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Review Article

Legumes: A Boon to Keep Soil Alive and Protect Biodiversity

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A B S T R A C T

Legumes have a great potential to enhance crop diversity as well as productivity and to reduce dependence on exterior inputs as legumes are well known for their illustrious capabilities such as nitrogen (N) fixation by biological means, increase in soil organic matter (SOM), efficient roles in nutrient and water retention, and improvement in soil properties which contribute to recover soil health. These manifold abilities of legumes make them potential candidates for management of agriculture in a sustainable way. Some legumes have the capability to solubilize in any other case unavailable phosphate by excreting organic acids from their roots, in addition to improving soil fertility. Legumes also assist to restoration of soil natural matter and limit pest and disease issues when used in rotation with nonleguminous crops. Research has shown that the organic nitrogen fixation procedure is the most environment friendly way to grant the giant amounts of nitrogen wished through legumes to produce high- yielding crops with an excessive protein content. The upshots of sustainable agriculture can be optimistic for higher food production and to ensure future food availability in an eco-friendly manner by reducing the usage of agrochemicals and maintaining the nutrient balances in the soil.

Introduction

Global populace will hit 9.6 billion human beings with the aid of 2050 (UN, 2013) and will face world challenges among which attaining meals security, reducing the risk of local weather exchange through lowering the net release of greenhouse gases into the ecosystem and assembly the increasing demand for energy are the most critical ones. In particular, the impact of climate trade and related biotic and abiotic stresses to which crop structures will be an increasing number of uncovered pose serious implications for global food production (Yadav *et al.*, 2015).

To meet these challenges, a policy framework needs to be developed in which the sustainability of production consumption patterns turns into central. In this context, meal legumes and legume-inclusive manufacturing systems can play essential roles by means of turning in more than one offerings in line with sustainability principles. Indeed, legumes play central roles (Voisin *et al*., 2014): (a) at food-system level, both for human and animal consumption, as a source of plant proteins and with an increasingly importance in enhancing human beings health; (b) at production-system level, due to the capability to fix atmospheric nitrogen making them potentially notably appropriate for inclusion in low-input cropping systems, and due to their function in mitigating greenhouse gases emissions (Lemke *et al*., 2007); and (c) at cropping-system levels, as diversification vegetation in agroecosystems primarily based on few important species, breaking the cycles of pests and diseases and contributing to stability the deficit in plant protein manufacturing in many areas of the world.

Legumes have a probably substantial position to play in enhancing soil carbon sequestration. They can also have considerable additional advantages beyond their significance involving nitrogen fixation and excessive protein feeds. These consist of advantageous impacts on biodiversity and soil quality. There is a great need for a strong focus on creating the role of legumes and their contribution to each the sustainable intensification of manufacturing and the livelihoods of small holder farmers in many components of the world (Mtambanengwe and Mapfumo, 2009). Apart from their makes use of as food and fodder they have a very necessary position in retaining soil fertility by fixing atmospheric nitrogen and enhancing soil structures and adding organic matters. Moreover, it is generally used as an intercrop and covers plants, and sometimes, it is cultivated as emergency vegetation due to its brief life cycle. Since it requires low fertilizer and other inputs this crop is relatively profitable in a most economical point of view. It also improves environmental quality by sequestrating carbon and mitigating other pollutants. Legumes are additionally a potential plant team in which some of the species having a capacity of remediating poisonous metals and organic pollutants.

Contribution of legumes in soil quality enhancement

Soil quality advantages of legumes include increasing soil natural matter, improving soil porosity, recycling nutrients, improving soil structure, decreasing soil pH, diversifying the microscopic lifestyles in the soil, and breaking disease build-up and weed problems of grass-type crops.

Natural carbon source

As stated previously, legumes are high in protein, and therefore, nitrogen rich. Because most crop residues incorporate a lot extra carbon than nitrogen, and microorganism in the soil need both, the nitrogen provided by legumes allows the decomposition of crop residues in the soil and their conversion to soil constructing natural matter.

