Chapter 13

# On-Farm-Produced Organic Amendments on Maintaining and Enhancing Soil Fertility and Nitrogen Availability in Organic or Low Input Agriculture

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Additional information is available at the end of the chapter

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**Abstract**

Maintaining and enhancing soil fertility are key issues for sustainability in an agricultural system with organic or low input methods. On-farm–produced green manure as a source of soil organic matter (SOM) plays a critical role in long-term productivity. But producing green manure requires land and water; thus, increasing biodiversity, such as by intercropping with green manure crops, could be an approach to enhance the efficiency of renewable resources especially in developing countries. This article discusses soil fertility and its maintenance and enhancement with leguminous intercropping from four points of view: soil fertility and organic matter function, leguminous green manure, intercropping principles, and soil conservation. Important contributions of leguminous intercropping include SOM enhancement and fertility building, biological nitrogen (N) and other plant nutrition availability. Under a well-designed and managed system, competition between the target and intercropping crops can be reduced. The plant uptake efficiency of biologically fixed N is estimated to be double that of industrial N fertilizers. After N-rich plant residues are incorporated into soil, the carbon (C):nitrogen ratio of added straw decreases. Another high mitigation potential of legume intercropping lies in soil conservation by preventing soil and water erosion. Many opportunities exist to introduce legumes in short-term rotation, intercropping, living mulch, and cover crops in an organically managed farm system. Worldwide, long-term soil fertility enhancement remains a challenge due to the current world population and agricultural practices. Cropping system including legumes is a step in the right direction to meeting the needs of food security and sustainability.

**Keywords:** soil fertility, nitrogen, living mulch, organic agriculture, leguminous intercropping

## 1. Introduction

Organic or low input farm is a production system that sustains agricultural productivity by avoiding or restricting synthetic fertilizers and pesticides. It takes soil fertility, which governs the plant productivity of the soil, as a key measure in gaining an optimum yield from a long-term point of view. The establishment and maintenance of soil fertility is a major issue within organic or low input farming systems.

Incorporation of organic residues and manures are key approaches to many integrated soil management strategies [1], including that of nitrogen, one of the key plant nutrients in organically or low input managed farming systems. Green manure, manure, and litter from animal husbandry are considered as soil amendments and major mineral nutrient sources after mineralization. Increased soil organic matter (SOM) is a key issue in maintaining soil fertility and provides plant nutrients. Thus, SOM and N availability are important indices of soil fertility [2]. However, taking economic issues into consideration, industrial N fertilizer is of more benefit than biological N fixation in current agricultural management [3]. In 1987, James indicated that from 1960 to 1977 (during the "green revolution"), legume seed production declined dramatically from 170,000 to 70,000 tons worldwide [4]. Because planting legumes requires land, water, and other resources, the ability to fix N is limited by agricultural conditions.

However, due to the contribution to soil fertility through its effects on the physical, chemical, and biological properties of soils, the role of green manure has been rediscovered and is receiving more attention in soil fertility maintenance and enhancement by farmers, agronomists, and governments around the world. Under current conditions, several opportunities exist for the use of legumes in short-term situations, such as simple rotation, double cropping or intercropping, and cover crops [5].

The method of growing more than one agricultural species mixture together, as intercrops, is generally regarded as one measure to increase the productivity of crop systems. Cover cropping can reduce soil and water erosion, the process by particles detached from the soil mass are transported by running water and wind. Intercropping enhances ecosystem services including crop yield, N use efficiency, pest and weed management, and reduces nitrogen losses to the environment [6]. Thus, the method of intercropping with green manure is of interest in organic or low input farming systems, especially in non-animal husbandry farm systems.

Regarding the question of acceptable long-term productivity with major crop rotation or intercropping with legumes [7], this article discusses soil fertility and the functions of SOM, leguminous green manure as a source of SOM, and its capability to modify the C:N ratio of added organic matter. Increasing N availability and other plant nutrients, the efficiency of intercropping and living mulch, and soil and water conservation are also considered. The objective of the review is to present a way to maintain and enhance soil fertility with green manure intercropping in an organically managed farming system.

