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Cover-Crop Technology for Soil Health Improvement, Land Degradation Neutrality, and Climate Change Adaptation

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Abstract

Soil health improvement, land degradation neutrality, and climate change adaptation are critical sustainable issues in Indian agriculture. While soil health deterioration and land degradation are rapid in both irrigated and rainfed/dryland ecosystems, climate change adaptation is more important under water stressed ecosystems. Rainfed ecosystems hold prominence globally as these occupy 80% of the world's cultivable land and constitute a major share to the global food basket. Of the available agricultural land in Asia, rainfed areas account for about 83.4% of the land area compared to 16.6% of irrigated land. Rainfed/dryland ecosystems encounter numerous constraints *viz*., low and erratic rainfall, low moisture, degraded and poor resource base, soil fertility decline, low productivity, etc. These factors eventually lead to the over-exploitation of existing natural resources and hasten the speed of their degradation. Sustenance of soil health is one of the most significant tasks for enhancing the agricultural productivity, and adopting feasible technologies for maintaining it becomes critical. Monocropping is being practiced majorly in rainfed regions because of soil moisture being a constraint in these areas. The practice of introducing cover crops in fallows rather than leaving the land vegetation-free has a potential to provide multiple benefits *viz*. erosion and runoff control, biological fixation of N, higher utilization of applied N, enhanced soil productivity and fertility, weed suppression, reduction in greenhouse gas (GHG) emissions, etc.

Key words: Cover crops, erosion control, nitrogen fixation, soil health, sustainability

Introduction

Increasing crop productivity and maintaining a clean environment are the major challenges before agricultural scientists in the 21st century. To meet these challenges, crop production practices need to be modified in favour of higher yields and minimum environmental pollution. Management of the crop residues is a key component which could impart sustainability to the cropping systems (Ruffo and Bollero, 2003). Historically, crop residues have played an important role of mulch in improving soil and water conservation and as an input for maintaining soil organic matter (SOM) and adding/returning nutrients to the soil (Srinivasarao et al., 2013c). To achieve these objectives, use of cover crops in cropping systems offers a viable option. Cover crops are defined as the close-growing crops that provide soil protection, and soil improvement between periods of normal crop production, or between trees in orchards and vines in vineyards. Cover crops are grown not for market purposes but for improving sustainability of soil and environmental quality. When plowed under and incorporated into the soil, cover crops may be referred to as green manure crops. Cover crops are also sometimes called as catch crops. In **Table 1**, important tropical and temperate cover crops are listed. Cover crops are usually killed on the soil surface before they mature by using appropriate herbicides. These crops are generally included in cropping systems as nutrient management tools (Ruffo and Bollero, 2003). Cover crops can be leguminous or non-leguminous. Legume cover crops are used as a source of nitrogen (N) for the following cash crop (Smith et al., 1987) while grasses are mainly used to reduce NO_3^- leaching and erosion (Meisinger et al., 1991). Biological N fixation by leguminous crops offers potential to reduce the need for N fertilizers for the succeeding crop (Singh et al., 2004; Srinivasarao et al., 2007). A bicultural of a legume and a grass is used with the intention of providing both benefits simultaneously (Ranells and Wagger, 1996).

Soil degradation is one of the major constraints threatening the food security of the country (Srinivasarao et al., 2021). Of the 328.7 million hectares (Mha) of total land, 36.70% (120.72 Mha) is degraded. Among the principal degradation processes, 60.27% (73.27 Mha) is affected by water erosion, 10.30% (12.40 Mha) by wind erosion, 14.50% (17.45 Mha) by chemical degradation, and 0.90%

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(1.07 Mha) by physical degradation (ICAR/NAAS, 2010). Soil loss due to water and wind erosion and human activities (removal of surface soils) causes land degradation. Inappropriate and poor management practices, as well as climate change, contribute to the physico-chemical and biological degradation of agricultural lands. Desertification, acidification, salinization, soil erosion, deforestation, and sand-dune encroachments are main causes for global land degradation. Globally, about 40% of the agricultural land is extremely degraded. More than 5 billion tonnes (Bt) of top soil is eroded every year; about 1.6 Bt (30%) of the soil is lost to sea through rivers. About 74 Mt of major nutrients is lost due to erosion. Thus, the country loses approximately 0.8 Mt, 1.8 Mt, and 26.3 Mt of N, P and K, respectively. Land degradation is more severe in States like Telangana, Madhya Pradesh, Odisha, Jharkhand, Karnataka, Jammu and Kashmir (J&K), Gujarat, Maharashtra, and Rajasthan. Water erosion and removal of vegetation are the significant processes responsible for land degradation in dry sub-humid and semi-arid regions, and wind erosion is the main process in the arid regions. Land is fundamental and interconnected system for all the livelihoods on Earth. Land degradation affects over two-third of the world today. If left unchecked, it will destruct society foundations, food security, health, economies, wellbeing and quality of life.

Multiple Benefits of Cover Crops

Cover crops are literally "crops that cover the soil" in agricultural fields when the soil is typically fallow. Cover crops classically protect the soil against water and wind erosion and help in increasing the soil productivity by providing green manures which add N to the soil.

Planting cover crops before or between main crops can enhance soil physical, chemical, and biological properties and consequently lead to improvement in soil health and yield of major crops (Indoria et al., 2018, 2017a; Kundu et al., 2016). Leaving cover crops as surface mulches in no-till crop production systems has the advantage of increasing N economy (Smith et al., 1987), conserving soil moisture (Morse, 1993), reducing soil erosion (Langdale et al., 1991), improving soil physical properties (Blevins and Frye, 1993), increasing nutrient retention (Dinnes et al., 2002), increasing soil fertility (Cavigelli and Thien, 2003), suppressing weeds (Creamer et al., 1996), reducing diseases and insects (Ristaino et al., 1996), reducing global warming potential (Robertson et al., 2000), and increasing crop yields (Triplett et al., 1996). Characteristics of various cover crops are mentioned in **Table 1** and important legume cover

Table 1. Characteristics of various cover crops (Source: Florentin et al., 2010)

Cover crop	Characteristics
Grey- seeded mucuna	Annual, herbaceous, produces good quantity of dry matter
Pigeon pea	Tolerates both drought and cold, excellent solution for soil restoration, greater amount of annual biomass even under extreme conditions
Jack bean	Annual, herbaceous, Tolerant to drought
Dwarf mucuna	Annual, herbaceous, develops little biomass in extremely degraded soils, and provides less soil cover during its development
Sunnhemp	Annual, having great biomass production, grows well on degraded soils
Pearl millet cover for long time	Annual, highly drought tolerant, grows rapidly and competes with weeds, leaves are excellent
Forage sorghum	Annual, allelopathic impact on growth of weeds; produces high vegetative biomass
Lablab	Biennial, herbaceous, good growth under drought conditions
Forage peanut degraded soil	Perennial, herbaceous, good biomass production in soils, produces no biomass in extremely
Creeping indigo	Perennial, herbaceous, tolerates drought and light frost, efficient in nodulation process, excellent cover for protecting the soil and resows naturally
Tephrosia	Perennial with vigorous taproot, capable of de-compacting soil, it has good residual effect
Leucaena	Perennial, great potential for nitrogen fixation and recycling, high nutritional value of leaves and branches meets the nutritional requirement of the animals.
Black oats	Annual, develops little biomass in degraded soils, excellent soil cover it provides after being flattened, high degree of weed suppression
White lupine	Annual, herbaceous, sensitive to drought, excellent nitrogen fixer.
Oilseed radish	Annual, Herbaceous, produces a great quantity of biomass
Hairy vetch	Annual, herbaceous, displays slow initial development but forms good soil cover
Rye	Annual, drought tolerant, highly responsive to both organic and inorganic fertilizers and competes with weed plants
Ryegrass	Annual, effective soil cover with adequate rooting system suppress the weed growth.

Photo 1. Some of the important legume cover crops in the field crops and agroforestry systems

crops in the field crops and agroforestry systems are shown in **Photo 1**.

Beneficial effects of the cover crops on soil management and crop productivity are discussed in the following sections. Potential benefits of cover crops are illustrated in **Figure 1**.