Improve porosity

Several legumes have aggressive taproots reaching 6–8 feet deep and a half inch in diameter that open pathways deep into the soil. Nitrogen-rich legume residues inspire earthworms and the burrows they create. The root channels and earthworm burrows make bigger soil porosity, promotion air movement and water percolation deep into the soil.

Reduce loss of nutrients

Because perennial and biennial legumes root deeply in the soil, they have the capability to recycle crop nutrients that are deep in the soil profile. This effects in a more environment friendly use of utilized fertilizer and prevents nutrients (particularly nitrate nitrogen) from being lost due to leaching under the root region of shallower-rooted crops in the rotation (Fig. 1).

Enhance structural stability of soil

The improvements are attributed to increases in more stable soil aggregates. The protein, glomalin, symbiotically along the roots of legumes and other plants, serves as a "glue" that binds soil together into stable aggregates. This aggregate stability increases pore space and tilth, reducing both soil erodibility and crusting.

Diminishes soil alkalinity

Because inoculated, nodulated legumes acquire their N from the air as diatomic N rather than from the soil as nitrate, their net effect is to lower the pH of the soil. In greenhouse studies, alfalfa and soybeans lowered the pH in a clay loam soil by one whole pH unit. Legumes could lower the pH and promote increased plant-soil-microbial activity on soils with a pH above the range for optimum crop growth and development.

Contribution of legumes in soil health enhancement

Biological Nitrogen Fixation

Legume plant and seed tissue is distinctly high in protein. This can be without delay attributed to a legume's capability to supply most of its personal nitrogen wants with the assist of symbiotic Rhizobia microorganism residing in their roots. Inoculated with the applicable stress of Rhizobia bacteria, legumes can furnish up to 90% of their own nitrogen (N). Shortly after a legume seed germinates in the presence of Rhizobia microorganism in the soil, the bacteria penetrate the root hairs and cross into the root itself. The bacteria multiply, inflicting a swelling of the root to shape pale pink nodules. Nitrogen gasoline present in the soil air is then sure by the microorganism which feed on carbohydrates manufactured by the above-ground plant in the course of photosynthesis (Naab *et al*., 2009). The bacteria produce ammonia (NH3) from the hydrogen obtained from the plant's carbohydrates and nitrogen from the air. The ammonia then provides a supply of nitrogen for the plant to grow. This symbiotic relationship between bacteria and legume lets in them both to flourish and produce a high-protein seed or forage crop. Even although legumes can repair nitrogen from the atmosphere, they can take up large quantities of soil nitrogen if it is available. Nitrogen release from a legume crop occurs as the above-ground plant residues, roots and nodules step by step decompose. Soil microorganisms decompose the highly nitrogen-rich organic cloth and launch the nitrogen to the soil when they die. Usually about two-thirds of the nitrogen fixed through a legume crop becomes handy the subsequent growing season after a legume in a rotation (Deakin and Broughton, 2009).

Carbon capture and storage

Soil carbon (C) sequestration refers to the process of conveying of atmospheric CO2 into the soil of a particular place via its plants. There are a number of benefits of soil carbon sequestration comprising enhanced biodiversity, progressing nutri- tional security, growing renewability, and water quality, along with the strengthened nutrient recycling (Lal *et al*., 2015).

The agricultural production processes also release a significant percentage of green-house gases which further add to global warming. The various processes behind the emission of greenhouse gases can be summed up as the processes relating to the production and application of the fertilizers, use of machinery, agronomic practices, and several soil processes also characterize the primary mechanisms toward the emission of such gases to the atmosphere from the cultivated areas (Dhakal *et al*., 2016). At the same time, agricultural practices are also responsible for the mitigation of various greenhouse gases. In this line, the inclusion of legumes in the cropping system provides numerous benefits including decreased dependence on nitrogenous fertilizers along with the mitigation of carbon footprints (Plaza-Bonilla *et al*., 2018).