## 2. Comprehensive soil fertility and the functions of SOM

### 2.1. Soil fertility aspects

Soil fertility is the crop productivity capacity of the soil due to the supply of plant nutrients and growth media. Long-term productivity can be taken into consideration instead of the yield in one growing season or year. Soil fertility includes sustainable availability and balanced forms of plant nutrients, soil water conservation, and aeration. It covers three aspects: physical, chemical, and biological properties. The physical property aspects mentioned in Table 1 [8] are related to soil texture and structure, which are related to the organization of particles and pores, reflecting effects on root growth, speed of plant growth, and water infiltration. Physical indicators include depth, bulk density, porosity, aggregate stability, texture, and compaction [9]. Loss of soil structure can occur through slaking and dispersion, often linked to intensive cultivation [10], compaction, and vital loss of the pore size distribution needed to maintain soil fertility [1]. Aggregates are the most profitable structural units of soil, offering water, air balance for root development, and the synthesis of complex organic compounds binding soil particles into structural units directly helps to build a loose, open, granular state with medium- to large-sized pores [11].

Chemical aspects include pH, salinity, organic matter content, phosphorus (P) availability, cation exchange capacity, nutrient cycling, and the presence of contaminants, such as heavy metals, organic compounds, and radioactive substances. These indicators determine the presence of soil-plant-related organisms, nutrient availability, water for plants and other organisms, and the mobility of contaminants [9].

| Physical | Chemical | Biological |
|---|---|---|
| Texture, | Organic C, | Microbial biomass C and N, |
| Depth of topsoil, | Total N, | Potentially mineralizable N, |
| Bulk density, | pH, | Soil respiration, |
| covers soil aeration, | Electrical conductivity, | Soil born pathogen repression. |
| water and nutrient holding capacity, | Extractable N, P, K, | |
| water infiltration, | Micro- and macronutrients availability, | |
| crust, | Salinity. | |
| temperature, | | |
| tillage condition. | | |

(Modified from Wienhold et al. [8]..)

**Table 1.** Physical, chemical, and biological soil indicators that may be included in a minimum data set for assessing soil quality.

Biological indicators include biomass of micro- and macroorganisms, their activities, and functions. Concentrations or populations of earthworms, nematodes, termites, and ants, as well as microbial biomass, fungi, actinomycetes, or lichens, can be used as indicators [9]. Soil biological properties are based on the soil being a living system; many kinds of organisms are involved in complex biological, chemical, and physical processes. A living soil is regarded as a healthy soil and favorable to plant growth because of the organisms' roles in soil development and conservation, specifically nutrient cycling and determining soil fertility.

### 2.2. The roles of soil organic matter on soil fertility

Organic and low input agriculture are regarded as a procedure to maintain SOM and soil fertility. In Switzerland, a long-term trial biodynamic system was reported to show a stable C content, while a C loss of 15% in 21 years was measured for the conventional system control. In the United States, a field trial showed fivefold higher C sequestration in an organic system (i.e., 1218 kg of C $ha^{-1}$ $year^{-1}$) versus conventional management [12,13]. Lal stated that the rate of organic C sequestration in soil with the adoption of recommended technologies depended on soil texture, soil structure, rainfall, temperature, farming system, and its management [14]. He also found that addition of 1 ton of degraded crop organic matter to the soil may increase crop yield by 20-40 kg $ha^{-1}$ for wheat, 10-20 kg $ha^{-1}$ for maize, and 0.5-1 kg $ha^{-1}$ for cowpeas. Apart from enhancing food security, C sequestration also has the potential to offset fossil fuel emissions by 0.4-12 tons of C $year^{-1}$ or 5-15% of global fossil fuel emissions [14].

Additionally, organic matter has both direct and indirect effects on the availability of nutrients for plant growth. The decay of organic matter liberates these nutrient elements, making them available to the succeeding crop. It is a major source of P and sulfur (S), and essentially the sole source of N through its mineralization by soil microorganisms. Organic matter serves as a source of energy for both macro- and microfaunal organisms. Earthworms and other faunal organisms are strongly affected by the quantity of plant residue material returned to the soil. During the decomposition process of organic tissue, soil particles are attached together as aggregates. SOM enhances the nutrient buffering capacity and the microbial activity, both strengthening soil fertility [15]. Additionally, organic matter contributes 30–70% to the cation exchange capacity, which allows soil particles to hold nutrients, thus preventing them from leaching out. Also, as a buffer, humus exhibits buffering over a wide pH range [16].