Soil Erosion Reduction

In conventional systems, raindrops falling on bare surface soil layers break the aggregates, with detached particles clogging the soil pores and obstructing the water infiltration. These rainwater drops run off the surface and along with them transport a portion of the soil, referred to as water erosion. Impact of water erosion on crop yields differs across soils, crop types, and management practices (Lal, 1987). Growing of cover crops aids in minimizing the risks associated with water and wind erosion (Langdale et al., 1991; De Baets et al., 2011). Cover cropping could be regarded as an effective practice that can be adopted to minimize soil erosion and lessen the leaching of N in areas where cover crops could be established in winter season, and expenses incurred on energy requirement for tillage and N fertilization are prominent. Reduction in soil erosion by cover crops has a positive correlation with SOM content; improvement in SOM contributes to increase water infiltration in the soil and minimize the rate of runoff from each rainfall event. The effectiveness of cover crops majorly varies with cover crop species, which can be attributed to variations in biomass cover. In

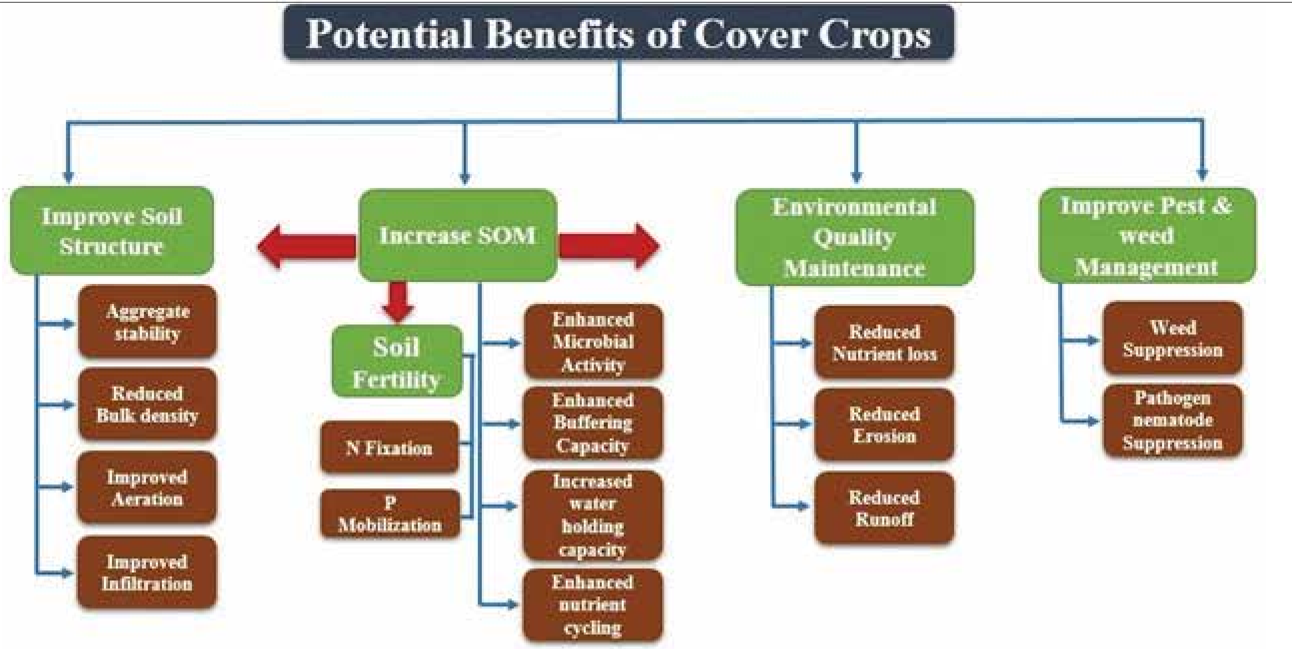

Figure 1. Potential benefits of cover crops

Missouri, under natural rainfall conditions, reduction in annual soil loss of 96%, 95%, and 97% by downy brome, Canada bluegrass, and chickweed winter cover crops, respectively was observed when compared to the no-cover crop. Winter cover crops curtailed the dissolved nutrient losses to the tune of 7% to 77% (Zhu et al., 1989). Utilization of a mixture of grasses + legumes as cover crop could provide more canopy cover, total biomass yield, and uniform surface coverage when compared to a single species (Wortman et al., 2012). Cover crops help in reducing the inter-rill erosion (Kasper and Singer, 2011) because the plant residues created by cover crops capture the raindrops and disperse their impact.

Organic Matter Buildup

Cover crops add on to the fertility of soil through the biological nitrogen fixation (BNF) route (Srinivasarao et al., 2011). A cover crop offers a natural way to reduce soil compaction, manage soil moisture, reduce overall energy use, and provide additional forage for the livestock. Small farmers choose to grow specific cover crops based on their needs and goals and the overall requirements of the lands they are working on. Cover crops raised in the summer are often used to fill in space during the crop rotations, help amend the soils, or suppress weeds. Winter cover crops help in holding the soil in place during winters and provide the surface ground cover. These crops, leguminous in particular, promote and trigger the BNF.

Soil Fertility Enhancement and Nitrogen Fixation

In addition to being a major store house of plant-available nutrients in the agricultural systems, SOM performs multiple functions like optimization of physical, chemical and biological properties of the soil (Florentin et al., 2010). Because crop residues are not adequate/enough to compensate for the loss of organic matter (through high rate of mineralization) in tropical and sub-tropical regions, utilization of a cover crop/green manure or a combination of green manure + cover crop could be a viable option in complementing the contribution of crop residues (Srinivasarao et al., 2020). Cover crops with higher biomass production could aid in both conserving and enhancing the SOM (Venkateswarlu et al., 2006). Soil organic matter enhancement caused by the inclusion of cover crops protects the surface from soil erosion and facilitates the provisioning of congenial conditions for habitat creation of habitats for microorganisms like fungi which contribute to improvement in soil biology and offer more pathways for nutrient management in the soil ecosystem. Inclusion of cover crops in crop rotations helps in maintaining and conserving essential soil nutrients (Kundu et al., 2013). Cover crops-induced enhanced SOM levels lead to the improvement in structure, water holding capacity, nutrient availability, and buffer power of the soil (Srinivasarao et al., 2012, 2019). Input of cover crop biomass over time also aids in the soil quality improvement (Sharma et al., 2018). Nutrient conservation by recycling assumes significance in soils with low water and nutrient holding capacity. As a part of the reclamation process, introduction of salt-tolerant cover crops *viz*., sorghum-Sudan grass and Seco-barley (*Hordeum vulgare* L.) stimulates recycling of substantial quantities of nutrients, thus preventing them from leaching into deeper zones of the soil profile (Lu et al., 2007).

Nitrogen Fixation and Utilization

Nitrogen contribution is the prominent benefit provisioned by leguminous crops. Cover crops, either leguminous or non-leguminous, impact the N fertilizer management (Bauer and Roof, 2004). Fixation of atmospheric N by leguminous cover crops reduces the N fertilizer requirement of succeeding crops (Reeves, 1994; Hoyt and Hargrove, 1986). Quantity of N fixed by various legume cover crops is summarized in **Table 2**. Major factors governing the rate of N_2 fixed by cover crops include the amount of plant available N in the soil and genetic potential of the legume.

Table 2. Quantity of nitrogen fixed by legume cover crops

Cover crops	Amount of N_2 fixed (kg ha^{-1} crop^{-1})	References
Peanut (*Arachis hypogaea* L.)	40–80	Brady and Weil (2002)
Cowpea (*Vigna unguiculata* L. Walp.)	30–50	Brady and Weil (2002)
Alfalfa (*Medicago sativa* L.)	78–222	Heichel (1987)
Soybean (*Glycine max* L.)	50–150	Brady and Weil (2002)
Fava bean (*Vicia faba* L.)	177–250	Heichel (1987)
Hairy vetch (*Vicia villosa* Roth.)	50–100	Brady and Weil (2002)
Ladino clover (*Trifolium repens* L.)	164–187	Heichel (1987)
Red clover (*Trifolium pratense* L.)	68–113	Heichel (1987)
White lupine (*Lupinus albus* L.)	50–100	Brady and Weil (2002)
Field peas (*Pisum sativum* L.)	174–195	Heichel (1987)
Chickpea (*Cicer arietinum* L.)	24–84	Heichel (1987)
Pigeon pea (*Cajanus cajan* L. Huth.)	150–280	Brady and Weil (2002)
Kudzu (*Pueraria phaseoloides* Roxb. Benth)	100–140	Brady and Weil (2002)
Chick pea (*Cicer arietinum* L.)	24–84	Heichel (1987)
Green gram (*Vigna radiata* L. Wilczek.)	71–112	Chapman and Myers (1987)
Lentil (*Lens culinaris* L.)	57–111	Smith et al. (1987)

