Crop Diversification and Food Security

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Abstract

Food security is a primary concern and necessity of every nation, and crop diversification is a dynamic tool to ensure the food security in a sustainable way. Crop diversification includes both growing of conventional crops and introduction of new nonconventional crops. Crop diversification is also an efficient tool for mitigating the adverse effects of climate change. In this chapter, authors have discussed various disadvantages of mono-crop culture like disease infestation, abiotic stress, and negative environmental consequences and also discussed how these consequences can be mitigated with crop diversification. Besides all these advantages, in a narrow scope, risk avoidance, land suitability, social norms, income level, and contact with extension officers are key challenges which hinder wide adaptation of crop diversification. Acceptance of new crops in the market is also a challenge. In this scenario, inclusion of oilseed crops and legume crops and the promotion of agroforestry system may be a viable option to adjust as new crops in already adopted cropping systems. But before adaptation of new crops, long-term experiments on the impact of crop diversification on soil properties, farmer income, food security, and global warming should be carried out to exclude the farmers' risk.

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26.1 Introduction

Food security is used to describe whether a country on the face of the globe has access to enough food to meet the dietary energy requirements of the population. Although a remarkable increase in food production was recorded in food production during the past century which has decreased the proportion of the hungry people of the world, more than one in seven people in the world has no or limited access to healthy, nutritious food at proper time. Many people are suffering from one or more forms of micronutrient malnourishment (World Bank 2008; FAOSTAT 2009).

Cereals are staple of millions across the globe which fulfill the dietary needs of the people. In the world, the cereal crops are grown in the monoculture systems which may threaten future food security due to loss of biodiversity and occurrence of new pest and diseases (Fraley 2017).

In this scenario, crop diversification is a dynamic tool to ensure the food security and achieve the goals of the sustainable agriculture development (Behera et al. 2007). The presence of new crops or introduction of new cropping system to improve the agricultural production on a particular form considering various economic returns from the value added crops with complementary marketing opportunities is termed as crop diversification (Clements et al. 2011).

There are two types of crop diversification, i.e., (1) horizontal and (2) vertical. In horizontal crop diversification, the crop growers grow various kinds of new crops such as fruits, minor crops (medicinal crops), cut flower crops, and vegetables. In vertical crop diversification, the farmers involve themselves in various value chain additions, or they adopt the alternative businesses such as fish farming, livestock rearing, and poultry shed business along with the cultivation of the crop species.

The main drivers of crop diversification include improving the income of small land holders, mitigating the effects of variability in the climatic factors on crop production, withstanding the fluctuation in prices, conserving the natural resources, withstanding the fluctuation in the prices of agricultural commodities, balancing the food demands, reducing the environmental pollution, decreasing the reliance on off-farm inputs, decreasing the pest (insets and weeds) and diseases problems (Smale and King 2005; Winters et al. 2006; Clements et al. 2011), and finally enhancing the community food security. However, the inclusion of new crop species in a cropping system for crop diversification depends on (1) quality and availability of resources such as rainfall, irrigation, and soil fertility; (2) the farmer access to the advanced technologies like that of water, fertilizer, seed, storage, marketing, and processing; (3) the investment capacity and food and fodder self-sufficiency of farmers; (4) the market-related factors especially input and output prices of commodities and economic and other trade policies that affect the prices (directly or indirectly); and (5) the infrastructural- and institutional-related factors including land tenancy, farm size, research, extension, government regulatory policies, and the marketing systems (Smale and King 2005; Clements et al. 2011).

Crop diversification is aimed to enhance the crop portfolio to encourage the farmers to not depend on a single crop (monoculture) to earn the income. Indeed, when the farmers focus on only one crop, it may cause the emergence of new pests, and crops may be damaged due to unavoidable events as drought, frost, and heat stress. Moreover, the farmers may also suffer if the price of that special crop grown at his farm went down immediately, thus providing him less income. On the other hand, crop diversification helps to improve the ecosystem biodiversity and strengthen the agroecosystem to respond better to environmental stresses, thus reducing the risk of complete crop failure and providing the farmers alternative source of income. Thus, crop diversification helps farmers by creating the better conditions for food security and by enabling them to grow surplus and diverse agricultural produce to be sold in the market to earn income. Crop diversification also helps the farmers to target the international and national markets with new agricultural products (cereals, legumes, oilseeds, sugar crops, fiber crops, medicinal plants). Besides, crop diversification especially in the developing countries can make a country self-reliant in terms of food production (Naeem et al. 1994; Chapin et al. 1997; Clements et al. 2011). The ecological benefits of crop diversification include reduced nutrient losses from soil, improved resource efficiency, higher resource uptake by plants, and increased productivity and stability of the production system (Hooper and Vitousek 1997; Tilman et al. 1997; Reich et al. 2001). In this chapter, we have discussed the problems of monocropping systems and have highlighted the potential benefits of crop diversification with various crops to improve the soil quality and farmer profitability to ensure the food security for future generations.