Water infiltration and root growth are promoted by lower bulk density, which tends to decrease with organic matter additions [11]. Organic matter has higher water-holding capacity (by 20 times) versus clay. Aggregate stability and water infiltration are increased by organic matter additions. This positive effect on the water-capturing capacity of the soil is likely to increase in importance with climate change, [15] because a higher water-capturing capacity strengthens resilience to droughts and reduces the risk of floods [17]. Thus, the need for irrigation is lowered, which has an additional adaptation and mitigation effect [15,18].

SOM enhances the nutrient buffering capacity and microbial activity, both strengthening soil fertility [15]. The addition of organic matter helps to protect the soil from erosion, acts as a buffer against dramatic changes in acidity, alkalinity, and salinity. The overall effects of organic matter are far greater than the simple analysis of its constituent nutrients; indeed, it is the engine that drives all the biological processes in the soil [19]. Increased SOM and microbial activity in organically farmed soils results from a combination of enhanced C inputs during fertilization and increased grass cover [20].

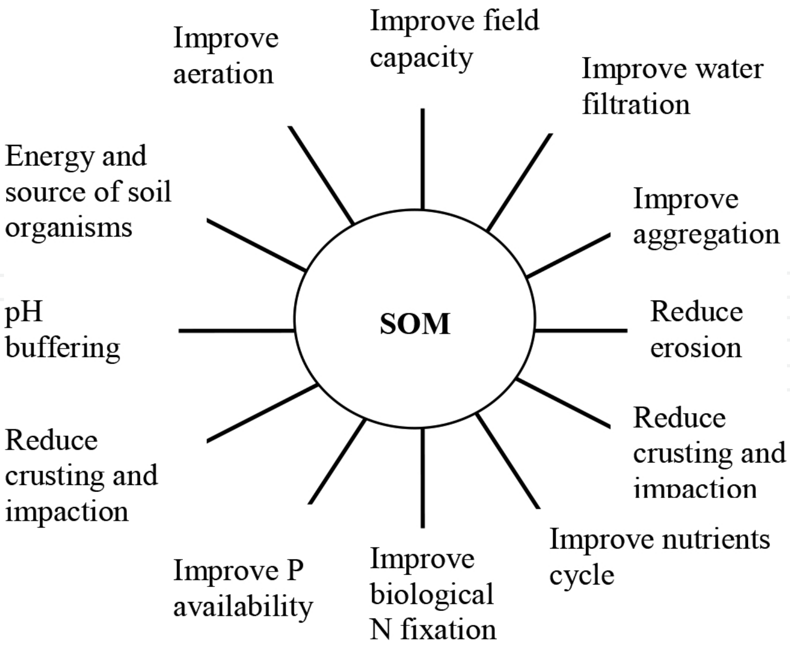


**Figure 1.** Soil organic matter contributes to soil fertility.

## 3. On-farm–produced organic amendments

### 3.1. SOM source and modified C:N ratio of added residues

Leguminous green manure has long been used as a SOM source as a component of cropping system in Africa, Asia, and Latin American. Cover crops and intercropping increase C sequestration in the soil [21]. Another possible benefit of legumes is the result of N fixation by the root nodules, which the amount of biological fixed N is a somewhat contentious issue in some case studies, but most of the organic N can be available to plants after residues have been composted [22]. Generally green manure can produce a dry weight of 5-9 tons or more biomass ha$^{-1}$ year$^{-1}$; about 40% of dry matter is C and 2-4% is N. While the N productivity of several major cultivated legumes has been reported as from 80 kg (berseem clover) to 190 kg (subclover) ha$^{-1}$ [23-25]. The ability of biological N fixation ranges from 40 to 200 kg in aboveground tissues ha$^{-1}$ due to the species of legume, bacterial strain, and agricultural conditions, such as climate and soil (Table 2).