Dinitrogen (N_2) fixation capacity of legumes is also regulated by soil pH, moisture content, and temperature. Although the quantity of N_2 provisioned by leguminous cover crop is sufficient to produce ideal yields of succeeding non-leguminous crops in few instances but in high N requiring cereals such as corn, supplementation of fertilizer N is required. Application of N fertilizer, however, could be significantly curtailed alongside maintaining ideal economic yields in such crops (Frye et al., 1988). Researchers have extensively evaluated the efficacy of different types of cover crops or mixture of cover crop species on productivity of succeeding crops and soil N availability. Cover crops contribute to reducing the potential of NO_3 leaching from agricultural fields (Brandi Dohrn et al., 1997; Staver and Brinsfield, 1998). Reduction in nutrient leaching by utilizing cover crops as a management practice could be attained by choosing cover crops that establish easily and can stay overwinter. Rasse et al. (2000) conducted studies to compare NO_3-N leaching under cover crops and no-cover crop treatments utilizing tension cup lysimeters. They reported that the cereal rye reduced leaching to the tune of 62%. With passive wick lysimeters study spanned over three years in corn-broccoli rotation, Brandi-Dohrn et al. (1997) reported 33 to 61% reduction in NO_3-N leaching with cereal rye cover crop in comparison to no cover crop. Cover crops aided in lessening both the leached N mass and NO_3 concentration in leachate to the tune of 20 to 80% in comparison to control *i.e.* no cover crop (Meisinger et al., 1991); brassicas and grasses were 2-3 folds more effective in comparison to legumes in minimizing NO_3 leaching. Incorporating a non-leguminous cover crop in the cropping system aids in lowering the rate of NO_3 leaching as it contributes to reduction in percolation of water and also effectually utilizes NO_3 that otherwise would leach down (Francis et al., 1998; Rasse et al., 2000; Shepherd, 1999). Accumulation of inorganic soil N amid major crop seasons by cover crops and its retention in organic form prevents the NO_3 leaching. Cover crop residue decomposes gradually and N released is successively made available to the next crop (Dinnes et al., 2002), which helps in reducing the doses of chemical fertilizers.

Soil Microbial Health

Cover cropping is a viable option to mitigate the soil degradation consequences and sustain the soil health. Cover crops form better agro-ecosystem comprising of soil microbiome which responds well to various environmental circumstances. Compared to bare fallow lands, cover cropped lands significantly increase the activity, abundance, and diversity of soil microbes by 22%, 27%, and 2.5% respectively (Venkateswarlu et al., 2006). Microorganisms play a crucial role in the sustenance of soil health because of their action in promoting nutrient cycling through the organic matter decomposition and overcoming the nutrient shortage (Turco et al., 1994). Proliferation of soil microorganisms is more under cover-cropped soils due to favourable environmental conditions like moisture, temperature and carbon availability (Kumar and Goh, 2000). Optimized soil biological environment leads to the buildup of SOM and improvement of the overall soil productivity (Kaspar and Singer, 2011). Cover crops can also promote microbial growth by releasing carbohydrates into the rhizosphere. Phosphorus-solubilizing bacteria and free-living and facultative endophytic diazotrophs are some of the microbes which benefit from the cover crop root exudates (Ganeshamurthy et al., 2007). In soils of low fertility, cover crops provide P and N to the growing plants (Ansari et al., 2015).

Climate Change Adaptation by Organic Matter Buildup

Cover crops are capable of improving the SOM status by protecting the soil layers from vagaries of soil (water/wind) erosion. These cover crops accumulate the biomass particularly below the soil surface. Microbial habitat created by the roots of cover crops contributes to favourable soil biology and balanced nutrient management (Ganeshamurthy et al., 2005). Carbon dioxide (CO_2) is a major greenhouse gas (GHG) emitted by vehicles, power plants and burning of fossil fuels, etc. Sequestrating atmospheric carbon into the soils helps to mitigate the GHG emission. Cover crops offer a viable option for enhancing carbon sequestration in soils, because these feed many soil organisms (bacteria, fungi, etc.) which increase the soil carbon levels over a period of time.

Recent studies on role of cover crops in mitigation of climate change by sequestering carbon and reducing GHG emissions have created interest (Kaye and Quemada, 2017). As per the USEPA study, cover crops planted across 8.1 Mha land had a potential to sequester 60 Mt of CO_2-equivalent GHGs yr^{-1} which was equivalent to the GHGs emitted by 12.8 million passenger vehicles. Addition of organic matter through cover crops facilitate carbon sequestration and improves the climate resilience by way of improving water infiltration, nutrient cycling, erosion control, and overall soil health.

Soil Moisture Conservation and Evapotranspiration Reduction

Cover crops reduce the evaporation losses from the soil surface, safeguard the soil moisture from the rainfall and irrigation, and help in improving soil moisture availability to the succeeding crops (Kundu et al., 2013). Cover crops act as a barrier between the soil surface and rainfall and act to reduce the intensity of rainfall on the soil surface. Water drops slowly trickle down into the soil pores formed by soil macro fauna enriched by cover crop root growth. This increase in water infiltration (in place of draining off) facilitates improvement in the soil water storage (Sharma et al., 2012). Basche et al. (2016) reported that the cover crops enhanced the soil's available water capacity, and field capacity by 21% to 22%, and 10% to 11%, respectively. Folorunso et al. (1992) reported that the cover crops reduced the surface soil strength by 38% to 41% and increased the soil infiltration rate by 37% to 41%. Cover crops also help in decreasing the surface drainage and sustaining the soil quality. These also cause reduction in water content through transpiration (Qi and Helmers, 2010).

Soil Aggregation

Cover crops alter physical properties of the soil directly through formation of aggregates and pores or indirectly through incorporation and decomposition of root and shoot residues (Indoria et al., 2016). The impact of cover crop on soil structure differs based on type of soil, soil depth, soil texture, climate, cropping system, tillage, cover crop species, cover crop biomass, and frequency of cover crop(s) in rotation (Kaspar and Singer, 2011). Patrick Jr. et al. (1957) reported that the hairy vetch improved the aggregation, reduced the bulk density, increased the porosity, and enhanced the water holding capacity of soil compared to control without cover crop. Soil aggregation alters major soil properties and shields SOC through the process of physical encapsulation facilitated by the microbial decomposers. Stabilization of soil aggregates, attained by different mechanisms, performs variedly against external factors such as rainfall, tillage, plant cover, etc. (Blanco Canqui and Lal, 2004). The relative stability and quantity of aggregates is also influenced by management practices (Six et al., 2004). Water stable aggregates assume importance as potential indicators of soil degradation and are critical for reduction of soil crusting and erodibility, and maintenance of water infiltration (Saygin et al., 2017). Roberson et al. (1991) reported that the rapid increase in stability of soil macro aggregates could be attained through the inclusion of a cover crop. Hermawan and Bomke (1997) observed higher structural stability (as reflected in mean weight diameter - MWD) in the succeeding winter crops. It is believed that the production of extracellular polysaccharides and fungal hyphae by cover crops aids in keeping macro aggregates intact (Degens, 1997; Oades and Waters, 1991). Cover crops contribute to SOC enhancement through addition of biomass C input and expedite the process of soil aggregation to protect the SOC (Villamil et al., 2006; McVay et al., 1989; Blanco Canqui et al., 2015). Replacing fallows with cover crops might increase soil water infiltration by enhancing organic carbon, increasing water stable aggregates, and improving hydraulic conductivity in the soil (Angers and Caron, 1998). McDowell (2019) reported that growing rye as a cover crop aided in enhancing the percentage of macro aggregates and particulate organic matter to the tune of 4.1% and 14.0%, respectively. Effects of cover crops on dynamics of soil aggregation are presented in **Figure 2**.

