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Review Article

The effectiveness of Rhizobium bacteria on soil fertility and sustainable crop production under cover and catch crops management and green manuring

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Abstract

The ability of adaptation of Rhizobia in diverse environment namely, soil, rhizosphere and grown within legume roots may lead to nitrogen fixation, in a complicated process which contain a coordinated exchange of signal between plants and the symbionts. Green manures, cash and cover crops have significant role in soil fertility. Green manuring techniques also can decrease biomass burning known as main source of air pollutant in the atmosphere. Catch crops have positive effects on both physical and chemical properties of soil, subsequent crop yield, decrease nitrogen leaching into the ground water, decrease soil erosion, and decrease nitrogen losses in cropping systems. Cover crops are those crops which cover the ground and protect loss of plant nutrients, the soil from erosion, decrease rate of soil moisture by evaporation, lower ground temperature and improve weed control and nutrient recycling. Rhizobia produce Nod factors during the early development of nodules upon perception of flavonoid molecules secreted by legume roots, and Nod factor's structure dependents on species, chemical, substitutions added which may influence legume specificity. The benefic effects of rhizobia may depend on rhizobium strain, the genotype of the legume, management practices and bio-physical environment. Rhizobium can directly promote both plant growth and plant health, and modulating root architecture and growth via the release of plant phytohormones. In this manuscript, we want to review the most important advantages and benefits of green manures, catch and cover crops with considering the positive effects of rhizobium on soil fertility and sustainable agricultural production.

Keywords: catch crops; crop nutrition; cover crops; green manure; Rhizobium; soil fertility

Introduction

Fertility system

Appropriate farm management methods for smallholders in all countries, especially developing countries are important (Soleymani *et al.*, 2016; Abdollahi *et al.*, 2018; Khoshkharam *et al.*, 2019; Shahrajabian *et al.*, 2020; Sun *et al.*, 2019, 2020). The most important parameters which are considered as main parameters to ensure productivity of smallholder production systems are crop production, soil fertility, soil surface and run off (Stopes *et al.*, 1996; Dorward *et al.*, 2003; Hartkamp *et al.*, 2004; Soleymani *et al.*, 2012; Yang *et al.*, 2017;

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Ogjabi *et al.*, 2018a, b; Novara *et al.*, 2019). Soil fertility status characterized by soil organic carbon, available nitrogen, phosphorus and potassium percentage (Rahman and Parkinson, 2007; Tittonell *et al.*, 2010; Batista *et al.*, 2016; Yang *et al.*, 2018). As low soil fertility is the main constraints which may influence agricultural production, considering soil fertility as alternation to all aspects of the natural environment is increasing (Mokwunye *et al.*, 1996; Sanchez *et al.*, 1997; Swift and Shepherd, 2007; Saikia *et al.*, 2019). Both soil quality and health may have significant influence on fauna abundance and diversity (Garbeva *et al.*, 2004; Muturi *et al.*, 2011), and soil fauna is an important part of soil quality (Ponge *et al.*, 2003). Soil faun which is a part of Eucaryota is divided into macrofauna, mesofauna, and microfauna (Giller *et al.*, 1997). Moreover, soil biota plays a positive role to ecosystem processes, especially by controlling both soil quality and health (Brussaard *et al.*, 1997; Swift and Bignell, 2000; Wall, 2004; Kibblewhite *et al.*, 2008). It has been reported proper organic matter management seems to be the most important practice which reduce the potentially negative effects of agricultural activities (Valarini *et al.*, 2002; Liu *et al.*, 2006; Melero *et al.*, 2006; Constantin *et al.*, 2010; Diacono and Montemurro, 2010), and it is the appropriate way for excessive nutrient application and losses (Stopes *et al.*, 2002). Soil erosion may influence both distribution of sediments and associated Carbon within the hillslope (Ritchie and McCarty, 2003; Zhang*et al.*, 2006; Nadeu*et al.*, 2012; Almagro and Martinez-Mena, 2014), and also litter decomposition dynamics via various abiotic and biotic mechanisms (Throop and Archer, 2009; Barnes *et al.*, 2012; Berhe, 2012; Hewins *et al.*, 2013; Lee *et al.*, 2014). Soil fertility is a basic to the productivity and sustainability of faming in agricultural fields. The management of soil fertility depends on integration of crops as supply of crop residues, livestock for drug, and the forest as a source of fodder and leaf litter. Key factors for soil fertility and productivity are shown in Table 1. In this review article, we want to focus on importance of green manure, cover crops and catch crops in sustainable production with increase soil fertility and productivity.

Table 1. Key factors for soil fertility and productivity

1-	Improve soil structure, water-holding capacity, aeration and drainage.
2-	High biomass crops as green manure and cover crops may increase the organic matter remaining in the soil for soil microbial and macrofaunal populations.
3-	Provide enough nitrogen for the agricultural systems.
4-	Control and decrease both weed, pest and disease life cycles in crop rotations.
5-	Keep soil cover to protect soil erosion and leaching.
6-	Decrease losses of nutrients in the system, and soil organic matter levels are enhanced or maintained.