The soils which have been deteriorated due to physical degradation, structural decline, and/or having reduced biodiversity can be restored by cultivating legume crops which are considered as the effective agents for improving soil organic carbon. The soil C sequestration is more pronounced in leguminous plants as com- pared to other nonlegume crops due to their leaf-shedding ability along with the ability of superior biomass production below the ground, and this effect is more pronounced if the farming practices of legumes are further accomplished in mixed farming along with the practice of crop rotation (Kumar *et al*., 2018). The carbon storage is further reported to be higher when the agronomic practices of legume cultivation are further accompanied by the other management practices such as no-tillage and mixed cropping (Veloso *et al*., 2018).

Furthermore, legumes also affect the soil biology, and thereby they potentially enhance the development as well as maintenance of the soil aggregates which fur- ther enhance the soil carbon storage by protecting it from decomposition. So, the net effect of leguminous crops on the SOC and the other structural attributes of the soil depend upon the interactions between the soil components and the crop residues (Oliveira *et al*. 2019).

Decline in greenhouse gas emissions

Legumes are also possibly to have a position to play in lowering GHG emissions from ruminant systems. An approach to decreasing methane emissions of current interest and supported by some initial evidence is the use of tannin containing forages and breeding of forage species with greater tannin content. Forage legumes such as *Lotus corniculatus* (birds foot trefoil) and *L. uliginosus* (greater trefoil) possess secondary metabolites acknowledged as condensed tannins in their leaves. They are no longer present on the leaves of white or purple clover but are existing in the inflorescences. Methane production values had been lower in housed sheep fed on purple clover and birds foot trefoil than on a ryegrass/white clover pasture (Dhakal *et al*., 2015). The emissions of nitrous oxide from soils improved linearly with the quantity of mineral nitrogen fertilizer applied and because structures containing legumes produce lower annual nitrous oxide emissions, alfalfa and different legume vegetation need to be regarded differently when deriving national inventories of GHG from agriculture.

The nitrous oxide emissions are from soils with alfalfa and soybean cropping, looking at soil floor emissions in evaluation with perennial grass. Low nitrous oxide emissions have been considered under grass and soil mineral N used to be up to ten instances higher beneath legumes however soil mineral N pools were not carefully associated to nitrous oxide emissions. Comparable emissions were viewed under timothy (*Phleum pratense*) as underneath legumes.

Legumes are soil-amendment crops with strong benefits on soil health and need to be an essential element of the farming systems

(Dhakal *et al*., 2016). Legumes have positive effects on soil processes such as benefiting agroecosystems, agricultural productivity, soil conservation, soil biology, SOC and N stocks, soil chemical and bodily properties, BNF, nitrous oxide (N_2O) emission, and nitrate (NO_3) leaching by means of lowering the need for chemical fertilizers. Above all, legumes are now utilized as soil nourishment agents. However, these benefits on soil health need to be quantified, and their mechanisms understood. Thus, incorporating legumes as a section of cropping systems is pertinent to higher soil fitness and productivity.

Enhanced nitrogen and phosphorus availability

The increased addition of N to the soil can escort to enhanced N losses via leaching and thereby does not essentially reveal the strengthening of soil N pool. Legume farming can rein- force the soil N pool if the quantity of fixed N is greater than the N taken away at the time of harvesting in the form of grains and leftover stubbles/stover.

Besides N, another imperative element for plant growth and development pro- cesses is P, whose deficiency leads to a great reduction of photosynthesis rate by means of destructive consequences on leaf section growth and thereby affects photosynthetic capability per unit leaf area (Chaudhary *et al*.,. 2008). As aerial metabolic and progressive events of plants are strongly linked with symbiotic associations of plant roots with rhizobacteria, the harmful effects of P deficiency are expected to have severe insinuations on the development and proper working of nodules as bio- logical nitrogen fixation (BNF) is an extremely energy-entailing procedure (Sulieman and Tran, 2015). In contrast to N, inorganic P reserves are nonrenewable and toward depletion. Consequently, development of legume cultivars having efficient N fixing capability in P-deficient conditions may possibly have tremendous importance in the enhancement of soil health and overall sustainability.