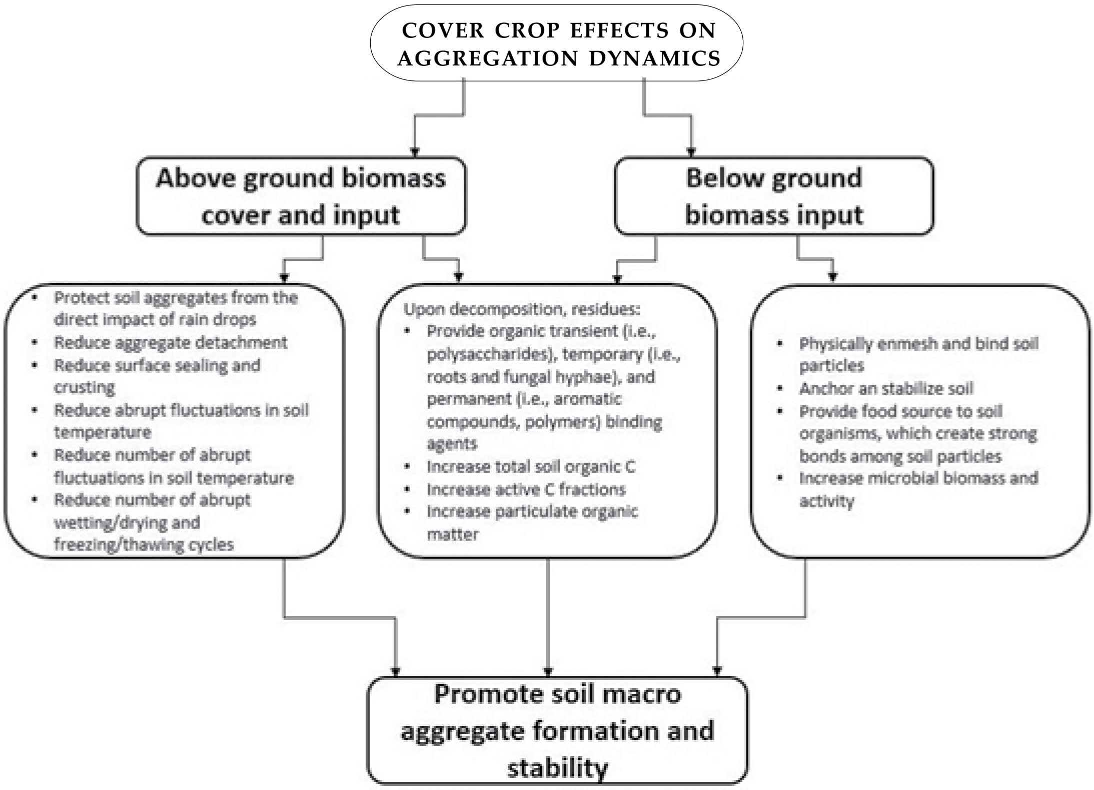

Figure 2. Effect of cover crops on aggregation dynamics (Adapted and modified from Blanco Canqui et al., 2013)

Reduced Weed Infestation

Weeds mine away the nutrients from the soil. Weeds act to reduce the available nutrient and SOM content, ultimately leading to decline in productivity of associated economically important crops. In agro-ecosystems, cover crops could be regarded as an effective tool to suppress weeds. Depending on the cover crop species planted, weed species respond variedly. Rate of decomposition, termination methods and management practices impact the potential effects of cover crops on population of weeds. Cover crop influences weeds. both directly and indirectly. It establishes direct competition with weed species by acting as live mulch or smother crop. Effect of legume cover crops on the reduction of weed infestation is summarized in **Table 3**. The second approach utilizes indirect suppression brought about by chemical means (Weston and Duke, 2003), physical means (Teasdale and Mohler, 2000; Teasdale et al., 1991), or manipulation of nutrient cycles. Florentin et al. (2010) reported that the infestation of weeds was significantly minimized in plots of cotton sown after cover crop associated with corn compared to the plots where no cover crop establishment had been done.

Improved Fodder Production

Sustainable increases in agricultural productivity are necessary to secure food availability and livelihoods, particularly in the developing world, in the coming decades. Such increases must come largely through better use of the land already under production as the potential to develop new lands is severely limited (Shaxson et al., 1989). Cover crops are the viable options for their use as animal food as well. Many cover crops are grown during fallow time between the main crops. Some cover crops are grown to specifically aid in production of the next crop. Legumes are frequently grown because of their ability to fix N. Grazing legume cover crops provides livestock with high quality feed while returning some of the N back into the soil via manure and urine. Grazing of cover crops appears to provide greater soil improvement benefits than harvesting forages as a stored feed. Harvesting cover crops as hay or silage removes organic matter that could potentially remain in the field and be incorporated back into the soil. As per Michigan State University, grazing of cover crops offers the opportunity to capture highly digestible nutrients for animals and provides benefits to the soil in their cropping systems.

Land Degradation Neutrality

Land Degradation Neutrality (LDN), a term coined at the UN Conference on Sustainable Development at Rio, 2012, is defined as the state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems. Neutrality implies no net loss of the land-based natural capital relative to a reference state, or baseline. Planning for neutrality involves projecting the likely cumulative impacts of land use and land management decisions, then counter balancing anticipated losses with measures to achieve equivalent gains. It is extremely urgent to restore the ecosystems which had undergone degradation leading to enormous economic, social and ecological costs (Cowie et al., 2018).

The LDN responds to the instant challenges like intensifying the production of food, fuel and fiber to meet future demand without degrading our limited land resource base. Bonn Challenge pledged to restore globally 350 Mha degraded land by 2030. India joined this global commitment and pledged the restoration of total 21 Mha by 2030. Prime Minister Shri Narendra Modi announced in UNCCD COP 14 that India will meet its pledge on achieving LDN by 2030 and is working on restoring 26 Mha of degraded lands. United Nations Sustainable Development Goal (SDG) 15 has set a target to achieve a Land Degradation Neutral World by 2030. It is projected that by 2050, land degradation and climate change can lead to 10% reduction in crop yields globally and up to 50% in certain regions; in addition, there could occur a forced migration of around 50 million to 700 million people. As per the Ministry of Environment, Forest and Climate Change (MoEFCC) of Government of India, country incurred an economic loss of Rs.3.17 lakh crore ($46.90 billion) due to land degradation in 2014-15, which constituted about 2.5% of the country's gross domestic product (GDP). Occurrence/severity of land degradation is not uniform across the country. As per NBSS&LUP (2004), out of 147 Mha degraded lands in India, 82.6 Mha and 12.4 Mha have been degraded due to water and wind erosion, respectively. Cover crops offer a viable and economical option to reduce soil erosion-induced land degradation. To avoid further land degradation and promote land restoration, multifunctional use

Table 3. Effects of legume CCs on the reduction of weed infestation

S. No.	Cover crops	Main crop	Dominant weed species	Extent of weed control	References
1.	*Medicago sativa* L.; *Lupinus albus* L.	*Triticum aestivum* L.; *Secale cereale* L.	*Chenopodium album* L., *Poa annua* L., *Stellaria media* (L.) Vill.	Reduced weed biomass (54% - *M. sativa*; 42% - *L. albus*)	Kruidhof et al. (2008)
2.	*Medicago sativa* L.; *Trifolium pratense* L.; *Pisum sativum* L.	*Triticum* aestivum L.	*Descurainia sophia* (L.) Webb. ex Prantl; *Sonchus boleraceus* L.; *Kochia scoparia* (L.) Schrad	Reduced weed dry matter (45% - *M. sativa*; 63% - *P. sativum*); increased of weed DM (11% - *T. pratense*)	Blackshaw et al. (2010)
3.	*Medicago polymorpha* L; *Medicago truncatula* Gaertn.; *Trifolium alexandrinum* L.; *T. pratense* L	*T. aestivum* L. and *Zea mays* L. rotation system	*Capsella bursa-pastoris* (L.) Medik.; *Stellariamedia* (L.) Vill.; *Thlaspi arvense* L.; *T. aestivum* L. (volunteer wheat)	Reduced density (41 –78%)and dry weight (26% – 80%) of winter annual weeds; reduced dry weights of summer annual (70% –*Medicago* spp.) and perennial weeds (35% - 75% *Medicago spp., Trifolium alexandrinum*)	Fisk et al. 2001
4.	*Medicago lupulina* L. (United Kingdom); Trifolium repens L. (Norway, Germany, Sweden);*Trifolium subterraneum* L. (Germany,Switzerland); mixture of *Trifolium repens* and *Lolium perenne* L. (Sweden); mixture of *Medicago lupulina, Sinapis alba* L., *Brassica napus* L.and *Raphanus sativus* L. (United Kingdom)	*Triiicum. aestivum* L. (first year); *Hordeum vulgare* L. in United Kingdom and Norway; and *Zea mays* L. at the other sites (in second year)	*Stellaria media* (L.) Vill.; *Chenopodium album* L.; Rumex spp.;*Tripleurospermum inodorum* L.) Sch.Bip.; (*Elymus repens* (L.) Gould	Reduced weed cover throughoutthe intercrop period (55% to 1% depending on site); no reduced weed biomass or density	Reimer et al. (2019)
5.	*Medicago lupulina* L.; *Trifolium pratense* L.; *Trifolium repens* L.; *Trifolium incarnatum* L.; *Trifolium resupinatum* L.; *Medicago alba* Medik.; *Vicia sativa* L.; mixture of *Medicago lupulina* L. and *Lolium multiflorum* Lam.	H. vulgare L.; T. aestivum L.	*Galeopsis* L. spp.; *Myosotis arvensis* (L.) Hill; *Stellaria media* (L.) Vill.; *Viola arvensis* Murr.; *Taraxacum officinale* Weber in Wiggers; *Tripleurospermum inodorum* (L.) Sch. Bip.; *Cirsium arvense* (L.) Scop.); *Poa annua* L.	Reduced weed density and biomass in*Triticum aestivum* above 50% (in *Hordeum vulgare* - no effect)	Salonen and Ketoja (2019)
6.	*Medicago scutellata* Mill.; *Vicia villosa* Roth.; *Trifolium subterraneum* L.	*Solanum tuberosum* L.	*Lolium temulentum* L.; *Stellaria media* (L.) Vill.	Reduced weed biomass (22%–57%)	Campiglia et al. (2009)
7.	*Medicago lupulina* L.; mixture of M. lupulina L. + *Loliummultiflorum* Lam. var. *westerwoldicum* Mansh.	*Beta vulgaris* L.	*Agropyron repens* (L.) P. Beauv.; *Chenopodium album* L.; *Echinochloa crus-galli* (L.) Beauv.; *Galium aparine* L.; *Viola arvensis* Murr.; *Amaranthus retroflexus* L.; *Solanum nigrum* L.; *Stellaria media* (L.) Vill	Reduced weed number (25%–38%— *Medicago lupulina*;44% –55% mixture of CCs and air-dryweight of weeds (21%–44% *Medicago lupulina*;45%–51%— mixture of CCs	Buraczynska and Ceglarek (2004)
8.	*Trifolium pratense* L.	*Triticum aestivum* L.	*Ambrosia artemisiifolia* L.	Reduced weed biomass (28% - 43%)	Mutch et al. (2003)