Rhizobium

Nodule-forming bacteria is divided into two genera, 1) the alpha-proteobacterial genera which are *Agrobacterium*, *Azorhizobium*, *Allorhizobium*, *Bradyrahizobium*, *Mesorhizobium*, *Sinorhizobium*, *Rhizobium*, *Methylobacterium*, *Devosia*, *Ochrobactrum* and *Phyllobacterium*, and 2) the beta-proteobacterial genera which are *Burkholderia* and *Cupriavidus* (Shahrajabian *et al.*, 2021). The most important *Rhizobium* species and their corresponding hosts are *Bradyrhizobium japanicum* for soybean (*Glycine max*), *Rhizobium fredii* for soybean (*Glycine max*), *Rhizobium phaseoli* for common bean (*Phaseolus vulgaris*), *Rhizobium leguminosarum* bv. trifolii for clovers (*Trifolium* sp.), *Rhizobium leguminosarum* for peas (*Pisum sativum*) and broad bean (*Vicia faba*), *Rhizobium* sp. or cowpea *rhizobia* group for cow pea (*Vigna unguiculata*), peanut (*Arachis hypogaea*), Bambara groundnut (*Vigna subterranean*).The metabolic diversity of *rhizobia* on the basis of their large, complex genomes are *Rhizobiumetli* (6.5 Mb), *Sinorhizobium meliloti* (6.7 Mb), *Mesorhizobium loti* (7.6 Mb) (Kaneko *et al.*, 2000), *Rhizobium leguminosarum* (7.8 Mb), and *Bradyrhizobium japonicum* (9.1 Mb) (Kaneko *et al.*, 2002). Rhizobial modulation symbioses consists of flavonoid signaling, Nod factor induction and perception, root hair responses which included calcium flux and spiking, gene expression, rhizobial infection, cell division and nitrogen-fixing nodule formation (Khoshkharam *et al.*, 2021; Shahrajabian *et al.*, 2021). Rhizobium are not just the most important group of nitrogen fixing soil bacteria (Werner, 2007), but also improves sustainable production by boosting organic nitrogen content (Karoney *et al.*, 2020). Notable parameters which have been related to successful establishment of the symbiotic interaction are chemotaxis of the bacteria towards the roots, root colonization and its hair deformation, infection thread formation, and rapid division or root cortex cells (Junier *et al.*, 2014; Wang *et al.*, 2016). Nitrogen fixation and legumes yields depend on the rhizobium strain, the genotype of the legume, bio-physical environment, and management practices (Wolde-meskel *et al.*, 2018; Flores-Felix *et al.*, 2019).

It has been reported that nodulation and growth of field pea would be highly improved by inoculation of rhizobia isolated from homologous host plants (faba bean and lenti) and its roots system (Argaw and Mnalku, 2017; Roberts *et al.*, 2017). Inoculated soils with specific strains of rhizobia may increase potential biological nitrogen fixation in legumes, but the efficacy of these rhizobia in promoting biological nitrogen fixation may be limited by competition from resident rhizobia already present in soils (Roper *et al.*, 2020; Mahmud *et al.*, 2021). *Rhizobium* inoculation (RI) and melatonin (MT) pretreatment increased cold-stress tolerance capacity, and it can maintain better root activity and nutrients uptake under stress (Irshad *et al.*, 2021). Rhizobial inoculation offers a cheap and highly effective means for the sustainable intensification of smallholder agriculture (Wolde-meskel *et al.*, 2018), and enhancing nodulation may require further development of specific inoculants (Thapa *et al.*, 2018; MacMillan *et al.*, 2021). *Rhizobium rhizogenes* mediated root proliferation system can be used for optimizing metal extraction from contaminated soils (Sahito *et al.*, 2022). Ju *et al.* (2019, 2020) also reported that co-inoculation can increase soil nutrients and reduce environmental risks. Exogenous NO and H_2S enhanced the metal resistance of legume-rhizobium symbiosis (Fang *et al.*, 2020). Inoculation with arbuscular mycorrhizal (AM) fungi and rhizobia increased *Phaseolus vulgaris* growth, and dual inoculation had a synergistic effect on nodule number and mycorrhizal rate; moreover, use of native strains is particularly effective in a low-fertility tropical soil (Razakatiana *et al.*, 2020). Dual inoculation with *Rhizobium* and AMF biofertilizer is more effective for promoting growth of faba bean grown in alkaline soils than the individual treatment, reflecting the existence of synergistic relationships among the inoculants (Abd-Alla *et al.*, 2014). The *Rhizobium*-inoculated maize/faba bean intercropping on the reclaimed desert soil with a moderate fertilizer N application rate enhanced productivity, biological N_2 fixation and apparent N recover with lower environmental risk (Mei *et al.*, 2021). *Rhizobium* strains tolerant to Cd may potentiate plant growth at contaminated sites, and soil inoculation with tolerant *Rhizobium* strains may assist phytoremediation (Cardoso *et al.*, 2018; Nunes *et al.*, 2018). There is a relationship between *Rhizobium*'s tolerance, heavy metal soil contamination and alterations in protein pool, as a result, the analysis of protein alterations seem to be a good indicator to estimate the level of stress imposed on *Rhizobium* populations submitted to heavy-metal contamination (Pereira *et al.*, 2006).