26.2 Problems of Monoculture Systems

The practice of growing a single crop on a specific piece of land year after year is termed as monoculture. However, the monoculture systems in the world are linked with increased use of costly input for crop maintenance (such as fertilizers, pesticides, and irrigation) and decreased biodiversity (McCord et al. 2015). As the monoculture cropping systems are managed with high levels of external agro-inputs such herbicides and synthetic fertilizers, they have negative environmental consequences (Altieri and Bravo 2007), thus impacting soil health, environmental quality, and biodiversity (Tilman et al. 2002; Fraley 2017). The problems of monoculture systems have been discussed below.

26.2.1 Soil Properties, System Productivity, and Profitability

Loss of soil nutrients, imbalance in soil microbial communities, and soil sickness due to autotoxicity of root exudates are the main reasons for low crop yield in monoculture systems (Bennett et al. 2012; Huang et al. 2006). The soil moisture within the monoculture is lower compared to diversified cultures (Lin 2007) due to low residue input.

As in monoculture systems, a single crop is grown on a farm land year after year. If the said crops belong to the Poaceae family, it will remove the soil nutrients and will not return any crop residues to the soil which will affect the long-term soil sustainability which may affect the future food security. Cereals are used as staple, and they are cultivated widely in the world to feed the ever-increasing population in monoculture systems (Power and Follet 1987). Thus, the scientists should discourage the monoculture of cereals across the globe as it may lead toward the loss of soil nutrient and depletion of soil organic matter. Moreover, if a cereal crop fails, the farmer will achieve no output, and the income generation will be low, thus reducing the profitability at farmer field. This will reduce the overall yield system productivity of a particular farm. For example, rice (*Oryza sativa* L.) monoculture produced lower yield as compared with soybean (*Glycine max* (L.) Merr.)-rice rotation in Brazil (Pinheiro et al. 2006). In crux, monoculture systems produce low yield due to poor soil fertility which ultimately lowers profitability at farmer field.

26.2.2 Diseases and Pests

The loss of biodiversity in monoculture systems causes increase in crop disease susceptibility with higher rates of disease transmission (Lin 2011) across the globe. For example, the insect pest outbreaks of the leaf beetle (*Phratora vulgatissima*) have been greater in willow (*Salix matsudana*) monoculture than natural willow habitats (Dalin et al. 2009). In a grassland study, the pathogen load was almost three times greater in monoculture where host abundance was at peak than diversified polyculture (Mitchell et al. 2002). Attack of army worm (*Spodoptera sunia*) completely destroyed the monoculture of tomatoes (*Solanum lycopersicum* L.) in Central America (Rosset et al. 1985). In a study, the continuous monoculture of false starwort (*Pseudostellaria heterophylla* (Miq.) Pax) enhanced the abundance of different fungal species (*Trichocladium*, *Fusarium*, *Myrothecium*, and *Simplicillium*) (Wu et al. 2016).

Andow (1983) reviewed the extent of increasing the monoculture of cotton (*Gossypium hirsutum* L.) and wheat (*Triticum aestivum* L.) on insect pest population of both crops. He found that increasing the monoculture of cotton led toward an increase in insect pest population; the population increase was not much evident in monoculture of wheat crop. The population of pollinators is also less in monoculture systems which affects the normal palliation process in crop plants. As the monoculture system lacks biodiversity, the unwanted species of insect pests can invade the whole crop fields due to availability of host plants and lack of natural predators which hinder the natural biological pest control in these systems.