S. No.	**Cover crops**	**Main crop**	**Dominant weed species**	**Extent of weed control**	**References**
9.	*Trifolium pratense* L.; *Trifolium repens* L.; mixture of *Trifolium pratense* L.and *Phleum pratense* L.; mixture of T. *pratense* L. and *Lolium spp.* L.	*Triticum aestivum* L.; *Avena sativa* L.	*Spergula arvensis* L.; *Stellaria media* (L.) Vill.; *Viola arvensis* Murray; *Chenopodium album* L.; *Erodium cicutarium* (L.) L'Herit;*Cirsium arvense* (L.) Scop.	Reduced weed biomass (74%) - mixture of *Trifolium pratense* and *Lolium*; increased seed bank and density of emerged weed (4.5 and 10 times in cloves)	Sjursen et al. (2012)
10.	*Trifolium incarnatum* L.; *Trifolium subterraneum* L.	*Zea mays* L.	*Solanum nigrum* L.; *Chenopodium album* L.; *Amaranthus retroflexus* L.; *Ammi majus* L.; *Cynodon dactylon* (L.) Pers.; *Geranium dissectum* L.; *Polygonumaviculare* L.; *Veronica persica* Poiret; *Xanthiumstrumarium* L.; *Echinochloa crusgalli* (L.) Beauv.	Reduced weed biomass (22% –46% *Trifolium incarnatum*;21%–67%\ *Trifolium subterraneum*	Bàrberi and Mazzoncini (2001)
11.	*Trifolium pratense* L.; *Vicia villosa* Roth.	*Zea mays* L.	*Amaranthus retroflexeus* L.; *Convolvulus arvensis* L.; *Acroptilon repens* (L.) DC.; *Cuscuta* sp.	Reduced weed biomass (77%) *Vicia. villosa*	Yeganehpoor et al. (2015)
12.	*Vicia villosa* Rotch.	*Apium graveolens* L.	*Stellaria media* (L.) Vill.; *Amaranthus blitoides* S. Wats; *Cyperus esculentus* L.; *Capsella bursa-pastoris* (L.) Medik.; *Portulaca oleracea* L.	Reduced weed biomass (70%)	Charles et al. (2006)
13.	*Vicia villosa* Rotch.	*Solanum lycopersicum* L.	*Amaranthus retroflexeus* L.; *Digitaria sanguinalis* (L.) Scop.; *Portulaca oleracea* L.	Reduced weed density (72%–79%) andAbove ground biomass (40%)	Campiglia et al. (2010)
14.	V. sativa L.	*Zea mays* L.	*Ipomoea grandifolia* (Dammer) O'Donell; *Euphorbia heterophylla* L.; *Digitaria sanguinalis* (L.) Scop.; *Cyperus rotundus* L.	Reduced weed dry matter (76%) and number (58%)	Cutti et al. (2016)
15.	*Vicia villosa* Rotch..; mixture of *Vicia villosa* Rotch. and *Secale cereale* L.	*Zea mays* L.	L. amplexicaule L.; *Stellaria media* (L.) Vill.; *Poa annua* L.	Decreased weed biomass (92% - *Vicia villosa* Rotch;97% - mixture of cover crops)	Seman-Varner et al. (2019)
16.	*Vicia villosa* Rotch.	Glycine max (L.) Merr.	*Amaranthus rudis* Sauer; *Setaria faberi* Herrm.	Decreased weed biomass (26%, in rolled system comparedto the burndown system)	Davis (2010)
17.	Mixture of *Vicia villosa* Rotch. and *Secale cereale* L.	*Glycine max* (L.) Merr.	*Amaranthus retroflexeus* L.; *Ambrosia artemisiifolia* L.; *Chenopodium album* L.; *Polygonum convolvulus* L.;*Panicum dich otomiflorum* Michx.; *Setaria faberi* Herrm.; *Setaria glauca* L.; *Cyperus esculentus* L.; T. o_cinaleWeber in Wiggers	Reduced weed density (67%–85% *Chenopodium album* L. *Amaranthus retroflexeus* L. &*Setaria* spp.), without *Cyperus esculentus* L.	Mirsky et al. (2011)

S. No.	Cover crops	Main crop	Dominant weed species	Extent of weed control	References
18.	*Vicia villosa* Rotch.; *Pisum sativum* L.	*Brassica oleracea* L. var. *acephala*	*Echinochloa crusgalli* (L.) Beauv.P.B.; *Cynodon dactylon* (L.) Pers.; *Convolvulus arvensis* L.; *Chenopodium album* L.; *Portulaca oleracea* L.; *Amaranthus retroflexeus* L;*Circium arvense* (L.) Scop	Reduced weed dry biomass(81%—*Vicia villosa*, 48%— *Pisum sativum*)and density (66%— *Vicia villosa*, 15% —*Pisum sativum*)	Mennan et al. (2009)
19.	Mixture of *Vicia villosa* Rotch. and *Secale cereale* L.	*Brassica oleracea* var. *capitata* f.Rubra	*Thlaspi arvense* L.; *Capsella bursa-pastoris*(L.) Medik.;*Galinsoga parviflora* Cav.; *Lamium amplexicaule* L.	Reduced weed number (25%)and fresh biomass (50%)	Golian et al. (2016)
20.	Mixture of *Vicia villosa* Rotch. and S. cereale L.	Capsicum annuum L.; B. oleraceavar. capitata f. rubra	*Chenopodium album* L.; *Capsella bursa-pastoris* (L.) Medik.; *Senecio vulgaris* L.; *Matricaria inodora* L.;*Lamium amplexicaule* L.; *Galinsoga parviflora* Cav.;*Echinochloa crusgalli* (L.) Beauv. P.B.; *Urtica urens* L.; *Fallopia convolvulus* (L.) Á. Löve;*Polygonum persicaria* L.; *Amaranthus retroflexeus* L; *Thlaspi. arvense* L.; *Stellaria media* (L.) Vill.; *Erodiumcicutarium* (L.) L'Herit	Reduced weed number and biomass (39%–58%—cover crops mulching,10%–45% - cover cropsincorporated into soil)	Kohut et al. (2013)
21.	*Vicia villosa* Rotch.; mixture of *Vicia villosa* Rotch. and *Secalecereale* L.	*Solanum lycopersicum* L.; *Cucurbita pepo* L.; *Capsicum annuum* L.	*Capsella bursa-pastoris* (L.) Medik.; *Setaria* spp.; *Chenopodium album* L.; *Amaranthus retroflexeus* L.	Reduced weed density (96% - mixture of cover crops, 80% - *Vicia villosa*)	Leavitt et al. (2011)
22.	*Crotalaria juncea* L.	*Solanum lycopersicum* L.	*Digitaria horizontalis* Willd.;*Gnaphalium spicatum* Lam.; *Cyperus* spp.; *Galinsoga parviflora* Cav..; *Amaranthus* spp.	Reduced weed dry matter (97%)	Da Silva et al. (2009)