Green manure

Green manures application has a long history (Khoshkharam *et al.*, 2010; Shahrajabian *et al.*, 2011; Soleymani *et al.*, 2011a, b, c). The positive influence of green manure on soil enzymatic activity has reported (Soleymani and Shahrajabian *et al.*, 2012a, b; Yang *et al.*, 2003; Jodaugiene *et al.*, 2010; Li *et al.*, 2018; Dai *et al.*, 2019; Adusumilli *et al.*, 2020). Mineral N may lead to changes in the composition of the soil microbial community and enzyme production (Burns, 1978; Elfstrand *et al.*, 2007; Iyyemperumal and Shi, 2008; Thorburn *et al.*, 2012; Lazcano *et al.*, 2013) or have indirect influence on the soil enzymes activities via changes in soil properties (Gianfreda and Ruggiero, 2006). Chen *et al.* (2019) also indicated that the green manure amendment may improve soil detritus micro-food web, and Puig *et al.* (2019) showed the importance of green manure for example *E. globules* in weed control as a feasible and environmentally friendly practice. The most important reasons for burning crop residues are clearing the land for upcoming cultivation, control of weeds and also providing nutrients for the next crop cycle (Dennis *et al.*, 2002; Huang *et al.*, 2012; Irfan *et al.*, 2014; Azhar *et al.*, 2019). Unlike green manuring, biomass burning known as main source of air pollutant in the atmosphere (Andreae and Merlet, 2001; Streets *et al.*, 2003; Hays *et al.*, 2005; Wuest*et al.*, 2005; Hagler *et al.*, 2006; Zheng *et al.*, 2011; Qin and Xie, 2011; Bond *et al.*, 2013; Ho *et al.*, 2016; Niu *et al.*, 2017; Chuang *et al.*, 2019). This pollution from biomass burning has been related to negative human health impacts (Awasthi *et al.*, 2010; Singh *et al.*, 2010; Rappold *et al.*, 2011; Liu *et al.*, 2015; Liu *et al.*, 2016; Reid *et al.*, 2016; Sirithian *et al.*, 2018; Zhou *et al.*, 2018; Tipayarom and Oahn, 2020). Traditionally, application of green manures to rice fields has been reported (Lee *et al.*, 2010; Gao *et al.*, 2013; Zhang *et al.*, 2017). Pollution in many Chinese cities are also related to open field burning of crop residues (Qiu *et al.*, 2014; Zhang *et al.*, 2016; Ni *et al.*, 2017; Hou *et al.*, 2019; Yin *et al.*, 2019). In China, open field burning of agricultural crop residue specially in summer harvest has been reported (Huang *et al.*, 2013; Li *et al.*, 2010a, b; Cheng *et al.*, 2014; He *et al.*, 2015; Dabin *et al.*, 2016), which has contributed to both high PM2.5 concentrations (Zhang *et al.*, 2010; Huang *et al.*, 2014). Wang *et al.* (2018) also discovered that biomass open burning in China, is the major distribution of biomass greenhouse gases emission. April, June and October are peak of emissions in regions located in the eastern China, central and northeastern China (Chen and Xie, 2014; Zhang *et al.*, 2017; Zhang *et al.*, 2019). China has a 3000 years history of using green manure to boost the yield of crops and improve soil fertility (Yang *et al.*, 2012; Zhang *et al.*, 2016). Biomass burning emissions, consist of carbon dioxide (CO_2), carbon monoxide (CO), elemental carbon (EC), organic carbon) (OC), particular matter (PM), and others (Jenkins *et al.*, 1992; Andreae and Merlet, 2001; Awasthi *et al.*, 2011; Huang *et al.*, 2014; Jain *et al.*, 2014; Ni *et al.*, 2015), and it may have local and regional impacts for weeks to months (Sanderfoot and Holloway, 2017; Lasko and Vadrevu, 2018; Yu *et al.*, 2019). Liang *et al.* (2020) noticed that biomass burning has an important role in regulating chemical properties of aerosols for carbonaceous components in East China. Crop residue open burning may release toxic air pollutants, such as particulate matter with black and organic carbon components, carbon monoxide and volatile organic compounds, also certain amounts of nitrogen oxides and sulfur oxides along with major greenhouse gases like methane, nitrous oxide and carbon oxide (Ma *et al.*, 2018; Oanh *et al.*, 2018; Yin *et al.*, 2019). Crop residue retention also led to improving soil functioning (Vanlauwe *et al.*, 2001; Giller *et al.*, 2009; Paul *et al.*, 2013; Pittelkow *et al.*, 2015; Murphy *et al.*, 2016). Green manuring can enhance soil microbial and enzyme activity, bacterial richness and diversity (Caban*et al.*, 2018). Forage and grain legumes as green manures can provide significant amount of nitrogen, reduce nitrate leaching and optimizing ecosystem services (Peoples *et al.*, 2009; Rasmussen *et al.*, 2012; Preissel *et al.*, 2015; Tribouillois *et al.*, 2016; Couedel *et al.*, 2018; De Notaris *et al.*, 2018; McKenna *et al.*, 2018; De Notaris *et al.*, 2019). Emissions of pollutants change according to type of agricultural residue, seasons and meteorology (Kaskaoutis *et al.*, 2014; Sen *et al.*, 2017; Ravindra *et al.*, 2019). Biomass burning could significantly affect tropospheric ozone variations in various regions (Trentmann *et al.*, 2005; Verma *et al.*, 2009; Toh *et al.*, 2013; Sarangi *et al.*, 2014; Alvarado *et al.*, 2015; Yadav *et al.*, 2017), and lead to climate change (Lal, 2004; Sahai *et al.*, 2007; Huang *et al.*, 2013; Zhang *et al.*, 2017). It has been reported that green manuring also can decrease the need for synthetic pesticides (Matthiessen and Kirkegaard, 2006; Bjarnholt *et al.*, 2008). Stark *et al.* (2007) discovered that application of green manure may boost the microbial biomass and activity. Bai *et al.* (2015) revealed the importance of integrated application of green manure and chemical fertilizer management for increasing maize yield and nitrogen use efficiency at the same time. Hou *et al.* (2015) observed that wheat straw retained in the agricultural field has more positive influence on soil fertility and rice quality than rice straw. Dalal *et al.* (2011) found that the impacts of crop residue retention and nitrogen fertilizer did not continually boost soil organic carbon (SOC) and total soil nitrogen with increasing period of conservation practices. Gao *et al.* (2018) indicated the increased in the degree of aromaticity, humification and average molecular weight of dissolved organic matter (DOM) in long-term planting of milk vetch and rape as green manures. Pu *et al.* (2019) also stated that the combination between residue retention and no-tillage has the highest advantage in increasing soil organic carbon (SOC) and total nitrogen (TN) in the North China Plain region, as both soil organic carbon and total nitrogen plan a vital role in keeping agroecosystem functions and productivity (Sparling *et al.*, 2006; Blanco-Canqui and Lal, 2009; Sugino *et al.*, 2013; Ghimire *et al.*, 2017).Growing both legumes and non-legume as green manure crops can decrease nitrate leaching (Moller and Reents, 2009; Askegaard *et al.*, 2011; Tosti *et al.*, 2014; Couedel *et al.*, 2018; Yao *et al.*, 2018); because nitrate leaching is directly correlated with surplus nitrogen in the soil (Chen *et al.*, 2014; Zhou *et al.*, 2016; Gao *et al.*, 2017). Djian-Caporalino *et al.* (2019) suggested the efficient usage of sorghum as a green manure in suppressing nematodes. Other researches also showed the influence of cover crops to improve productivity of subsequent crops by lowering the un-wanted pressure of pests and pathogens (Gomes Carneiro, 1982; McSorley, 2001; Djian-Caporalino *et al.* 2005; Ratnadass *et al.*, 2012; Kruger *et al.*, 2013; Curto *et al.*, 2015). Gao *et al.* (2015) observed key effects of green manure on both biogeochemical cycle and microbial communities. Zhang *et al.* (2019) found cultivation of summer legumes as green manures is better choice compare to bare fallow for dryland regions. Santos *et al.* (2018) confirmed the positive effects of green manure on Brazilian melon production which ensure yield without applying synthetic nitrogen fertilizer. The negative impacts of green manuring systems are increase in weed and pest pressure, increase nitrogen loss because of poor synchrony, and loss of cash crop when under sowing green manures.

