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Improving Soil Fertility and Crops Yield through Maize-Legumes (*Common bean* and *Dolichos lablab*) Intercropping Systems

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Abstract

Declining crops yield in the smallholder farmers cropping systems of sub-Saharan African (SSA) present the need to develop more sustainable production systems. Depletion of essential plant nutrients from the soils have been cited as the main contributing factors due to continues cultivation of cereal crops without application of organic/ inorganic fertilizers. Of all the plant nutrients, reports showed that nitrogen is among the most limiting plant nutrient as it plays crucial roles in the plant growth and physiological processes. The most efficient way of adding nitrogen to the soils is through inorganic amendments. However, this is an expensive method and creates bottleneck to smallholder farmers in most countries of sub-Saharan Africa. Legumes are potential sources of plant nutrients that complement/supplement inorganic fertilizers for cereal crops because of their ability to fix biological nitrogen (N) when included to the cropping systems. By fixing atmospheric N_2, legumes offer the most effective way of increasing the productivity of poor soils either in monoculture, intercropping, crop rotations, or mixed cropping systems. This review paper discuses the role of cereal legume intercropping systems on soil fertility improvement, its impact on weeds, pests, diseases and water use efficiency, the biological nitrogen fixation, the amounts of N transferred to associated cereal crops, nutrients uptake and partition, legume biomass decomposition and mineralization, grain yields, land equivalent ratio and economic benefits.

Keywords: cropping system, BNF, N-transfer, biomass decomposition, nutrient uptake, grain yields

1. Introduction

In traditional agriculture, arable land is left fallow for some years to allow soil to acquire self-rejuvenation, but due to increased population pressure, fallow periods are shorter and are not sufficient to restore the soil nutrient pools sufficient to support economic crop yields (TASDS, 2001). The agricultural systems based on high external inputs are not sustainable and threatens food security in Tanzania, particularly at the smallholder levels (Birech & Freyer, 2007). A sustainable cropping system as an integral part of a complete farming system of soil, water, air, plant, animal, and human resources have to be endorsed (Arshad & Martin, 2002; Rahman, 2013). Intercropping is the common cropping system which involved the cultivation of two or more crops at the same time in the same field (Balthazar, 2014). The common crops combination in intercropping systems in Tanzania and Africa at large is maize and a variety of legumes such as beans, cowpeas, dolichos lablab, pigeon peas, green gram and bambara nuts (Waddington et al., 1989; Balthazar, 2014). Maize-legumes are important components of intercropping systems in improving soil fertility, controlling weeds, diseases and insects, conserving soil moisture, reducing soil erosion and improving soil microbiology (Fageria et al., 2005; Delin et al., 2008). Maize is the most cereal crop produced by about 82% of all Tanzanian farmers (NBS, 2007). In sub-Saharan Africa, maize is a staple food for an estimated 50% of the population and provides 50% of the basic calories. Maize production estimates in Tanzania in 2005-2007 were 3.4 million tonnes, which were grown on an area of two million hectare or about 45% of the cultivated area (NBS, 2007). This low maize productivity is associated with high level of dependency of agriculture to exogenous factors such as drought, flooding, pests and high costs of agro-inputs.

Bean (*Phaseolus vulgaris* L.) is one of the most important legumes in the world because of its commercial value, extensive production, consumer use and nutrient value (Xavery et al., 2006; CABI, 2007). For example, beans consumption per capita in Eastern and Southern Africa is 40-50 kg year^{-1} (Blair et al., 2010). These crops are good sources of proteins, vitamins, and minerals such as Fe, Zn, P, Ca, Cu, K, and Mg, and are excellent sources of complex carbohydrates (Camacho & Gonzalez de Mejia, 1998). It has positive impact on soil fertility improvement through BNF process and upon incorporation of residues into the soils (Blair et al., 2010). In East Africa, Tanzania is a major beans producing country where it is estimated that over 75% of rural households in Tanzania depend on beans for home consumption as well as cash crop income (Hillocks et al., 2006).

Dolichos lablab (*Lablab purpureus*) is popular as a nitrogen-fixing green manure to contribute to soil N and improve soil quality. Lablab is a popular choice as a cover crop on infertile, acidic soils, and it is drought tolerant once established (Hector & Jody, 2002). When in symbiotic association with *Bradyrhizobium japonicum*, Dolichos lablab plants can fix up to 400 kg N ha^{-1}yr^{-1} (Benselama et al., 2014), reducing the need for expensive and environmentally damaging nitrogen fertilizer. Maass et al. (2010) observed that *D. lablab* may suffer from low yields when grown as a main cash crop, and suggest that it is more popular in home gardens and mixed-cropping schemes. Moreover, lablab is a traditional food and fodder crop in Africa, including Tanzania (Maass et al., 2010), and offers great potential for smallholder farming systems. However, nowadays, lablab's utilization by farmers is in steady decline, being outperformed by other leguminous species such as common bean (*Phaseolus vulgaris*) and cowpea (*Vigna unguiculata*) (Bourgault & Smith, 2010).