Being crucial for a symbiotic relationship, adaptive morphological and physiological approaches for enhancing P acquisition have developed by plants to combat restrictions of the rate of symbiosis in P-constrained states. These approaches are harmonized at multiple levels and include upholding of high amount of P in nodules than the surrounding tissues/organs; enhancement of root surface area, amount of root exudates excretion, and articulation of transporters and aquaporins for improved uptake of P; increase in fixed N per unit of nodule in order to reimburse decrease in nodule number; etc. (Verma *et al*., 2015). The enhanced P acquisition actively involved in enhancing the efficiency of BNF in nodules which largely contributes to N balance in the soil. Nearly all legume cultivars grown by the farmers exhibit all these approaches, thereby presenting a superlative way to maintain soil health with the aim of sustainable agriculture by improving N and P availability in soil. Therefore, legumes have a vital function ineffectual management of dependence on inorganic fertilizers and improving soil fertility.

Amelioration of acidic soils

Intensive agricultural system has resulted in reduced soil pH especially in humid regions, making the soil more acidic which is a solemn way to degrade agricultural terrain (Behera and Shukla, 2015). The continuous application of a large amount of ammonium-based N fertilizers to the soil ecosystems, surface leaching of NO_3^- ions, acid rains, and harvesting of alkaline plant materials from the arable lands are the major factors rinsible for soil acidification. In turn, this acidified soil is a major obstruction for crop productivity in several provinces across the global cultivated areas (Baquy *et al*., 2017).

Legume farming assisted with liming and cautious P supply is a primary step for recovery of acidic soils under stumpy N and P conditions. Legume farming adds considerable amounts of residues to the soil ecosystem which over time increase the soil organic matter, thereby helping in combating problems related to the acidity of the soil. Furthermore, the development of such legume cultivars which are able to grow under acidic conditions with low P and N availability has been an astonishing achievement. It has been found that acid soils have recovered in Brazil owing to the use of fast-growing legume trees (FGLTs) and their corresponding symbiotic associates (Chaer *et al*., 2011) under constraints of soil acidity. Therefore, the addition of legumes in intensive agricultural system prevents runoff of the frail soil surface, thereby helping in reinstating soil organic content and richness.

Contribution of legumes in enhancing soil properties

Intensive agricultural practices lead to the degradation of soil aggregates resulting in soil erosion and loss of SOM. Consequently, other physicochemical and biological properties of soil get adversely affected and result in making the soil infertile and decreasing crop productivity to a great extent. Legumes as cover crops increase SOM which aids the soil particles to aggregate, and the mulching of crop residues obtained from leguminous plants is considered a good technique of sustainable soil management as it precludes the erosion of soil, improves water retention capability, helps in refurbishment of soil bio- diversity, buffers temperature fluctuations (Chen et al. 2018), and thus helps in the improvement of the soil structure (Fig. 2).

Physical properties of the soil

Important soil physical properties are bulk density, porosity, combination stability, and texture. These properties are additionally associated with water related methods including aeration, runoff, erosion, water maintaining capacity, and infiltration rate. Legume vegetation have a manageable to enhance physical properties of soil by being a soil conditioner and enhancing the physical residences (Lal, 2012). Leguminous cover crops have a tremendous effect on soil physical properties broadly speaking due to the manufacturing ability of large biomass which affords substrata for soil organic undertaking and soil organic matter (Lal, 2015). Furthermore, leguminous cover vegetation are grown to protect the soil from loss of plant nutrients and erosion, while green manure plants are grown for the motive of improving soil bodily properties. Moreover, some plants can physically modify the types of soil profile. Legumes additionally have an effect on soil shape by means of their impact on aggregation. Leguminous cover crops can expand or keep an appropriate soil C/N ratio and increase in preserving soil organic carbon stock. Legume plants often result in higher infiltration of water, due to direct effects of the crop residue in soil formation and aggregation (Liang *et al*., 2010; Srinivasarao *et al*., 2012; Meena *et al*., 2015; Meena *et al*., 2017).