of land is needed within the boundaries of the soil-water system (**Figure 3**). It has been proved that the unsustainable practices degrade the lands and coupled with climate change these practices are responsible for triggering poverty and famines in the under-developed global areas. Growing cover crops is an economically effective soil conservation practice as it covers the soil surface and causes less soil disturbance, and consequentially protects the soil from erosion-related degradation (Indoria et al., 2017a,b). Implementation of cover crops as a sustainable management practice can reduce and reverse the long-term land degradation and contribute to achieve the LDN goal set for 2030. Long-term studies have demonstrated that compared to the use of mineral fertilizers and pesticides, the adoption of conservation agriculture (CA) practices (such as green manure, mulching and cover crops, etc.) is better for sustenance of soil biota (Henneron et al., 2015). Compared to the bare soil, cover crops reduce water evaporation and weed emergence; and augment water infiltration, organic carbon retention and nutrient status (Ranaivoson et al., 2017). Desert Development Programme (DDP), Drought Prone Areas Programme (DPAP), Green India Mission (GIM), and National Afforestation Programme (NAP), etc. are the land degradation management initiatives being implemented at the national level and various state governments in the country. Under GIM, 32,066 ha of degraded lands were afforested and restored (GIM data is from

Figure 3. Action plan for reaching the vision and goal of LDN

2016-2017). Desert Development Programme (DDP) was launched in 235 blocks of 40 districts in 7 States to mitigate the adverse impacts of desertification. From 2012-13 to 2016-17, a total of 282,389 ha of degraded lands were restored and afforested across the country under NAP.

Programmes launched by several State Governments for reversing land degradation such as, Haritha Haram in Telangana; Chettu Neeru in Andhra Pradesh; Watershed Management and Farm Ponds in Rajasthan, Andhra Pradesh, Karnataka, and Maharashtra; crop residue management strategies in Punjab and Haryana; CA in many states; and *jhum* land rehabilitation in NEH are few examples of work in this direction.

Climate Change Adaptation and Mitigation

Cover crops hold potential to lower the GHG emissions and mitigate the climate change effects. Inclusion of cover crops in cropping systems could enhance the C sequestration and reduce the loss of nutrients including soil inorganic nitrogen, and curtail the N_2O emissions (Paustian et al., 2016). Irrespective of tillage treatments (no till, chisel plow and mold board plow) in 12 year field trial, enhanced SOC sequestration was registered where cover crop had been included *vis-a-vis* no cover crop (Olson et al., 2014). Plots with a non-legume cover crop history tended to have higher N_2O emissions than the plots with a legume cover crop (Guardia et al., 2016). Quemeda et al. (2013) reported reduction in nitrate leaching from the fields under cover crops. Growing leguminous cover crops promotes the BNF and reduces the requirements of mineral N fertilizers. Reduced N rates lead to reduction in the N_2O emissions and consequentially lower global warming potential (Camargo et al., 2013). Emerging concerns on global warming have aroused the interest on enhancing the atmospheric sequestration of GHGs *viz*. CO_2 in terrestrial ecosystems (**Figure 4**). Management practices contributing to CO_2 sequestration include practicing conservation tillage and including cover crops in the crop rotation (Sainju et al., 2002). Cover crops considerably reduce the N leaching and enhance the SOC sequestration without impacting the direct N_2O emissions (Abdallah et al., 2018). Bayer et al. (2009) reported that the mitigation potential of cover crops in terms of net GHGs balance was 2.06 ± 2.10 Mg CO_2eq ha^{-1} yr^{-1}. *Mucuna* sp. as a cover crop exhibited a remarkable potential to enhance the C stocks and promote C sequestration in sub-tropical no-till soils. Cover crop technology contributes towards achieving the LDN goal, developing climate change adaptation and mitigation strategies, and mitigating the drought effects through facilitation of enhanced and improved soil health/soil fertility buildup (**Figure 4**).

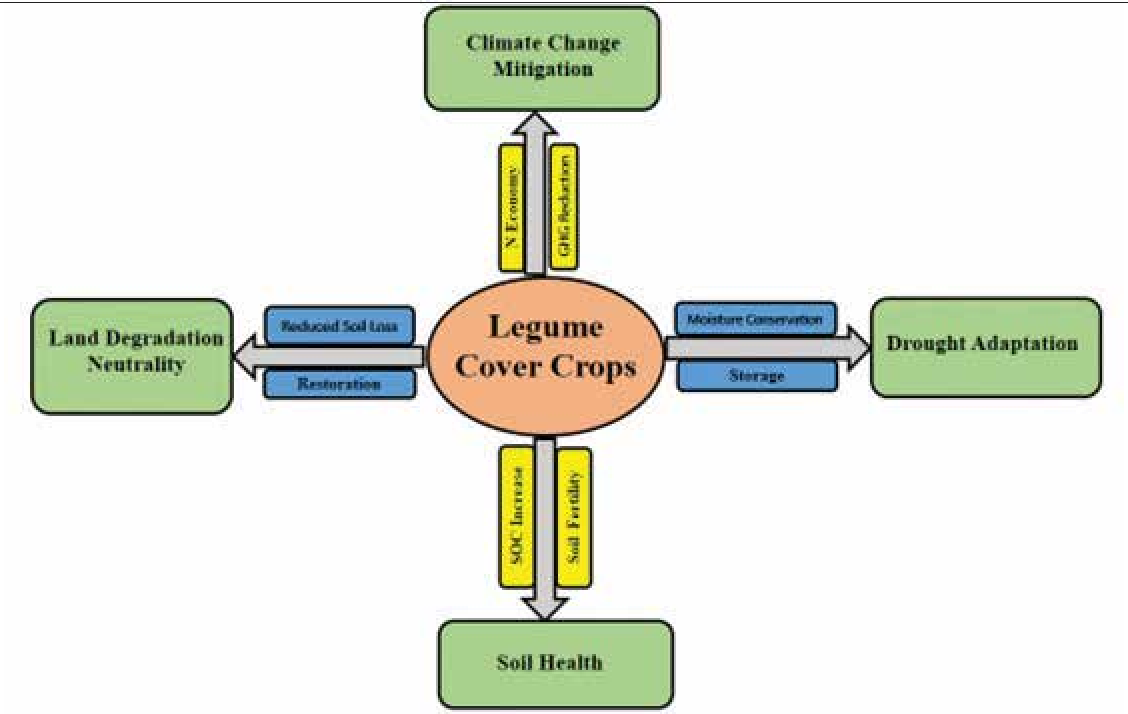

Figure 4. **Climate change adaptation, mitigation, land degradation neutrality contribution process through cover crop technology**

Opportunities for Cover Crops

In most of the semi-arid regions of Andhra Pradesh, a single crop is grown during the rainy or post-rainy season, with land remaining fallow for the rest of the period. Region relies majorly on the south-west monsoon rains during June to September. Around 20-30% of annual rainfall received remains unutilized and is lost as the run-off. Cultivation of legumes can be practiced with this unutilized rainfall for use as the offseason fodder or for *in situ* incorporation into the soil to enhance the SOC and partly meet the nutrient requirement of the rainy season crops. The resource-poor marginal farmers of drought-prone regions sow horse gram late in the rainy season as its growing period coincides with the declining rainfall. Under deficit rainfall conditions, horse gram is not an assured crop for grain production but it is a guaranteed crop for production of biomass in *rabi* season (Srinivasarao et al., 2011; Kundu et al., 2013). Venkateshwarlu et al. (2006) confirmed the possibility of on-farm generation of horse gram biomass as they got 3.03-4.28 t fresh weight biomass of horse gram ha^{-1} yr^{-1} with the use of off-season rainfall in a 10-year long-term experiment. Incorporation of biomass for extended periods led to the improvement of organic carbon, microbial biomass (MB) and nutrient content of the soil.