Catch crops

Catch crops have positive effects on both physical and chemical properties of soil, subsequent crop yields, limit nitrogen leaching into the ground water, decrease soil erosion, and decrease nitrogen losses in cropping systems (Thorup-Kristensen, 1994; Vos and van der Putten, 1997; Lupwayi and Haque, 1998; Wilczewski, 2004; Berntsen *et al.*, 2006; Eichler-Lobermann*et al.*, 2008; Kosteckas and Marcinkeviciene, 2009; Constantin *et al.*, 2010). In some researches, catch crops have been found more effective in capturing excess nutrients compare to reduce tillage and N inputs management (Thorup-Kristensen *et al.*, 2003; Constantin *et al.*, 2010). Piotrowska and Wilczewski (2012) found that application of catch crops as green manures may increase soil enzyme activity, because rate of nitrogen mineral fertilization applied along with green manure influence soil enzymes. Catch crops can be used in the rotation with other crops, such as seeded after main crop harvest to capture excess nutrients in conventional systems, or planted after animal manure application, but it is not common to cultivate after green manures (Olesen *et al.*, 2007; Herrera *et al.*, 2010; Olesen *et al.*, 2000; Cicek *et al.*, 2014; Cicek *et al.*, 2015). Zhou *et al.* (2020) suggested that mixture of green manure and rice straw has positive influence on increasing soil fertility and rice yields. Gruter *et al.* (2017) revealed the positive influence of green manuring with organic matters on increase soil Zn and Cd concentrations. Decrease in N leaching in conventional (40-50%), and organic system (30-38%) have been reported by catch crops (Aronsson and Torstensson, 1998; Askeggard *et al.*, 2005). Important parameters which influence selection of catch crops are speed of establishment, growth rate, rooting depth, cold tolerance, lignin and nitrogen content, synchrony of nitrogen mineralization from cash crop demand (Ranells and Wagger, 1997; Thorup-Kristensen *et al.*, 2003; Crews and Peoples, 2005; Tonitto *et al.*, 2006; Constantin *et al.*, 2011; Munkholm and Hansen, 2012). Grasses such as barley (*Hordeum vulgare*) and Brassicas such as oilseed radish (*Raphanus sativus*) have high rapid nitrogen uptake and consider as appropriate crops as catch crops (Thorup-Kristensen *et al.*, 2003). The undesired impacts of catch crops are immobilization of nitrogen during cover crop decomposition, pre-emptive competition by cover crop which occurred because of increase nitrogen fertilizer requirements.