Chemical properties of the soil

Soil chemical properties for sustainability are connected with the capability to provide vitamins for crop and retaining/denaturing hazardous chemical compounds or factors to the agroecosystem. Soil cation alternate capability (CEC), pH, nutrient levels, and soil organic carbon concentration are the primary chemical elements used toward the evaluation of soil fertility. Soil chemical properties have been associated with leguminous crops, and thus, the particulars of a soil property are easily interpreted and permit a rapid enhancement of the soil chemical properties through N-fixation and root biomass. Legume-based rotation induces modifications in the pH of the rhizosphere sector of soil. Root exudation of legumes and change or release of organic acids on the epidermal cell of root surfaces can also enhance P availability (Varma *et al*., 2017). soil pH is decreased by the production of organic acids and CO_2 upon degradation of soil OM added of legumes, and concomitantly, pH is raised also due to the reduction of H^+ into H_2O and CO_2 (Buragohain *et al*., 2017). In addition, changes in pH are broadly recognized to affect the increase and undertaking of microorganisms, which are additionally necessary aspects in nutrient cycling processes. Leguminous green manure is a well-known generator of soil natural matter. Green manure, apart from increasing soil N, releases P, continues and renews the soil natural carbon, and improves soil chemical characteristics. Incorporation of legume residues is really useful to the soil for growing soil natural carbon awareness which is not only vital to agricultural productiveness however also to sequestration of C from atmospheric CO_2 (Ayarza *et al*., 2007).

Observed that when leguminous cover plants are used as green manure and incor- porated into the soil, their residues make bigger availability of N, P, K, and trace elements to the succeeding plants due to the lowering of the soil pH brought about by the CO_2 produced in the process of decomposition.

Biological properties of the soil

Soil microorganisms have a necessary link between plant productiveness and soil nutrient availability as they are indirectly directly engaged in the nutrients cycling through the conversion of inorganic and organic types of nutrients (Douxchamps *et al*., 2013). Legumes are one of the necessary components to increase soil microbial biomass in soils. Legumes play a necessary function in SMB and energetic key strategies such as nutrient cycling and soil organic matter decomposition and, thus, improve crop productiveness and soil sustainability. Some microorganisms which interact physically with leguminous vegetation in the rhizospheric zone can also enhance crop productivity positively by enhancing plant increase and development.

The abundance, as well as diversity of microorganisms, is directly proportional to the plant production comprising the above- and belowground biomass. The presence and abundance of microbial life are directly involved in the nutrient accessibility along with the transmission of nutrients from the soil to plants, thus improving soil fertility and plant-soil health (Duchene *et al*., 2017). The practice of intercropping with legumes helps in the development of diverse kinds of roots and thus is responsible for changing complete root distribution as well as architecture, along with the modification in the process of exudation in the rhizosphere. Thus, it will strongly influence the microbial community along with their interactions with the plant, thereby promoting beneficial attractions. Intercropping of cereals with legumes also promotes complementarily and facilitation in the agro- ecosystems (Duchene *et al*., 2017).

Significance of legumes

Increased cultivation of legumes is integral for the regeneration of nutrient- deficient soils and for imparting wanted protein, minerals, and nutritional vitamins to human beings and livestock. Legumes can be an ability of improving the livelihoods of smallholder farmers round the world.

Role of legumes in nutrition of humans

As a supply of protein, grain legumes (such as pigeon pea, chickpea, soybean or mung bean) are a true supply of protein, with a protein content material ranging from 17 to 40%.

By combining cereal and grain consumption, farmers and their families can achieve protein stability and dietary improvement.