Weeds may also be a severe issue in monoculture systems. For example, the monoculture of wheat for several years in Alberta has encouraged the infestation of downy brome (*Bromus tectorum* L.) (Blackshaw 1993). In Alberta, the herbicide-resistant weeds were more prevalent on the monoculture farms without having any fall-seeded or forage crop in rotation (Beckie et al. 2004). In crux, monoculture of field crops favors the insect pest and diseases; weed management also becomes difficult.

26.2.3 Pest Resistance and Negative Environmental Consequences

As pest pressure is higher in monoculture systems, the common pest control strategy in these systems is the excessive use of pesticides. Although the excessive use of pesticide will kill more pests, nonetheless the pesticide residues in food may impact the human and animal health. The excessive use of pesticides may also encourage the phenomenon of pesticide resistance in different pests. Currently, 500 cases of pesticide resistance have been reported in the world (Gut et al. 2017); most of these cases have been reported in the monocultures of roundup-ready crops (cotton, corn, and soybeans) especially in the United States and Europe. In the United States, ~4.05 million hectares of fields has been infested by the roundup-resistant pigweed (*Amaranthus retroflexus* L.) (Neuman and Pollack 2010). This increase rate of roundup resistance may threaten the future food security of the United States as cereals are dominating the monoculture systems of the world and they totally depend upon the use of synthetic nitrogen fertilizers for their proper growth and development. Thus, the excessive use of synthetic fertilizers (especially nitrogenous fertilizers) in cereal monoculture systems may cause the emission of greenhouse gases (i.e., nitrous oxide), thus causing global warming (Lassaletta et al. 2016). Likewise, leaching of the nitrogenous fertilizers may pollute the underground water and may cause eutrophication (Ayoub 1999). In crux, monoculture systems may aggravate the pest resistance phenomenon and have negative environmental consequences.

26.3 Benefits of Crop Diversification

Crop diversification reduces climatic variability and also has potential to increase the production and promote the ecosystem stability on degraded or marginal lands (McCord et al. 2015). Crop diversification has a number of benefits as described below.

26.3.1 Improvement in Soil Properties

Crop diversification reduces the chance of vulnerability to the external stresses which occur as a result of climate change (Altieri 2004; Baumgartner and Quaas 2010; Lin 2011). Moreover, crop diversification helps in cycling the nutrients and water. For example, inclusion of legume crops in the monoculture systems may improve the rooting ability, water use efficiency, nutrient uptake (Morris and Garrity 1993; Lithourgidis et al. 2011), activities of soil microbes, soil structure (Hernanz et al. 2009), soil water retention (Miller et al. 2003; Angus et al. 2015; Kazula et al. 2017), soil organic matter (Stagnari et al. 2017), and availability of nitrogen and phosphorus (Shen et al. 2011; Jensen et al. 2012) on diverse soil types. Kazula et al. (2017) found an improvement in soil water retention and the plant available water in diversified crop rotation than a maize monoculture. In another study, Katsvairo et al. (2002) found that the infiltration of water and the earthworm density were higher in a legume-cereal crop rotation as compared with the monoculture of cereal maize.

Moreover, legumes also fix the atmospheric nitrogen which may benefit the upcoming cereal crops. In contrary, in Australia, the availability of nitrogen to wheat crop grown after legume was higher against wheat grown after a cereal crop (Chalk 1998). In another finding, the uptake of nitrogen was higher in the durum wheat (*Triticum durum* L.) when it was grown after vetch (*Vicia sativa* L.) than durum wheat monoculture (Giambalvo et al. 2004). The hydrogen gas produced during the nitrogen fixation promotes the growth of other soil bacteria thus improving the soil health (Angus et al. 2015). Few species of the legume plants [such as chickpea (*Cicer arietinum* L.)] produce various kinds of organic acids (such as citrate and malate) which mobilize the fixed soil phosphorus reservoirs (Hocking 2001).

The inclusion of those crops which produce leafy biomass for soil cover, in the cropping system, may help to reduce soil erosion. Moreover, the crops with deep and firm root system may also reduce soil erosion when incorporated in the cropping system. For example, a wheat sunflower (*Helianthus annuus* L.) rotation in Australia accomplished with conservation tillage reduced soil erosion as compared with the monoculture of sunflower (Carroll et al. 1997). In rice-wheat rotation, the inclusion of dual-purpose legume crop is recommended to make the system more sustainable with low dependence on the synthetic nitrogen (Sharma and Prasad 1999; Sharma et al. 2000). In crux, the inclusion of oilseed crop and legume crops in the monoculture cereal system is very useful for improvement in soil properties on long-term basis.

