some species, such as crucifers also observed to decrease soil pathogen populations (Subbarao and Hubbard 1996). Cover crop based cropping system affects disease causing organisms by changes in moisture, temperature, bulk density, soil compaction, and nutrient dynamics.

Insect management

Cover crops function against range of insects, including aphids, beetles, caterpillars, leafhoppers, moths, and thrips as detailed in Table 5. Role of cover crops as biological control agent is related to changes in biophysical status of soil, creating favorable niches for beneficial organisms, release of toxic exudates and changes in soil ecology. Cover crops also enhance biodiversity by establishing more congenial conditions for free-living fungivors, bactivores, and other predators. Along with reduced proliferation of pests, dispersal of visual and olfactory clues emitted by host crops is hindered by mulch crops resulting in more effective insect pest suppression (Tillman *et al.* 2004). Changes in cropping systems affect insect pests and their natural enemies. Some live mulch crops so-called "trap crops" are used to attract pests towards mulch crop being more favorable habitat away from the main crop (Shelton and Badenes-Perez 2006). Trap crop areas can be established within crops, within farms, or within landscapes. In many cases the growing season for both trap crop and food crop is same. Once pests are trapped in large numbers in the cover crop habitat, the confined area occupied by these trap crops can be treated with a pesticides to reduce the pest population. Besides, some crops attract natural predators of pests by providing them favorable habitat (Table 2). This is a type of biological control known as habitat augmentation, achieved by using cover crops. Prior to the arrival of important insect pests of vegetable crops, beneficial insects can be attracted into an area by the moisture, shelter, pollen, honeydew, nectar, and insect prey associated with a cover crop. These predators survive and reproduce on nectar, pollen, thrips, and aphids and get established before the arrival of key pests. A more diverse planting could be of high value to natural enemies as they provide a greater variety of refugia and nectar sources.

Future challenges

Despite the diversified services provided by the cover crop systems, conventional farmers hesitate to adopt these systems due to a number of factors such as complexity of mulch crop-based systems, additional resources in terms of land, labor, and other inputs, deficit knowledge of management practices and suitable extension services. Although such systems provide multiple benefits, there are also several additional challenges. Competion between live mulches and main crop can result reduced yield. Especially for short duration high-value commodities like vegetables where yield reduction due to competition may significantly affect price premiums, such systems may adversely affect returns. Under water-deficit conditions, use of cover crops will deplete residual soil moisture levels and thereby, can reduce yields of commercial crops. Use of winter crops as live mulch in semiarid conditions reduced soil water storage by 65–74 mm, thereby, impacting the pre irrigation needs of subsequent crops and/or performance of subsequent annual crops. In perennial systems (e.g. vineyards), perennial crops used as cover crops have both higher root densities and deeper root systems, thus, causes more pronounced soil water depletion (Celette *et al.* 2008).These issues should be addressed by researchers and cover crop systems should be designed accordingly for easy adoption by farmers. Understanding the practical hindrances in adopting live

Table 5 Insect-pest management through cover crops

Cover crop	Insect pest/natural enemies	Reference
Alfalfa (*Medicago sativa* L.) and kura clover (*Trifolium ambiguum* M. Bieb.)	Corn borer (*Ostrinia nubilalis* Hubner)	Prasifka *et al.* (2006)
Trifolium spp.	Eggs and larval densities of pest caterpillars reduced in broccoli (*Brassica oleracea* L. var. italica)	Hooks & Johnson (2003)
Alfalfa (*Medicago sativa*)	Increased predators to manage outbreaks of the invasive soybean aphid (*Aphis glycines* Matsumura)	Schmidt *et al.* (2007)
Strawberry clover, white clover and yellow sweet clover	Aphids infestation of leek by thrips	Legutowskaand Kucharczyk (2000)
Buckwheat	Increased longevity and fecundity of parasitoids in the laboratory that attack sharp shooters, a key pest of grapes	http://biocontrol.ucr.edu/irvin/research/wsare.html
White clover, spring vetch (*Vicia lathyroides*) and field bean (*Vicia faba*)	Shorten feeding period of the flea beetle (*Phyllotreta cruciferae*) on broccoli	Hooks & Johnson (2003)
Cowpea (*Vigna unguiculata*)	suppress pest populations of pepper	Mochiah (2011)
Chinese bushclover (*Sericea lespedeza*) and Sunn hemp (*Crotalaria juncea* L.)	Reduce the aphid-borne virus, Watermelon mosaic virus (WMV), incidence and associated yield losses in pumpkin	Murphy *et al.* (2007)
Sunn hemp (*Crotalariajuncea* L.)	Reduce incidence of lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller) on bean (*Phaseolus vulgaris* L.)	Gill *et al.* (2010)
Yellow sweet clover, white clover	Reduced imported cabbageworm and cabbage looper numbers on broccoli heads late season, increase in the abundance of spiders and overall reduction of lepidopteran pests on broccoli foliage	Hooks and Johnson (2001)
Basil (*Ocimum basilicum* L.) and summer savory (*Satureja hortensis* L.)	Reduced infestations of *Aphis fabae* Scopoli (Homoptera: Aphididae) adults in broad bean (*Vicia faba* L.) plots	Basedow *et al.* (2006)
Ocimum sanctum L. and *Ocimum basilicum* L.	Reduces the numbers of eggs laid by the pulse beetle *Callosobruchus chinensis* Linn. (Coleoptera: Bruchidae) in *Vigna radiata* (mung)	Kiradoo and Srivastava (2010)
Sunn hemp (*Crotalaria juncea* L.) and marigold (*Tagetes patula*)	Increased abundance of soil mesoarthropods and acterivorous, fungivorous, and omnivorous nematodes throughout the cropping cycle of cucumber	Wang *et al.* (2011)
Greenleaf (*Desmodium intortum*) and silverleaf (*D. uncinatum*)	Stem borer in maize (*Zea mays* L.)	Khan *et al.* (2000)
Fodder radish (*Raphanus sativus)* showed.	White grub control in rice+fodder radish system	Rabary *et al.* (2011)

mulch technology by the producers and dissemination of knowledge and management skills for using this technology can help in its widespread adoption. Such adaptive learning and innovation cycles should be an integral part of training programs to enhance the efficiency of technology transfer.

Conclusion

Agricultural revolution based on extensive use of chemical fertilizers and pesticides increased agricultural production but posed many challenges with respect to sustainability issues. Conservation agriculture is the need of hour to tackle the problems aroused due to inorganic agriculture. Cover crop is being seen as an integral component of conservation farming in the light of integrated soil management—an essential building stone for sustainable agriculture. Cover crops can help in C sequestration by reducing soil erosion which is the major cause for C emission from soil. Use of cover crops can alter rhizosphere microbial population in favour of plant growth due to diverse energy sources. Besides cover crops serve as an alternative to use of chemicals for controlling weeds and insect-pest and diseases management. Plethora of studies has established the weed suppressing ability of living mulches in different cropping systems. The mulch crop mixtures with complementary canopy characteristics (e.g. rye and clover) and differential root traits (e.g. fibrous vs deep tap roots) show better cover-crop performance and thus, more effective weed control. Previous studies shows that members of brassicaceae family especially mustards and other plant species such as hairy vetch and rye effectively controlled bacterial and fungal diseases of commercial crops. Cover crops function against range of insects, including aphids, beetles, caterpillars, leafhoppers, moths, and thrips. However, the knowledge and skill of using cover crop technology is still in infancy stage. It is needed to create awareness and skill development by imparting trainings to the farmers. The package of practices for use of cover crops in general or for dealing with special kind of problems at regional and global level is must for widespread use of cover crops in cropping systems.

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