Horticulture Systems

Horticulture systems offer many windows for cover crops. Including cover crops in horticulture system assumes that there will be more benefits than the losses with respect to competition for resources. The soil is covered with vegetation during a relevant part or all year round. Cover cropping has the potential to reduce the erosion losses, increase the SOM, promote nutrient cycling, and improve the functional biodiversity. Cover crops can be managed as green manures or in a similar manner to the natural vegetation where once sown they may self-reseed without supplemental work or cost. Cover crops along with main crop promote plant community diversity through the enhanced productivity, community stability, and nutrient-use efficiency (Tilman, 1996; Tilman et al., 1997, 2001). For example, when a mixture of sorghum-Sudan grass and cowpea is planted following tomato harvest, mixture responds to the residual N levels with N-scavenging by the grass component to prevent winter leaching. Cover crops offer the best option to control weeds in between the main crop rows compared to herbicides, thereby helping in imparting sustainability to the horticulture systems.

Cover crops are highly recommended for orchards of high yield potential where water stress is not a problem. In rainfed horticulture systems established on shallow soils having steep slopes with a great risk of soil erosion, best option is to go in for an early-maturing self-reseeding annual legume cover crop (Rodrigues et al., 2015b). Early-maturing annual legumes improved the N nutritional status of the trees and olive yield over a treatment of natural vegetation fertilized with 60 kg N ha^{-1} (Rodrigues et al., 2015a). Cover crops play a crucial role in promoting nutrient cycling, and improving the nutrition and productivity of trees In rainfed horticulture systems, adoption of cover cropping technology faces a hurdle as it competes for water with the main crop, with latter running a risk of yield reduction. Severity of the problem gets accentuated with increase in aridity. However, cover cropping is still possible in rainfed horticulture systems where it poses little competition for water (Srinivasarao et al., 2015).

Agro-forestry Systems

According to the United Nations Food and Agriculture Organization (FAO), perennial tree crops account for over 10% of the global agriculture production. Under the intensive management of these perennial systems, application of inorganic fertilizers is required to satisfy the high nutrient requirements of these crops. Inclusion of cover crops in perennial and annual cropping systems yields the benefits like protection of soil from erosion, enhanced soil and root health, and cost reduction associated with economy on fertilizers, irrigation, and herbicides usage, etc. In agroforestry system, trees act to improve land cover in addition to providing C inputs (root biomass, litter and prunings) to the soil. Like cover crops, these trees often reduce the soil erosion and facilitate C buildup and sequestration. Most significant increases in C stocks occur in fine-textured soils, where C is better protected through soil aggregation (Ingram and Fernandes, 2001). Potential contributions of cover crops and trees in rehabilitation and maintenance of the soil's physical characteristics such as better bulk density, mechanical resistance and soil aggregation which lead to improvement in systems' productivity have been well established (Alegre and Rao, 1996; Alegre et al., 2005; Rao et al., 1998). Crop production can be improved due to nutrient cycling of litter fall occurring from shallow or deep roots of trees and cover crops (Nair et al., 1999). Alegre et al. (2017) reported that raising butterfly pea (*Centrosema macrocarpum*) legume cover crop in different tree cropping systems reduced the soil compaction up to 20 cm depth, increased the mean total N accumulation up to 232 kg ha^{-1}, and controlled the weeds up to 100% within 3 months. In addition to enriching soil fertility, biomass of this cover crop could be used as a fodder for the animals (Alegre et al., 2017). To diversify the farm products and exploit the benefits tree-crop interactions, perennial crops like coffee or cacao etc. can be mixed with trees such as *Erythrina* spp., *Inga* spp. and *Cordia* spp., etc. (Szott et al., 1991).

Mono-cropped Rainfed Regions

Cultivation of crops along the slope and mono-cropping of finger millet (*Eleusine coracana*) is a common practice in southern dry zone of Karnataka. Little attention was paid to the soil fertility sustenance until recently. Now technology has been developed in which fall ploughing and sowing of horse gram and its subsequent *in situ* incorporation at the pre-flowering stage (40-45 days after sowing) is done. It is followed by sowing of finger millet. Establishment of Nashe grass (*Pennisetum hohenekere*) as live barrier on contours as inter-terrace land treatment constituted the part of this technology. The live barrier of Nashe grass with *in situ* incorporation of horse gram biomass helped in harvesting 2.5 t ha^{-1} grain yield and 3.8 t ha^{-1} straw yield of finger millet; benefit: cost (B:C) ratio under this technology was Rs. 1.95 Re^{-1} against Rs. 1.74 Re^{-1} under farmer's practice. Farmers keep land fallow during *kharif* season in medium to deep black soils in northern dry zone of Karnataka and cultivate sorghum, sunflower and chick pea during *rabi* season. Splash erosion and runoff occurring in *kharif* season leads to loss of topsoil, decline in soil fertility, and decrease in crop yields. Raising quick growing species of cover crops, for example, sunhemp, green gram, cucumber, and ridge gourd in *kharif* which quickly cover the ground surface in 45 days helps in reducing the surface run off, conserving rain water *in situ*. Leguminous cover crops, when incorporated at harvest or during vegetative stage, contribute towards buildup of soil N fertility which benefits the succeeding crop(s). The practice of including cover crops in *kharif* has been found to give yield advantages ranging from 43% to 300% in various crops. Some examples of the benefits accruing from inclusion of different cover crops in crops/ cropping systems are presented in **Table 4**. Horse gram is a successful alternative crop/ cover crop which provides assured grains under delayed rainfall conditions where other crops like maize, cotton, rice and tomato fail during drought years, particularly in rain-dependent conditions of the southern Indian states **(Photo 2).** It provides opportunity to build up soil fertility and organic carbon due to leaf litter and root systems, besides giving some economic produce (grain) and dry

Table 4. Benefits of various cover crop- cropping systems (Source: Srinivasarao et al., 2014)

Cover crop-cropping system	Yield (kg ha^{-1})		Yield increase over conventional practice	B:C ratio
	Kharif crop	*Rabi* crop		
Fallow - Sunflower	-	550	-	0.33
Fallow - *Rabi* Sorghum	-	500		0.30
Cucumber - *Rabi* Sorghum	6,250	1,750	250	5.47
Green gram - Sunflower	400	750	50	0.96
Cucumber - Sunflower	6,250	788	43	7.00
Ridge gourd - *Rabi* sorghum	375	2000	300	1.11
Ridge gourd – Sunflower	1250	1650	200	1.78
Bitter gourd – *Rabi* sorghum	1000	1800	260	2.27

fodder for livestock feed during typical drought years.

Rice Fallows - Legume Cover Crops

Rice is the most important crop during *kharif* season in Eastern India, occupying an area of around 26.8 Mha, which accounts for around 63.3% of total rice average of the country. Out of this area, around 11.7 Mha remains fallow during succeeding winter season due to different limitations. The resource-poor farmers of these regions are not able to meet the expenses of irrigation and fertilizers to produce crop during *rabi* season. Efficient utilization of these fallow lands may improve productivity and sustainability of these regions. Cover crops *viz.* cowpea, horse gram, velvet bean, etc. can be taken up in these fallows.

Limited North East Monsoon Regions

The North-Eastern Hill (NEH) Region of India is one of the most fragile and multifarious ecosystems of the world, comprising of eight states *viz.* Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, Tripura and Sikkim. This region accounts for 3.4% of total cultivable area of the country. Out of 3.5 Mha under rice, only 33% is under double cropping and remaining area remains fallow. There lies an opportunity of practicing cover cropping in these regions for sustaining the productivity.

Maize is the second most important cereal crop of the NEH Region after rice. It is generally grown during *kharif* season in uplands, sloping lands and shifting cultivated in about 0.23 Mha area. Farmers of the NEHR leave their land fallow during the *rabi* season due to negligible and very less rainfall which is not able to support the crop cultivation (Babu et al., 2016). Introduction of cover crop *viz.* cow pea and horse gram is a viable option which would contribute to enhancing soil fertility status and also shield the soil against the erosion losses.