26.3.2 Improvement in System Productivity and Profitability

The on-farm crop diversification is very useful for the market-oriented smallholders (Bradshaw et al. 2004; Fraser et al. 2005) as it provides a farmer with small land holdings a better marketable harvest and buffer against the variations in market events if a market is oversupplied with a crop (McCord et al. 2015).

Many studies have reported that inclusion of new crops in an existing cropping system improved the system productivity and profitability. For example, the overall system productivity and profitability of rice-wheat cropping system was improved due to inclusion of sesbania (*Sesbania sesban* (L.) Merr.) as a brown manure crop due to improvement in soil properties (Nawaz et al., 2017). In another study, the highest net return, benefit-cost ratio, economic efficiency, system productivity, and energy productivity was recorded in Jute (*Corchorus capsularis* L.)-rice-potato (*Solanum tuberosum* L.) system in India (Kumar et al. 2014). The intercropping of wheat with chickpea improved the land use efficiency and total productivity (Banik et al. 2006). In India, the inclusion of medical plants such as basil (*Ocimum basilicum* L.) and menthol mint (*Mentha arvensis* L.) in pea (*Pisum sativum* L.)-based system improved the gross/net returns and benefit-cost ratio, thus improving the economic profitability (Khan and Verma 2018). In another study, inclusion of mungbean (*Vigna radiata* (L.) Wilczek) in a maize-wheat system improved the system productivity by 25% and net returns by 28% than monoculture of maize and wheat without mungbean (Jat et al. 2018). Pooniya et al. (2018) also observed highest net returns, system productivity, and energy efficiency in rice-wheat-summer mungbean system than sole rice-wheat system in India. In crux, the inclusion of legumes in cereal-based monoculture system may improve the system productivity and profitability.

26.3.3 Pests and Diseases

Crop diversification has been believed to suppress the crop pest, thus increasing the production (Lin 2011) and improving the resilience against climate change. Indeed, crop diversification buffers the microclimatic fluctuations (Holt-Gimenez 2002; Tengo and Belfrage 2004; Lin 2007; Philpott et al. 2008) which suppress crop pest and disease pressure (Mitchell et al. 2002; Perfecto et al. 2004).

The diversification of the cropping systems with the inclusion of allelopathic crops (as crop rotation or as cover crops) might be a viable option to reduce the weed pressure which is otherwise higher in monoculture systems. For example, we have noted that the weed flora is always lower in the winter season crops [e.g., wheat, barely (*Hordeum vulgare* L.)] following the sorghum (*Sorghum bicolor* L. Moench) crop (author personnel observation) which is due to the presence of suppressive allelochemicals of sorghum in the rhizosphere of the post-sorghum crops. Moreover, the decomposing residues also help to reduce the insect pest and diseases in crop plants (Farooq et al. 2011).

Planned crop rotations suppress the weeds. For example, the density of giant foxtail (*Setaria faberi* [R.] Hermm.) was low in the crops following wheat (Schreiber 1992). The rice-wheat cropping system of the Indo-Gangetic Plains is heavily infested with weeds. However, the inclusion of allelopathic crops such as sorghum, maize, and pearl millet (*Pennisetum glaucum* L.) after harvest of wheat and prior to sowing of rice may control weeds in upcoming rice crop. Likewise, for the control of wild oat (*Avena fatua* L.) in continuous monoculture wheat fields, the growing of fodder crops such as Egyptian clover (*Trifolium alexandrinum* L.) and oat (*Avena sativa* L.) may provide control of this weed for at least 1 year. Indeed, the weeds will be removed with fodder, and there will be no seed setting in weeds in that season, thus lowering weed pressure (Peters et al. 2003; Farooq et al. 2011).

In a sunflower-wheat rotation, the wild oat and Canada thistle (*Cirsium arvense* [L.] Scop.) population was low in post-sorghum wheat (Cernusko and Boreky

1992). In Russia, Grodzinsky (1992) found 40% weed suppression in the post-rapeseed field crops. In another study, inclusion of spring canola (*Brassica napus* L.) in rotation reduced the weed population. Various other studies have reported that crop rotations reduce the pressure of insect pest pressure (Benson 1985), diseases (Dick and van Doren 1985; Edwards et al. 1988), and the nematode (Dabney et al. 1988).