Factors that influence the ability of microorganisms to break down added plant materials includes the C:N ratio of organic matter and components of organic C and N [26]. The C:N ratio of plant tissue reflects the kind and age of a plant from which it was derived. Non-legume plants may have a high C:N ratio, over 60 (cow straw), up to even 250 (wood tissue) [27,28]. Non-leguminous green manure with high a C:N ratio (over 25), will cause microorganisms to tie up available N in the soil. Thus, added materials with C:N ratios above 25:1 can result in N being bound by soil microbes in the breakdown of C-rich crop residues, thus pulling N away from the root zone of crop plants. Legumes usually have a low C:N ratio (about 10-15) and can help to modify the SOM C:N ratio to an adequate level. The optimal C:N ratio for rapid decomposition of organic matter is between 15:1 and 25:1 [29]. The addition of N-rich plant residues, such as legume plants, to aid the decomposition process may be advisable with these high-C residues: the lower the C:N ratio, the more N will be released into the soil for immediate crop use [30].

| Crop | Biomass* (tons $ha^{-1}$) | Nitrogen (kg $ha^{-1}$) |
|---|---|---|
| Sweet clover | 4.3 | 130 |
| Berseem clover | 2.7 | 75 |
| Crimson clover | 3.5 | 108 |
| Hair vetch | 4.3 | 118 |
| Subclover | 5.4–10.1 | 184 |

*Dry weight of plant aboveground material (sources: [2325])

**Table 2.** Yearly average biomass yields and nitrogen yields of several legumes.

### 3.2. Intercropping with green manure

Intercropping refers to multiple crops planted at same time on the same land, growing and interacting with each other during the whole or part of the growing season within a crop system [31,32]. Intercrops or mixture crops influence the farming system in ways including the lower density of each species helping to reduce plant pathogen infection opportunities, raising land productivity as a result of reducing the effects of unsuitable conditions, which may be not so unsuitable to other intercrops, positive effects on weed control, border effects, and enhancing plant nutrient and soil humidity use efficiency. Intercropping can be regarded as a method of weed suppression and offering habitats for beneficial organisms. According to space arrangements and temporal practices, intercropping is commonly divided into four subcategories [31]:

1. *Row intercropping*: growing two or more crops at the same time with at least one crop planted in rows.
2. *Stripe intercropping*: growing more than one crop together in stripes wide enough to permit separate crop production using machines but close enough for the crops to interact with each other.
3. *Mixed intercropping*: growing two or more crops with no distinct row arrangement.
4. *Relay cropping*: planting a second crop in a standing crop at a time when the standing crop is at its reproductive stage but before harvest. According to plant density or land features, the crop with high seeding rates is called the major crop, and the other crop is the secondary crop.

Crop mixtures may gather more light and plant nutrients than pure standing crops, as a result of differing root depth and stem height. Generally, the land equivalent ratio (LER) is one of the major measures to judge how complementary crops are under intercropping. The mathematical equation is stated as [33]:

$$LER = (Yij + Yji / Yjj + Yii),$$

where Yij is the grain yield per unit area of species i grown in a mixture with species j, Yii is the grain yield per unit area of species i grown in a pure stand, Yji is the grain yield per unit area of species j grown in mixture with species i, and Yjj is the grain yield per unit area of species j grown in a pure stand.

When the LER is below 1, it indicates that competition exists between different components rather than them being complementary. Generally, under a well-managed intercropping system, the LER is 1.2-1.5 and sometimes even above 1.5. These results are due to the rational use of natural resources for crop growth. As Paolini et al. reported, after 2-year case studies on mixture crops of sunflower and chickpea, total LER figures averaged 1.16 as to aboveground biomass yield and 1.25 as to grain yield [34]. They also pointed out that an unfavorable climate for one species is not so unfavorable to another. The conclusion can be made that when the climate or other agricultural factor becomes the key limiting factor for one crop, the other crop will likely get sufficient plant nutrients and soil moisture water supply; one species will be more tolerant of the unfavorable condition than the other.