Cover crops

Cover crops are those crops which cover the ground and protect loss of plant nutrients, the soil from erosion (Reeves, 1994; de Figueiredo *et al.*, 2015; Kim *et al.*, 2015; Teague *et al.*, 2019), decrease rate of soil moisture by evaporation (Carvalho *et al.*, 2017; de Oliveira *et al.*, 2019), lower ground temperature (Derpsch *et al.*, 2014) and improve weed control and nutrient recycling (Alvarez *et al.*, 2017; Wendling *et al.*, 2019). Cover crops may lead to other desired and undesired impacts in agroecosystems. White mustard and white clover are suggested cover crops for integrated pest management for weed control and prevention of Fusarium head blight (Kadziene *et al.*, 2020). The most important parameters to optimize the benefits of cover cropping are soil type, climate, cover crop species and tillage practices (Kahimba *et al.*, 2008; Siczek and Lipiec, 2011; Turmel *et al.*, 2015; Daryanto *et al.*, 2018). Cover crops not only control pest insects (Bottenberg *et al.*, 1997; Liang and Huang, 1994; Tillman *et al.*, 2004), and reduce insecticide inputs (Burgio*et al.*, 2016; Vogelweight and Thiery, 2017; Dong *et al.*, 2018; Gomez *et al.*, 2018; Bowers *et al.*, 2020), but also provide floral resources for native bees (Ellis and Barbercheck, 2015), increase reptile abundance (Carpio *et al.*, 2017), and benefits birds (Castro-Caro *et al.*, 2014, 2015), and benefits some birds populations (Wilcoxen *et al.*, 2018). Increase organic matter in soils under residue management practices such as cover crops may lead to increase microbial activity which results in increase degradation of pathogens and control diseases (Hoitinik *et al.*, 1997; Bockus and Shroyer, 1998; Bailey and Lazarovits, 2003; Wiggins and Kinkel, 2005; Janusauskaite and Ciuberkis, 2010). The deep-rooted cover crops have tremendous benefits such as reducing N losses and increasing Nitrogen Use Efficiency (NUE) in farming systems (Soratto *et al.*, 2011; Rosolem *et al.*, 2018; Shelton *et al.*, 2018; Walmsley *et al.*, 2018; Rocha *et al.*, 2020), while Chen *et al.* (2019) reported that biological indicators of soil health are more sensitive than C and N stocks to residue management. Most reported cover crop species are from *Fabaceae* (legumes; bean family), the *Brassicaceae* (cabbage family), and the *Poaceae* (grasses) (Zahran, 1999; Turk and Tawaha, 2003; Maltais-Landry, 2015; Tribouillois *et al.*, 2015; Elhakeen *et al.*, 2019). Cover crops boost aboveground biodiversity (Balota *et al.*, 2014; Calderon *et al.*, 2016), and also legume species provide considerable nitrogen (Mazzoncini *et al.*, 2011; Kramberger *et al.*, 2014; Verzeaux *et al.*, 2016; Guzman *et al.*, 2019). Diversity in cover crops management may lead to higher stability in biomass production (Yachi and Loreau, 1999; Tilman *et al.*, 2006; Haughey *et al.*, 2018). The type of cover crop used depends on the final goals, which can be grass, brassica or legumes. No-till, reduced and minimum tillage also can increase bird abundance, greater nest density and success, and increase the number of productive territories (Basore *et al.*, 1986; Duebbert and Kantrud, 1987; Higgins, 1977; Flickinger and Pendleton, 1994; Fiener and Auerswald, 2003; Martin and Forsyth, 2003; VanBeek *et al.*, 2014). Wendling *et al.* (2019) concluded that when growing cover crops, mixtures with high species diversity increase chance of stable and higher biomass production. In crop rotation cover crops lead to increase the spatial and temporal plant diversity in agroecosystems (Bukovsky-Reyes *et al.*, 2019). A grass may prevent soil erosion, add nitrogen and organic matter and control weeds, while a brassica may reduce soil compaction, control nematodes, weeds, prevent soil erosion and provide nutrients for following cultivation. Roots of cover crops may alleviate soil compaction by bio-drilling which is known as environment-friendly solution (Chen and Weil, 2010; Chen and Weil, 2011; Ren *et al.*, 2019). Brennan and Acosta-Martinez (2017) also found that carbon inputs from cover cropping are the main driver of changes in the soil food web and soil health in agricultural systems. Snapp and Surapur (2018) found that a rye cover crop had not significant influence on soil carbon, but managed nitrogen and increased sustainable production. Many researches have been reported about positive influence of cover crops in no tillage conditions (Mitchell *et al.*, 2007; Villamil *et al.*, 2006; Mitchell *et al.*, 2015; Pantoja *et al.*, 2015). Singh *et al.* (2018) noticed that both soil aggregation and biological health positively affected by residue retention under rainfed conditions even in a short-term adoption. Mitchell *et al.* (2017) indicated that usage of no-tillage and cover cropping may benefit soil health by improving biological, chemical and physical indicators of soil functions. Environmental conditions and cover crop duration are responsible for potential effects of cover crop on cash crop sowing date (Quiroga *et al.* 2005; Verburg *et al.*, 2012; Pinto *et al.*, 2017). The positive influence of cover crops in grapevine vegetative growth, yield, berry, wine quality and reduce pest development have been reported (Monteiro and Lopes, 2007; Guerra and Steenwerth, 2012; Mercenaro *et al.*, 2014; Muscas *et al.*, 2017). The use of cover crops is considered as an organic farming technique to manage fallow fields in sustainable ways (Lawley *et al.*, 2011; Zhu *et al.*, 2012; Zhou *et al.*, 2016; Tang *et al.*, 2017; Randrianjafizanaka *et al.*, 2018). Cover crops and residue are notable sources of dissolved reactive phosphorus to run off (Sharpley and Smith, 1989; Ulen *et al.*, 2010; Lozier *et al.*, 2017; Cates *et al.*, 2019). It has reported rye as a winter crop has great ability to weed control as an annual cover crop because of its aggressive growth pattern (Teasdale *et al.*, 1991; Snapp *et al.*, 2005; Blackshaw, 2008; Flood and Entz, 2009; Teasdale *et al.*, 2012; Evans *et al.*, 2016). Increase in water infiltration rate and field saturated hydraulic conductivity because of application of cover crops has been reported (Nouri *et al.*, 2019). Winter cover crops such as the milk vetch (*Astragalus sinicus*), and the ryegrass (*Lolium* spp.), are famous winter cover crops because of high nutritional value and form high-quality pastures (Chen *et al.*, 2012; Tang *et al.*, 2014; Xie *et al.*, 2018). Some cover crops may exude allelochemicals which suppress crops pests and soil-borne diseases, and also cause avoidance behaviors by earthworms (Stroud *et al.*, 2017). Yang *et al.* (2019) indicated that increased in crops WUE, and decrease deep percolation is because of wheat cover crop to summer crops rotation. Hwang *et al.* (2015) found that mixture of legume hairy vetch and non-legume barley can increase nutrient productivity compare to sole usages of them. Jahanzad *et al.* (2017) concluded that application of forage radish and winter pea are better alternatives to rye because they lead to less nitrogen fertilizer application, sustained potato tuber yield and mineral concentration. The positive impacts of cover crops on potato production have been reported in former researches (Rosen and Bierman, 2008; Essah *et al.*, 2012; Buysens *et al.*, 2016). Some important barriers of considering cover crops are the lack of robust scientific results on the net effect of cover crops and cost (Daryanto *et al.*, 2018; Daryanto *et al.*, 2019). Cover crops categorized into legumes, non-legumes and mixture of both have been indicated in Table 2.