As a supply of essential vitamins and minerals, legume seeds contain tremendous quantities of minerals (calcium, zinc, iron) and nutritional vitamins (folic acid and diet B).

Role of legumes in nutrition of animals

Cereal crop residues supplemented with forage legumes notably increase normal animal productivity. For example, improved fowl egg production has been mentioned when pulse grains are protected in their feed. Adding the residue from legume flora into cattle forage can expand the digestibility and typical quality of cereal crop residues. For example, maize residues tend to be high in carbohydrates however low in protein; therefore, adding leguminous flora will make a contribution to multiplied livestock nutrition.

Fig.1 Benefits of legume crop in improving soil sustainability (Stagnari *et al*., 2014).

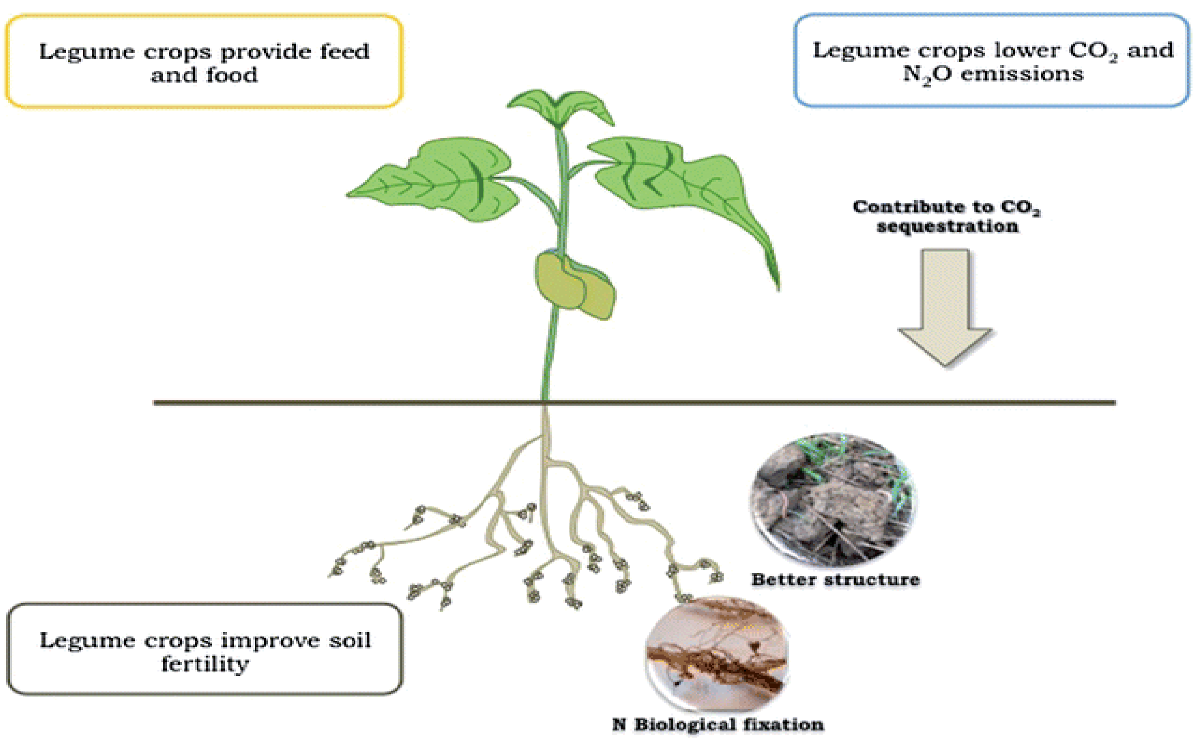
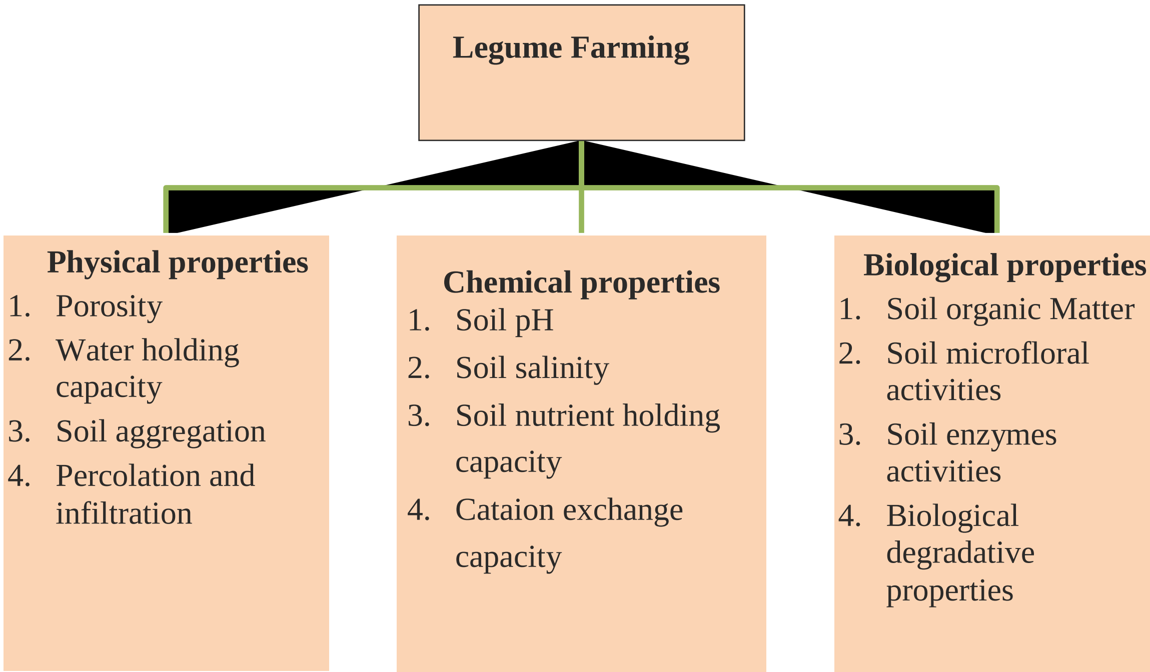