The inclusion of cover crops in cropping systems may suppress the weeds, insect pests, and diseases (Brandsæter et al. 2000; Hartwig and Ammon 2002; Gallandt and Haramoto 2004; Hiltbrunner et al. 2007). Use of legume cover crops such as jumbie bean (*Leucaena leucocephala* (Lam.) de Wit), velvet bean (*Mucuna pruriens* (L.) DC.), jack bean [*Canavalia ensiformis* (L.) DC.], and wild tamarind [*Lysiloma latisiliquum* (L.) Benth.] reduced the population of barnyard grass [*Echinochloacrus-galli* (L.) Beauv] in maize (Caamal-Maldonado et al. 2001). Use of barely as cover crop reduced population of barnyard grass and crabgrass [*Digitaria ciliaris*(Retz.) Koel.] in soybean (Kobayashi et al. 2004). Use of cover crops such as hyacinth bean (*Lablab purpureus* L.), velvet bean, and jack bean suppressed the mission grass [*Pennisetum polystachion* (L.) Schult.] in rubber (*Hevea brasiliensis* L.) plantation (Kobayashi et al. 2003). Likewise, use of spiderlily (*Lycoris radiate* L.) as cover crop suppresses the rice weeds (Iqbal et al. 2006).

Crop diversification also supports the predator of pests. For example, there was greater spider abundance in a diversified cropping system (Sunderland and Samu 2000). On the other hand, in coffee (*Coffea arabica* L.)-agroforestry system, a great diversity of the predators was recorded owing to the shade of trees. Moreover, more trees in a cropping system also favor the residence of predator birds which prey on different harmful insects of the crops (Perfecto et al. 2004). In a study, Armbrecht and Gallego (2007) found greater efficiency of the predatory ground-dwelling ants against coffee berry borer (*Hypothenemus hampei* (Ferrari)) in a diversified coffee system than a monoculture system.

In the diversified fields, when the pests want to invade a field, they encounter more resistance due to the presence of natural predators which limit their movement. Thus, the diversified farms have well-defined biological pest control than monocultures. On the other hand, the biological control in diversified farms may be introduced artificially. The biological control is cost-effective and more eco-friendly than chemical control once established. For example, in the United States, it costed just $2 million dollars to establish a successful biological control; a successive chemical control costed $180 million dollars. The biological control has less risk of resistance development and has less harmful side effects; the chemical control is highly risky in terms of resistance development with many side effects (Bale et al. 2008). Thus, biological control might be most pragmatic on diversified farms due to greater biodiversity than the chemical control.

Another idea for managing pests in monoculture systems is the growing of another crop as trap crop with the main growing crops. For instance, strip planting of maize in cotton may attract the cotton bollworms, thus reducing its attack on cotton crop (Lincoln and Isley 1947). The stem borer (*Chilo partellus*) in India has been reported to be attracted by sorghum crop. Ali and Karim (1989) reported that the trap crops have been used to control jassid (*Amrasca biguttula biguttula* (Ishida)) in cotton. In a study, the intercrop of tomatoes with beans in Central America reduced the attack of army worm (*Spodoptera sunia*) (Rosset et al. 1985). In Canada, the use of sterile bromegrass (*Anisantha sterilis* (L.) Nevski) has been effectively used for the control of wheat stem sawfly (*Cephus cinctus*) (Van Emden and Dabrowski 1997).

26.3.4 Environmental Benefits

Biodiversity in crop diversification ensures buffer against the environmental variations (Yachi and Loreau 1999) as different species perform differently against environmental extremes, thus lowering the impacts of cropping systems on the aerial and soil environments. The introduction of legumes in the cropping system for crop diversification may reduce the emission of greenhouse gases (especially nitrous oxide) owing to their ability to fix the atmospheric nitrogen with low reliance on the use of synthetic fertilizers which are otherwise extensively used in monoculture cereal-based systems in the world (Lithourgidis et al. 2011; Jensen et al. 2012). Stagnari et al. (2017) reported that the emission of greenhouse gases such as nitrous oxide and carbon dioxide per unit area is 5–7 times less in legume-based systems than other field crop-based systems. Jensen et al. (2012) observed that the flux of nitrous oxide was lower in legume-based systems than the crop rotations based on nitrogen fertilization. In the United States and Europe, legume incorporation in cereal-based cropping systems has resulted in less use of nitrogen fertilizer, thus decreasing the N fertilizer-based greenhouse gas emission (Lemke et al. 2007; Nemecek et al. 2008). Moreover, the government of the United States has shifted its agricultural policies to promote diversified farming.