Altieri found that in Mexico, 1.73 ha of land had to be planted with maize to produce as much food as 1 ha planted with a mixture of maize, squash, and beans [35]. Additionally, maize + squash + bean polyculture can produce up to 4 tons $ha^{-1}$ of dry matter for plowing into the soil as compared with 2 tons in a maize monoculture. In Brazil, a maize or sorghum mixture with cowpeas or beans can lead to LER values of 1.25-1.58 [35]. Sometimes under intercropping management, a major crop cannot get the maximum yield obtainable in a monoculture due to competition from the other crop or a lower density versus a pure stand. By interplanting, farmers achieve several production and conservation objectives simultaneously [36]. Polycultures produce more combined yield in a given area than could be obtained from monocultures of the component species; sometimes, the LER can be above 1.5, although the yield variability of cereal + legume polycultures are much lower than that for monocultures of the components [37]. The intercrop treatments represented the highest LER was 1.52 for baby corn/pea intercropping system [38]. And other maize/bean intercropping achieved LER values were 1.76 and 1.92 [39]. Cover cropping is also considered as a the practice of growing pure or mixed strands of legumes, cereals, or natural vegetation to protect the soil against erosion, ameliorate soil structure issues, enhance soil fertility, and suppress pests, including weeds, insects, and pathogens [31]. The cover crop approach has been used for thousands years ago and is regarded as a sustainable method of agricultural production.

### 3.3. Living mulch

Living mulch refers to a legume cover-crop, which is undersown with an annual crop. Common living mulches include white clover, hairy vetch, and red clover. A living mulch can improve soil structure and water penetration, prevent soil erosion, modify the microclimate, and reduce weed competition [40]. An ideal crop occupies underused time or space in an existing system. It does not compete with the cash crop for light, water, or nutrients, and attracts beneficial organisms, while keeping harmful pests away. It should be readily established and grow rapidly. It should produce an abundant growth of both shoots and roots in a short time, and its growth habits should encourage ground cover soon after its establishment [41]. Common living mulches can offer soil cover, especially during the seedling period and after harvest of the target crop when the crop plant does not cover most of the soil surface. Subclover planted as a living mulch was able to regenerate and provide the succeeding crop with abundant and N-rich residues [42]. The main benefits of living mulches include enhancement of soil structure, improvement of soil fertility, and positive effects on pest management and environmental quality [43].

Changing from a monoculture to an intercropping system requires several important management practices based on natural laws. Successful management requires investment in experience and research to modify the system into an economically acceptable, ecologically sustainable, and technologically practicable one. In the case of winter wheat, a major crop around the world, legumes, as rotation crops or intercrops, have been tested for the establishment of the cropping systems. According to Caporali and Campiglia, in search of strategies for increasing sustainability in cropping systems, they have been focusing for 10 years on the use of plant resources, such as self-reseeding winter annual legumes (*Trifolium* and *Medicago* species) native to the Mediterranean environment [44]. Although subclover and annual medics are well-known forage crops in cereal-lay farming systems under the Mediterranean climate around the world, their use is practically unknown in more intensive cash-crop sequences, such as the 2-year rotation between a winter cereal (wheat, barley) and a summer crop (rainfed sunflower, irrigated corn), as is common in central Italy. In this rotation, an annual legume is used as a living mulch in winter cereals, and after its self-reseeding, as either a green manure or living mulch for the succeeding summer crop. This alternative cropping system has proved to have the potential to induce a significant shift toward a less energy-intensive and a more environmentally friendly management type, while maintaining the same cash-crop sequence of the conventional one [44].

The foundation of the system began with the screening of self-reseeding legumes species and cultivars and ended with the implementation and performance assessment of an entire alternative cropping system (winter cereal/summer crop rotation). The yield of winter wheat intercropped with subclover was not significantly different from that of a pure wheat stand in a drier crop year, while in the wetter year the grain yield of the intercropping system was significantly higher than the pure stand. However, in both crop years, grain yields were significantly lower that obtained using 130 kg $ha^{-1}$ mineral N fertilizer, by 11% and 23%, respectively. Additionally, a positive correlation between the amount of subclover biomass plowed in and the vegetative and productive characteristic of sunflower was found in dry and wet years. Subclover green manure was so effective that sunflower yield in the alternative system was higher than that of the conventional one fertilized with 130 kg $ha^{-1}$ of inorganic N. Subclover green manure also affected biomass and the composition of the weed community in the sunflower crop. Subclover mulch from a sod strip intercropping system with wheat was also effective in positively influencing the aboveground biomass production of the succeeding crops, the effect being dependent on the amount of dry mulch left by the different subclover species and cultivars [44].