Table 2. Cover crops categorize to legumes, non-legumes and mixtures

Cover crop	Main advantages
Legumes	Great ability to fix, accumulate and supply large amount of nitrogen (Peoples *et al.*, 1995; Caporali, 2004; Ghaley *et al.*, 2005; Kim *et al.*, 2007; Na *et al.*, 2007; Campiglia *et al.*, 2010), they can also used as successful tool to control weeds (Pilipavicius *et al.*, 2010; Arlauskiene *et al.*, 2011; Masilionyte and Maiksteniene, 2016; Velicka *et al.*, 2016).
Non-Legumes	Prevent soil erosion, trap nutrients, reduce nutrient leaching losses, and increase the soil organic carbon stock (Vos and van der Putten, 2001; Lee *et al.*, 2010; Jeon *et al.*, 2013; Poeplau *et al.*, 2015; Fiorini *et al.*, 2020)
Legumes-non legumes	It is an efficient technique to merge the advantages of the single species in the cover crop practice to achieve both environmental and agronomic benefits; it may lead to a radical modification of the biochemical composition into the soil (Ranells and Wagger, 1997; Crew and Peoples, 2005; Tosti *et al.*, 2010). The intercropping of legumes and non legume led to facilitative interactions (Ofori and Stern, 1987; Jensen, 1996; Hauggaard-Nielsen and Jensen, 2005; Fan *et al.*, 2006). The adoption of mixtures also can improve the nitrogen use efficiency (Tosti *et al.*, 2012). They can enhance soil C and No storage and improve both soil health and environmental quality (Muhammad *et al.*, 2019).

It has suggested that leguminous green manure convert into biochar as an alternative method to maintain or increase soil organic carbon, soil fertility and crop yields (Chan *et al.*, 2008; Kimetu *et al.*, 2008; Major *et al.*, 2010; Van Zwieten *et al.*, 2010; Chen *et al.*, 2014). Prechsel *et al.* (2017) found that cultivation of cover crops with application of reduced tillage has the potential to minimize aquatic eutrophication. Roth *et* *al*. (2018) mentioned the importance of estimating cover crops residue N content to estimate N cycling benefits of cover crops. The C/N ration of cover crop residue is a key parameter which impact residue decomposition (Aulakh*et al*., 2001; Zhang*et al*., 2008; Lynch *et al*., 2016); Cover residues with higher nitrogen concentration or lower C/N ratio decompose rapidly (Fosu *et al*., 2007; Abera *et al*., 2014), and also, they may have higher global green house gas (GHC) emissions (Gentile *et al*., 2008; Kallenbach *et al*., 2010; Guardia *et al*., 2016). Increase in contact with soil microorganisms can decompose residues faster (Farahbakhshazad *et al*., 2008; Ladoni *et al*., 2015; Wickings *et al*., 2016; Lynch *et al*., 2016). Legume cover crops can maintain a low tissue C:N, but grass cover crops tend to have a tissue C:N ration which may increase with plant maturity (Greenwood *et al*., 1990), and N supply dependent on the timing of cover crop termination (Clark *et al*., 1994; Clark *et al*., 2007a; Vaughan and Evanylo, 1998) which is lower than that from legumes (Miguez and Bollero, 2005). Application of oat as cover crops can increase polyphenol content in olive leaves (Chehab *et al*., 2018). The most important advantages of cover crops are presented in Table 3. The most important benefits of green manure and cover crops are shown in Table 4. The advantages of incorporating cover crops into summer crop rotations in connection with soil water relations are indicated in Table 5.