Agroforestry, a technique of crop diversification, helps to control the atmospheric greenhouse gas concentration globally (Mbow et al. 2014). Agroforestry buffers uncertain climates owing to regulation of microclimate and water flow (Nguyen et al. 2013) in the cropping system. Agroforestry, a broader term which includes crop diversification, crop rotation, live fences, boundary plantings, perennial crops, etc., helps to conserve and protect natural resources (as by mitigating nonpoint pollution source (dust)), control soil erosion, and protect wildlife and pollinator habitats (Molua 2005). It provides rapid shift in ecological conditions along with restoring soil and water resources (Molua 2005; Du-Toit et al. 2004). Crop diversification also helps to reduce the use of pesticides which is a common practice in monoculture system, thus reducing the negative impacts of pesticides used on food chain and aerial environment.

Crop diversification with legumes also helps to sequester carbon within soil. Indeed, the fixed nitrogen and the carbon portion of the shoots, roots, and leaves of legumes are incorporated into the soil after their decomposition. In a study on sandy-textured soil, the cultivation of legumes increases the soil organic carbon against cultivation of oat (*Avena sativa* L.) on the same soil (Hajduk et al. 2015). Heenan et al. (2004) also reported that the soil organic carbon was enhanced by

3.8 t ha^{-1} in top 100 cm soil in subterranean clover (*Trifolium subterraneum* L.)-wheat rotation accomplished with crop residue retention. In crux, crop diversification especially through legume crops may benefit the environment through reduction in greenhouse gas emission and carbon sequestration.

26.4 Constraints in Crop Diversification

In a narrow scope, risk avoidance, land suitability, social norms, income level, and contact with extension officers are key challenges in crop diversification (Cutforth et al. 2001; Di Falco and Perrings 2003). Moreover the diversification of crop species is also influenced by rainfall patterns, the farmer experiences, the community-level traits, and the household demographics of the farmers (Jarvis and Hodgkin 2000; Neill and Lee 2001; Ryan et al. 2003; Degrande et al. 2006). Sometime, introduced crop species in a diversified cropping system may cause a severe pest invasion in that region (Ojasti 2001; Hall 2003). Likewise, the new crop species introduced in a cropping system may not have great access to national and international markets due to poor government policy including the subsidies, the supply and price of inputs, and the infrastructure for the storage and transportation of agricultural produce. Farmers also face risk from poor economic returns if crops are not selected based on a market assessment. For example, drought-tolerant crop varieties may fetch a low market price if there is not sufficient demand (Clements et al. 2011). In crux, the various socioeconomic, environmental, and market-related factors may influence crop diversification. The government policies should focus on the provision of subsidies to the famers adopting crop diversification. The government should also provide funding to the research organization for conducting research on crop diversification.

26.5 Conclusion and Future Research Thrusts

Continuous monoculture of cereal-based and other field crop-based systems may threaten the food security of future generations in climate change scenario. Indeed, continuous monocultures of field crops result in the loss of biodiversity which has disturbed the ecosystem and resulted in increased threat of pests and diseases. Monoculture systems also negatively impacted the soil properties and may enhance the impact of global warming due to release of greenhouse gases. In this scenario, crop diversification might be a viable option to improve biodiversity; manage insect pests, weeds, and diseases; and reduce the emission of greenhouse gas. Due to their importance in food security, inclusion of oilseed crops and legume crops and the promotion of agroforestry system in cereal-based cropping systems may be a viable option to improve soil properties, sequester carbon, and reduce global warming impacts, and use of synthetic pesticides and fertilizers may be reduced. Crop diversification will also improve the system productivity and will ensure food security for future generations. However, long-term experiments on the impact of crop diversification on soil properties, farmer income, food security, and global warming should be carried out on diverse soil types under variable climatic conditions.

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