### 3.4. Competition between intercrops and intercropping principles

The struggle for nature's resources is always an issue within any crop system because plant growth needs not only space and time, but also light, mineral nutrients, and water. The competition can be considered to have two main aspects: aboveground competition and root system competition. In rain-fed agriculture, under limited water conditions, a major competition can occur between the target crop and legumes for water resource. The wheat yield under intercropping conditions with legumes reportedly decreases with less water availability versus a pure stand, although legume intercropping with a major crop can enhance the N content of the soil [45]. Mc Gowan and Williams found that subclover depleted soil moisture more than barley. At 19 weeks after sowing, maximal soil moisture was observed when barley was in a high density and a pure stand, 7.5% at 5-15 cm and 9.9% at 15-30 cm depth, while for subclover in a pure stand, it was 6.2% at 5-15 cm and 8% at 15-30 cm depth [46]. Taking into account negative effects between intercrops, how to best balance between competition and companion effects is a task for experimental research.

As Altieri and Rosset pointed out, a production system must be designed to reduce nutrient losses by effectively containing leaching, runoff, and erosion, and improving nutrient recycling mechanisms [40]. Diversity is a natural design, while monoculture is an anthropogenic creation. So intercropping should be organized according to natural laws. The cultivars within a cropping system must be suitable for the local climate and soil conditions. Under the circumstances of intercropping, cooperation between different species is also required; at least, competition should be eliminated as much as possible. As the main competition between two crops is canopy competition and root system competition, the principles of a well-managed intercropping system can be summarized as follows:

Tall and short crops are growing together to minimize struggle for sunlight and reduce air humidity of the microclimate. Crops with deep and strong root systems intercropped with the species with sallow root systems can reduce underground competition. The density of a major crop should be reduced to adjust the growth of itself and leaving optimum space for another intercrop.

Select different maturity dates to minimize competition as much as possible [47].

When crops are planted together according to these principles, competition between different species will be less than would exist within the same species. The success of intercropping systems at low levels of interspecific competition has also been explained in terms of more balanced and efficient use of soil moisture due to temporal complimentarily in water requirements of the two species [48]. In the case of legume intercropping, high companion effects between the two crops are caused by biological N fixation, producing N that benefits the target crop and offering soil cover. Simultaneously, the negative effects of legumes on the major crop should be reduced by a well-managed system.

## 4. Soil N availability and other plant nutrient availability enhancement

Nitrogen plays an important role in yield determination when relatively adequate levels of other agricultural factors exist. Continued use of inorganic fertilizers has not only altered the soil p H, soil structure, and texture, but has also disrupted niches for micro- and mesofauna, which are essential for nutrient recycling [49]. Alternatively, under systems of organic farming management, when industrial N fertilizer is not used, organic matter origin-N, after biological degradation, is converted into mineral N forms, ammonium and nitrate, and becomes a major factor in plant production. However, as the mineral N content in soils increases beyond the capability of plants to take it up, it will cause N leaching and increase other kinds of N losses into the environment. In this case, it is important to understand the N cycle and soil N balance within an agroecosystem.

As common knowledge, the origin of all kinds of N is air $N_2$, 79% by volume of the earth's atmosphere. Soil microorganisms, free-living or associated with legumes, fix atmospheric N. This complex biological process begins with air N and ends with organic N. After organic matter decays, $NH_4^+$, which is ready to be used by higher plants, is released. $NH_4^+$ can be converted into $NO_3^-$ by nitrifying bacteria and generally most $NH_4^+$ is modified into $NO_3^-$ in the soil. Thus, over 90% of soil N is typically $NO_3^-$, not $NH_4^+$, although $NH_4^+$ can be formed from $NO_3^-$ through the process of denitrification in soils [50].

The denitrification process starts with $NO_3^-$ and converts it to $NH_4^+$, N mono-oxides (NOx, greenhouse gases), and $N_2$. Denitrification of nitrate produces about 90% $N_2$ and 10% NOx. However, the natural N balance has been affected by industrial N fixation since the green revolution. Symbiotic N amounts to about 100-175 million tons each year in the 1970s world-wide, with industrial fixation of 3.5 million tons, and lightning may fix 10 million tons of N, a value that has probably not changed over time [51] . In 1989, industrially fixed N increased to 80 million tons in response to the needs for high-yielding crops [22].