Table 3. The most important advantages of cover crops

Cover cropping	Conditions and Benefits	Reference
Vineyard cover cropping	It is used in winegrowing regions, mainly in areas with summer rainfall with irrigation. Decrease sensitivity to diseases such as grey mould (*Botrytis cinerea* Pers.), and powdery mildew (*Eryisphenecator* [Schw.] Burr.) which may lead to reduction of fungicide. The reduction of grapevine growth and yield due to cover cropping has been shown to increase with the level of soil coverage by a permanent cover crop. Cover crop may affect inflorescence formation and bunch number per vine and yields in the following year, and it is an effective technique to reduce the use of herbicides and fossil fuels.	Gaudel (2002) Morlat and Jacquet (2003) Monteiro and Lopez (2007) Tesic *et al.* (2007) Jacometti *et al.* (2010) Ripoche *et al.* (2011) Valdes-Gomez *et al.* (2011) Giese *et al.* (2014) Guilpart *et al.* (2014) Frey (2016) Delpuech and Metay (2018) Marques *et al.* (2018)
Maize-cover cropping	Cover crops showed 30 to 70% reductions in nitrate concentration, and 10 to 60% reductions in water runoff. Small grains can be the only viable option to establish a fall-seeded cover crop that may withstand the long winters and resumes growth in spring. Long-term contribution of cover crops can improve soil and water quality. Farms which integrate crop and livestock operations can take advantage of the additional forage supplied by a fall-seeded cover crop. Cover crops can effectively benefit maize system performance in row-crop systems. Cover crops between two crops can control weeds and may decrease the need to use herbicides.	Teasdale and Mohler (2000) Kasper *et al.* (2001) Brust *et al.* (2014) Kladivko *et al.* (2014) Arbuckle and Roesch-McNally (2015) Bergtold *et al.* (2017) Alonso-Ayuso *et al.* (2018) Marcillo *et al.* (2019)
Grass-legume cover crop	Grass: legume cover crop mixtures with subsurface banded poultry litter can lower N_2O emissions compared to legume monoculture. As with cover crops, N_2O emissions following manure applications are influenced by manure	Motavalli *et al.* (1989) Munoz *et al.* (2004) Almagro and Martinez-Mena (2014) Garcia-Franco *et al.* (2015) Yao *et al.* (2017)

	chemical composition, timing, and placement and their interactions with weather and soil type. Leguminous Green Manure-Based cropping systems can be replaced summer fallow and it can be a useful alternative way to improve soil fertility and promote sustainable crop production. Legume green manure instead of summer fallow is significantly effective measure for persistent reducing the carbon footprint (CF) reduction.	Davis *et al.* (2019) Yao *et al.* (2019)
Bicultures of grass and legume cover crops	It is able to reduce NO_3^- leaching to similar levels as grass monocultures. It is often less than nitrogen supply from a legume monoculture. This method can increase the overall level and diversity of services provided by a cover crop. In grass-legume cover crop bi-cultures, the grass component can dilute the N content and increase the C:N ration of the mixture, reducing the N supply potential relative to a legume monoculture. In this method, the seeding rate of the grass species is important which can impact the N content and C:N ration of the mixture.	Ranells and Wagger (1997) Clark *et al.* (1994) Creamer *et al.* (1997) Miguez and Bollero (2005) Clark *et al.* (2007a, b) Sainju *et al.* (2007) Benincasa *et al.* (2010) Bergkvist *et al.* (2011) Tosti *et al.* (2012) Smith *et al.* (2014) Tosti *et al.* (2014) Poffenbarger *et al.* (2015) Finney *et al.* (2016) White *et al.* (2017)
Cover crop shoot	In apple orchard sward ecosystems, herb shoots are incorporated into the soil via mowing and wilting. Mowing can facilitate the incorporation of cover crop shots into soil and improve the properties of soils in apple orchards.	Monteiro and Lopez (2007) Gomez *et al.* (2009) Zhou *et al.* (2019)
Antagonist crops	Plant derived natural products of antagonist crops have been introduced as the most appropriate alternative way to synthetic chemical control of plant-parasitic nematodes (PPNs). They can produce anthelmintic compounds which may help to suppress the nematode population. Suppression of *M. incognita* on tomato, *M. chitwoodi* and *Meloidogyne arenaria* has been reported. Crops like mustard, oilseed radish, sudangrass and rapeseed can reduce root lesion nematode populations. Some important compounds against *Meloidogyne* spp. include a glycoside (asparagusic acid) isolated from *Asparagus officinalis* L., 2-phenylethyl glucosionlate from *Brassica* spp., and two novel nematicidal compounds, nonacosane-10-ol and 23a-homostigmast-5-en-3β-ol isolated from the roots of *Fumaria parviflora* Lam.	Mojthahedi *et al.* (1993) Potter *et al.* (1998) Chitwood (2002) Pandey *et al.* (2003) Ferraz and de Freitas (2004) Pakeerathan *et al.* (2009) Collange *et al.* (2011) Naz *et al.* (2013a, b) Naz *et al.* (2014) Naz *et al.* (2015)
Legume cover crops-olive	Legumes are economical and environmentally friendly compare to other types of cover crops, which lead to sustainable agricultural production. Application of legumes as cover crops can reduce the limitation in the use of agro-chemicals determined	Campillo *et al.* (2003) Graham and Vance (2003) Crews and Peoples (2005) Ovalle *et al.* (2010) Nasim *et al.* (2016)

	by ecological regulations and high soil losses recorded in the olive groves. It can also contribute in soil protection against erosive agents.	Magrini *et al.* (2016) Reckling *et al.* (2016) Ordonez-Fernandez *et al.* (2018)