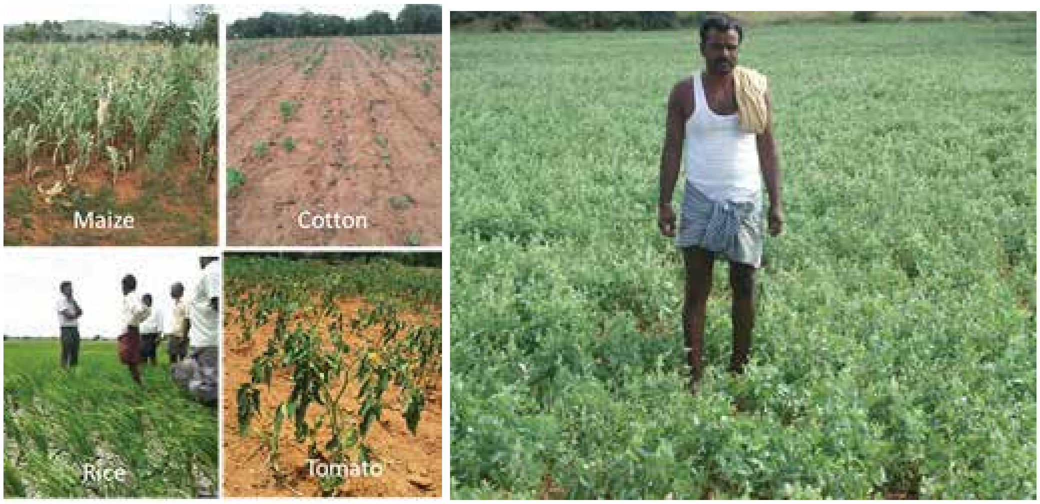

Photo 2. Drought-induced wilted maize, cotton, rice and tomato (left) and successful cover crop of horse gram (right) during 2015 drought year in Southern India

Critical Requirements for Cover Crops Promotion in India

In India, total 1-2 million farmers are estimated to be growing cover crops, while mulching is being practiced by around 5 million farmers (Srinivasarao et al., 2013a,b, c 2014). Also under rainfed conditions, availability of crop residues is very low due to poor biomass production of various crops. Nevertheless, competition between feeding of crop residue to livestock and practicing of the principles of conservation agriculture *viz*., cover crop is a major constraint for promotion of cover crops under rainfed conditions (Srinivasarao et al., 2013a). Generally, in Eastern India under rainfed areas, most of the farmers leave the land fallow or cultivate short duration pulses as a second crop after rice, which act as a cover crop.

Timely Seed Availability and Quality of Seeds

In some areas, demand for seeds of cover crops has pushed up the seed prices. In general, seed growers harvest seed from plant material for the purpose of distribution, storage or sale. In order to produce quality seeds, growers must use carefully regimented techniques to maintain genetic diversity and identity. Genetic purity standards are established by the state seed laws and seed certification agencies to assure growers that the seed they buy is labeled accurately for the crop and variety. Going forward, the quantity and variety of cover crop seed will need to be increased to meet the demand. Once seed is harvested, it must be cleaned and checked for purity and viability. Seed is run through machines to remove chaff and excess plant material, making it easier to sow the seeds through mechanical planters. It reduces the risk of fungal or bacterial infection during storage. As demand for certified cover crop seed grows, the current infrastructure and protocols will not be able to process all the needed cover crop seeds in addition to the commodity and specialty crop seeds they are already processing. Also, farmers need more cleaning facilities within close proximity to their operations so that they will not have to travel long distances.

Technology Transfer and Agro Advisories

Cover crop systems are much more complex than conventional systems. Site-specific knowledge has been the main limitation to the spread of cover crops. Managing these technologies efficiently will be highly demanding in terms of understanding the basic processes and component interactions, which determine the whole system performance. For example, surface-maintained crop residues act as mulch and, therefore, reduce soil water losses through evaporation, and maintain a moderate soil temperature regime (Gupta and Jat, 2010). However, at the same time crop residues offer an easily decomposable source of organic matter and could harbor undesirable pest populations or alter the system ecology in some other way. No-till systems will influence depth of penetration and distribution of the root system which, in turn, will influence water and nutrient uptake and mineral cycling. Thus the need is to recognize conservation agriculture as a system and develop management strategies. A core group of scientists, farmers, extension workers and other stakeholders working in partnership mode will, therefore, be critical in developing and promoting new technologies. While the basic principles which form the foundation of conservation agriculture practices, that is, no tillage and surface managed crop residues are well understood, adoption of these practices under varying farming situations constitutes the key challenge. These challenges relate to the development, standardization and adoption of farm machinery for seeding with minimum soil disturbance, and developing crop harvesting and management systems (Bhan and Behera, 2014).

Conservation agriculture practices, *e.g.* no-tillage and surface maintained crop residues, yield resource improvement only gradually, with benefits accrual taking long-time. Indeed, in many situations, benefits in terms of yield increase may not come in the early years of evaluating the impact of conservation agriculture practices. Understanding the dynamics of changes and interactions among physical, chemical and biological processes is basic to developing the improved soil-water and nutrient management strategies (Abrol and Sangar, 2006; Indoria et al., 2016, 2017a, b). Therefore, research in conservation agriculture must have long-term perspectives.

Awareness and Incentives by Governments

ICAR has been creating awareness among farmers on usefulness of mulch during the droughts or delayed monsoons (ICAR, 2014). Also under the National Policy for Management of Crop Residues (NPMCR), retaining the straw as surface mulch instead of burning is being promoted for *in-situ* management of crop residues (Department of Commerce, 2014). For development of rainfed areas, National Mission for Sustainable Agriculture (NMSA) has been providing 50% assistance of the cost limit to 4000/- per hectare for adopting *in-situ* soil conservation practices like mulching and bunding.

Collaborative Approaches (Researchers, Extension Advisories, Line Departments, NGOs, SHGs, FPOs, Industry, Policy Makers)

Major research institutes, Non-Government Organizations (NGOs)/Civil Society Organizations involved in the research and promotion of cover crops

Table 5. Major Research institutes, NGOs/Civil Society Organizations engaged in R&D on cover-crop technology

S. No.	Research institutes, NGOs/Civil society organizations
Department of Agriculture, & Farmers Welfare	
1.	ICAR - Indian Institute of Farming Systems Research, Modipuram
2.	ICAR - ICAR-National Rice Research Institute
3.	ICAR - Central Research Institute for Dryland Agriculture
4.	ICAR - Central Arid Zone Research Institute
NGOs/Civil Society Organizations	
5.	BAIF Development Research Foundation
6.	PRADAN; Living Farms
7.	Centre for Dignity
8.	Samaj Pragati Sahayog
9.	Jamnalal Kaniram Bajaj Trust
10.	Self-Reliant Initiatives through Joint Action
11.	Samuhik Vikas Sansthan
12.	Nature Institute for Welfare of Society
13.	Jeevit Mati Kisan Samiti, Kedia
14.	Center for Sustainability Policy and Technology Management

are listed in **Table 5**.

Way Forward

- Pulses/green manure crops are the most suitable cover crops after the cultivation of nutrient exhausting cereal crops. It is desirable to promote the raising of cover crops to arrest the deteriorating soil health.
- Mulching practices should be promoted under rainfed areas, as these could cause 50-60% increase in the yields of different crops.
- There is a need to develop specific policies for bringing in more area under cover crops in rainfed/irrigated ecologies.
- There is a need for having farmer's participatory on-farm research to evaluate/refine the cover-crop technology in the initial years. Large scale demonstrations in the subsequent years should be held to validate these technologies.
- Dearth of the availability of trained persons at ground level is one of the major limiting factors in adoption of the cover crop technology. There is a strong need to increase the capacity building by organizing extensive trainings on practicing cover crops.
- Lack of timely availability of quality seeds of cover crops is the major constraint. Assured availability of quality seeds will go a long way in successful adoption of this technology.
- Subsidy may be provided as an incentive to cover crops growing farmers for popularizing the practice, especially to the cash-constrained farmers.
- There is a need to identify the best suitable cover crops based on the experience of existing weed infestation, plant diseases, pests and nematodes, and other biotic and abiotic problems or else the cover crop may increase the occurrence of a disease in the subsequent crop if it happens to be a host for the organism that causes the disease.

Conclusions

Cover crops offer a new paradigm for agricultural research and development. It differs from the conventional agriculture in that it offers an opportunity to arrest and reverse the downward spiral of resource degradation, improve the factor productivity, decrease the cultivation costs, and make agriculture more resource use efficient, competitive and sustainable with aim of achieving specific food grains production targets in the country. Cover crop reduces the impact of rain drops on the soil surface, thereby minimizing the breakdown of soil aggregates. This greatly minimizes soil erosion and runoff, and improves water infiltration. Decreased soil loss and runoff translates in to a reduced export of valuable nutrients, pesticides, herbicides, and harmful pathogens associated with manure from farmland which would otherwise degrade the quality of streams, rivers and water bodies and pose a threat to human health. Promoting cover crops for LDN systems will be highly demanding in terms of the knowledge base. This calls on the scientists to address problems from a system's perspective and work in close partnerships with farmers and other stakeholders to strengthen the knowledge and information-sharing mechanisms.

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