By the year 2050, the world population is expected to double from a level of more than 5 billion. It is reasonable to expect that the need for fixed N for crop production will also at least double. If this is supplied by industrial sources, synthetic fertilizer N use will increase to about 160 million tons of N per year [51]. Consequently because of its relatively low plant uptake level, generally around 50% or less, several major environmental reasons exist to seek alternative fixed N fertilizers, including the fact that it affects the balance of the global N cycle, pollutes groundwater, increases the risk of chemical spills, and increases atmospheric nitrous oxide ($N_2O$), a potent greenhouse gas. The global budget for $N_2O$ appears to be out of balance, exceeding sinks by 30-40% and increasing at 0.25% each year [7]. In this case, biological N fixation should receive more attention because about 2 tons of industry-fixed N is needed as fertilizer for crop production to equal the effects of 1 ton of N biologically fixed in a legume crop [51].

In cultivated land, the soil N balance is a complex system covering serial biological processes and physical and chemical processes. It includes plant N uptake, N fixation, organic N mineralization, nitrification and denitrification, nitrate leaching, and other losses, as $N_2$ or

NOx, released into the atmosphere [52]. In the case of organic farms, soil available N is primarily from legumes as green manure and organic fertilizers. SOM reportedly supplies most of the N and S and half of the P uptake by plants within an organic farming system [53,54]. The plant tissues of green manure contain most of the micro or macro plant nutrients, including N, potassium (K), P, and S. Phosphates, K, calcium (Ca), magnesium (Mg), S, and other micro plant nutrients are accumulated by cover crops during the growing season. Hoyt indicated the nutrients content of cover crops; see **Table 3** [55]. These nutrients are maintained in the residues of green manure plants; later, they become available to successive crops after incorporation into the soil.

| Crop | N | K | P | Mg | Ca | Biomass |
|---|---|---|---|---|---|---|
| Hair vetch | 152 | 144 | 19 | 19 | 56 | 3520 |
| Crimson clover | 124 | 154 | 17 | 12 | 67 | 4573 |
| Rye | 96 | 117 | 18 | 9 | 24 | 6057 |
| Austrian winter pea | 156 | 172 | 21 | 14 | 49 | 4443 |

**Table 3.** Green manure biomass productivity and nutrient content (kg $ha^{-1}$) [55].

During the composting process of green manure, some carbonic and other organic acids are formed as by-products of microbial activities. These organic acids react with insoluble mineral rocks and phosphate precipitates, releasing phosphates and exchangeable nutrients [29]. Gardner and Boundy found that wheat intercropped with white lupin (*Lupin albus L.*) has access to a larger pool of P, Mg, and N than wheat grown in monoculture [30]. The former two nutrients were probably mobilized by exudates of organic acids from the lupin root and then taken up by wheat roots.

The nutrients content of different legumes can be estimated by the mathematical formulation described by Peet [56]:

Rye: N = 0.0194 × biomass – 17.4

Hairy vetch: N = 0.0409 × biomass – 3.1

Crimson clover: N = 0.0204 × biomass + 13.8

Austrian winter pea: N = 0.0402 × biomass – 9.2

Caley peas: N = 0.0426 × biomass – 6.1

Subclover: N = 0.0280 × biomass + 2.9,

where "biomass" is the dry weight in kg $ha^{-1}$, and the N content, N, is also in Kg $acre^{-1}$.

For legumes, on average, pounds of K = pounds of N, and pounds of P = 10% of N.

The study of cowpea/maize intercropping shown that cowpea had used atmospheric N for crop growth and also fixed the nutrient into the soil for subsequent crop. The soil residual mineral N was increased by 82% compared with initial soil N. This demonstrated that biological $N_2$ fixation by cowpeas replenished the available N to both crops and also for subsequence crop [57].

## 5. Soil and water conservation by cover cropping

Soil conservation is an important issue in sustainable management, especially on hillsides. Cover crops or living mulch provide important benefits in soil and water conservation. The primary function of alley cropping on sloping lands is erosion control and soil conservation [51,54] . Two forms of soil erosion exist: sheet and rill erosion. Sheet flow is the removal of a relatively uniform thickness of soil and is usually caused by rain-splash, surface runoff, and wind. In rill erosion, water flows with soil particles in small channels [58]. Soil erosion decreases water availability, infiltration rates, water-holding capacity, nutrients, organic matter, and the depth of the soil. Soil erosion not only causes plant nutrient loss but also SOM loss. The latter affects field capacity and soil aggregation structure. Soil erosion has a negative effect on the productivity of soils (Table 4) [59]. The eroded soil typically contains about three times more nutrients than the soil left behind and 1.5–5 times more organic matter. The major costs to a farm associated with soil erosion come from the replacement of the lost nutrients and reduced water-holding ability, accounting for a productivity loss of 50-75% [60].