Table 4. The most important benefits of green manure and cover crops

Benefits	
Cover Crops	Provide soil cover
	Loosen compacted soil
	Improved water infiltration
	Maintain or increase soil organic matter
	Prevent soil erosion
	Suppress weeds
	Reduce insects, pests and diseases
Green manuring	Suppression of soil-borne diseases
	Increase organic matter content
	Improve soil structure
	Improve soil water holding capacity
	Improve soil fertility (nutrients and microbial activity)
	Increase crop yield

Table 5. The advantages of incorporating cover crops into summer crop rotations in connection with soil water relations

1-	Influencing infiltration and runoff of precipitation (Dabney, 1998; Kaspar *et al.*, 2001), and reduce both water and wind soil erosion (Langdale *et al.*, 1991; Decker *et al.*, 1994; Delgado *et al.*, 1998).
2-	Decreasing high surface evaporation by mulching (Bonder *et al.*, 2007; Qi *et al.*, 2011a)
3-	Consuming stored soil water by transpiration (Gabriel *et al.*, 2012: Qi *et al.*, 2011b)
4-	Altering the soil water use patterns for the subsequent crops (Unger and Vigil, 1998; Gabriel *et al.*, 2014), improve soil health (Liu *et al.*, 2005), and to scavenge nitrogen from the soil profile to improve water quality (Kaspar and Singer, 2011; Lacey and Armstrong, 2014; Roth *et al.*, 2017; Ruffatti *et al.*, 2019).

Conclusions

Over the past several years, both soil fertility and health has increased popularity, and considering physical, chemical and biological parameters related to soil may improve soil functions. Both soil quality and health may have significant influence on fauna abundance and diversity. Soil fertility is a basic to the productivity and sustainability of faming in agricultural fields. The important parameters to keep or enhance soil fertility and productivity are improve soil structure, water-holding capacity, aeration and drainage, increase usage of covers crop and green manure system to increase organic matter, and soil microbial and macrofaunal populations, provide enough nitrogen for the agricultural systems, control and decrease both weed, pest and disease life cycles in crop rotations, keep soil cover to protect soil erosion and leaching, and decrease losses of nutrients in the system. Rhizobia are the most important group of nitrogen fixing soil bacteria which can lead to mutualistic symbiotic association (root nodules) with leguminous plants. Rhizobium may improve sustainable production by increasing organic nitrogen content. Rhizobia produce Nod factors during the early development of nodules upon perception of flavonoid molecules secreted by legume roots, and Nod factor's structure may depend on species, chemical substitutions added which may influence legume specificity.

Nitrogen fixation and legumes yields depend on the rhizobium strain, the genotype of the legume, bio-physical environment, and management practices. From many studies, it has been reported that the combination of *Arbuscula mycorrhiza* and *Rhizobium* are more effective than individual applications as the maximum root colonization, root nodulation and the highest yield obtained in many samples. Catch crops have positive effects on both physical and chemical properties of soil, subsequent crop yield, limits nitrogen leaching into the ground water, decrease soil erosion, and decrease nitrogen losses in cropping systems. Catch crops can be used in the rotation with other crops, such as seeded after main crop harvest to capture excess nutrients in conventional systems, or planted after animal manure application, but it is not common to cultivate after green manures. Grasses such as barley (*Hordeum vulgare*) and Brassicas such as oilseed radish (*Raphanus sativus*) have high rapid nitrogen uptake and consider as appropriate crops as catch crops. Green manuring is soil conservationist practice which increase soil organic matter, increase or maintain the main crop yield especially in the long-term, decrease the environmental effects of the main crop, and improve soil fertility. It is also considered as a great source of nitrogen for following cultivation. Green manures may incorporate to soil at both green or maturity stage. The most notable advantages of green manuring are suppression of soil-borne diseases, increase organic matter content, improve soil structure, improve soil water holding capacity, improve soil fertility and increase final crop yield. Unlike green manuring, biomass burning known as main sources of air pollutant in the atmosphere. The most important reasons for burning crop residues are clearing the land for upcoming cultivation, control of weeds and also providing nutrients for the next crop cycle. Forage and grain legumes as green manures can provide significant amount of nitrogen, reduce nitrate leaching and optimizing ecosystem services. Field crop residue burning may lead to emissions of particulate matter, carbon dioxide, sulphur dioxide, oxides of nitrogen, Ammonia, methane, Oxides of nitrogen, Organic carbon, Elemental carbon, Volatile organic compounds, and polycyclic aromatic hydrocarbons. Cover crops which are grown with two purposes of capturing excess N and preventing leaching losses are known as catch crops. Cover crops categorize to legumes, non-legumes and mixtures. The most important benefits of cover crops are provided soil cover, loosen compacted soil, improved water infiltration, maintain or increase soil organic matter, prevent soil erosion, suppress weeds, reduce insects, pests and diseases. Diversity in cover crops management may lead to higher stability in biomass production. Winter cover crops such as the milk vetch (*Astragalus sinicus*), and the ryegrass (*Lolium* spp.), are famous winter cover crops because of high nutritional value and form high-quality pastures. Soil is the vital natural parameter, and hunger and famines are because of unfertile and unproductive soil. Techniques like green manuring, usage of catch and cover crop can increase not only soil fertility, but also sustainable crop production.

Authors' Contributions

Both authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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