Fig.2 Soil properties influenced by inclusion of legumes under intensive agriculture system



Role of legumes in soil and crop improvement

For most effective yield, plants require mineral nutrients and the most essential of which is nitrogen. Exhausted soils are often low in nitrogen, meaning that farmers are usually applying inorganic fertilizers. However, as fertilizer expenses increase, farmers battle to acquire properly yields. This trouble can be addressed by incorporating legumes into the cropping system. Leguminous plant has a close relationship with nitrogen-fixing microorganism known as Rhizobium. By biologically fixing nitrogen ranges in the soil, legumes grant a fantastically low-cost approach of changing nitrogen in the soil, improving soil fertility and boosting subsequent crop yields.

In conclusion, the use of nitrogen-fixing legume-based leys, whether they are used for grazing, conservation or mulched to build soil fertility, is the basis of most organic systems. Their use is enshrined in the organic standards, which require the inclusion of legumes in rotations. The wider benefits of legumes, particularly in providing food for pollinators, are also increasingly being recognized. Globally, the amount of carbon di oxide respired from the root systems of N_2-fixing legumes could be comparable to, or higher than, the carbon di oxide generated during nitrogen-fertilizer production.

However, the carbon di oxide respired from the nodulated roots of legumes originated from the atmosphere via photosynthesis, so any of the carbon di oxide that was not subsequently recaptured by the plant and eventually escaped from the legume canopy to the atmosphere would essentially be carbon neutral. By contrast, all the carbon di oxide released during the synthesis of fertilizer nitrogen would be derived from fossil energy and represents a net contribution to atmospheric concentrations of carbon dioxide.

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