| **Erosion level** | **Organic matter (%)** | **Phosphorous ( kg ha$^{-1}$)** | **Plant-available water (%)** |
|---|---|---|---|
| Slight | 3.0 | 67 | 7.4 |
| Moderate | 2.5 | 66 | 6.2 |
| Severe | 1.9 | 43 | 3.6 |

**Table 4.** Soil fertility effects of erosion [59].

Soil erosion is connected to water erosion. Water erosion increases the amount of runoff, so that less water can enter the soil matrix and become available to the crop. In severely degraded soils, water infiltration may be reduced by as much as 93%, and so water conservation is linked to soil conservation [61]. Increased SOM content can enhance field capacity and consequently reduce soil erosion. Another effect of reducing soil moisture losses is that the soil cover reduces evaporation in fields. Vegetation acts as a buffer to the soil because rain-splash is an important detaching process in soil erosion. Raindrops striking bare soil have the ability to throw soil particles through the air over distances of several centimeters [62]. A vegetative cover also contributes to slope stability. In Nigeria, in land with a 14% slope and under total rainfall of 1412 mm during a 3-month study period, maize alley cropping with contour hedgerows of *Lucaena leucocephala* and *Gliricidia sepium* established at a 6-m interhedgerow spacing with prunings used as mulch effectively contained erosion by 85% and 73%, respectively [63]. The aboveground components of the plant, such as the leaves and stems, absorb some of the energy of falling raindrops, running water, and wind. The belowground components, the root system, contribute to the strength of the soil, holding soil particles in place. Living mulch can reduce soil and water erosion significantly, as the presence of the canopy slows down raindrops, reducing surface runoff and enhancing water filtration. A well-developed root system holds soil particles together, reducing soil erosion. Moreover, evapotranspiration of plants produces a drier soil environment due to the capable of withstanding a higher intensity and longer duration of rainfall compared with a slope that lacks vegetation [63].

## 6. Conclusions

Agriculture systems have evolved over long periods as a consequence of modifications of climate, agricultural technology, and socioeconomic conditions [64]. In recent decades, cropping systems, both in developed and developing countries, have become increasingly simplified with markedly reduced diversity in vegetation patterns over time and across the landscape. Concomitantly, a large increase has occurred in the use of synthetic fertilizers and pesticides [65]. Consequently, agriculture is suffering stress from environmental issues, such as nitrate leaching to groundwater, nitric oxide release to the air, and $CO_2$ from the fertilizer industry being released into the atmosphere [66]. Thus, the establishment of an adequate crop system that is economically acceptable, environmentally sustainable, and technically practicable is the task of agronomists and farmers.

Organic agriculture is regarded as a sustainable agricultural system, taking into consideration soil fertility conservation, which covers soil physical properties, plant nutrient availability, and erosion control, as its key issues [67]. In organic agricultural practices, biological N fixation has received increased attention from agricultural agronomists and producers. Although the economic value of biological N fixation by legumes varies widely, when the cost of production of the legumes is taken into consideration, opportunities still remain to plant legumes as a short-term rotation crop or an intercrop or living mulch [68]. Seeds of grain legumes can be used as a fast nitrogen available fertilizer in organic production at low temperatures in early spring [26]. Intercropping management has long been practiced and has played a crucial role in sustainable agriculture. One of the main benefits of an intercropping system is the rational utilization of natural resources. The management of intercropping is primarily according to natural laws within an agroecosystem. The regulation that major crops cannot cover the entire soil surface during the whole growing season provides chances for other plants growing as mixture crops, temporarily or spatially. Although competition between intercrops is always observed, a well-managed polyculture system can provide a higher total production than all of the crops planted as pure stands. Crop diversity, in both time and space, appears to be a critical element of sustainable agroecosystems that require few external inputs. Green manure, a major measure for the self-sufficient maintenance of soil fertility, offers organic matter to soil and fixing $N_2$ into organic form in the case of legumes.

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