The Soil fertility depletion is a widespread limitation to yield improvement in maize based intercropping systems throughout Eastern and Southern Africa (Mekuria & Waddington, 2002; Keston et al., 2013). It is widely considered as a major factor contributing to low productivity and non-sustainability of existing production systems and a major source of low returns to other inputs and management committed to smallholder farmers (Sanchez & Jama, 2002; Mekuria & Waddington, 2002). As the case with most other SSA countries, Tanzania faces a challenge of declining soil fertility with nitrogen considered the main limiting factor to crops growth (Keston et al., 2013). Nitrogen is an essential element for plant growth and development and a key issue of agriculture because it is an important component of plant cells at the structural, genetic and metabolic levels, getting involved in many processes of plant growth and development which finally lead to yield as well as the quality of harvested organs such as seeds or shoot biomass (Salon et al., 2011). A study by Unkovich et al. (2008) indicates that nitrogen fertilizers contribute to resolving the challenge the world is facing, feeding the human population, although urea which is the most commonly used nitrogenous fertilizer, has now become a costly input for farmers. The solutions to smallholder farmers' soil fertility problems may be found in the strategic combination of organic resources and nitrogen-fixing legumes that work symbiotically with special bacteria, *rhizobia*, which live in the root nodules. The symbiosis is manifested by the development of nodules on the roots of legumes acting as factories of nitrogen fixation (Collins, 2004). *Rhizobium* inoculants may be used as a cheaper substitute for urea in the production of food legume crops (Karim et al., 2001). The beneficial effect of *rhizobial* inoculates in increasing yield of leguminous crops results from the activity of its root nodule bacteria, which fix atmospheric nitrogen making it available for the plants. Legumes can meet most of their N needs and contribute to soil N through symbiotic nitrogen fixation (Maobe et al., 1998). Estimates indicate that legumes can fix up to 200 kg N /ha/ year under optimal field conditions (Giller, 2001).

Decomposition and mineralization of legumes organic residues is another key process in ecosystem's carbon cycle, releasing carbon to the atmosphere and is determined by climate and litter quality (Zhang, 2009). It involves insect and microbial decomposers, organically-bound nutrients are released as free ions to the soil solution which are then available for uptake by plants (Mureithi et al., 2005). The use of high quality plant residues could ensure timely nutrients release for enhanced crop uptake. Legumes produce the high quality residues and therefore, offer a low cost opportunity for maintaining soil fertility by contributing nutrient during decomposition (Ibewiro et al., 2000; Baijukya et al., 2004) and improving soil organic matter and soil physical properties (Mureithi et al., 2005).

Plants acquire nutrients from two principal sources which are the soil, (through commercial fertilizer, manure and/or mineralization of organic matter); and the atmosphere (through symbiotic N fixation) (Vance, 2001; Rahman, 2013). Total mineral nutrient uptake is the sum of nutrient content in the stover and grain and estimates the total quantity of a mineral nutrient required to produce a crop (Bender, 2012).

Land equivalent ratio (LER) is an important tool used to evaluate the advantages of intercropping systems; it measures the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops as a collection of separate monoculture (Mazaheri et al., 2006). It further estimates the levels of intercrop interference going on in the intercropping systems which indicates the resources utilization by the component crops (Yancey & Cecil, 1994).

Biological nitrogen fixation by grain legume crops has received a lot of attention because it is a significant N source in agricultural ecosystems (Peoples et al., 2002; Ndakidemi, 2006; Rahman, 2013). The N balance of a cropping system can be improved using legumes but the magnitude of biological N fixation of legumes is highly variable and depends on several factors, such as plant species, inoculation, soil nitrate and water contents (Bender, 2012). However, studies on N_2 fixation in the complex cereal-legume cropping systems are few and therefore there is a need to identify and develop cereal-legumes intercropping systems that would influence N_2 fixation in agricultural systems and complement fertilizer-N use as a sustainable means for soil fertility improvement and consequently crops yields.

2. Cereal-Legume Cropping Systems

Cropping system is an effective ecological farming system that manages and organizes crops so that they best utilize the available resources such as sunlight, water, air, soil, farm labour and equipments (Steiner, 1982). Intercropping system is a type of mixed cropping and defined as the agricultural practice of cultivating two or more crops in the same space at the same time (Andrews & Kassam, 1976; Sanchez, 1976). This is a common practice in SSA, and it is mostly practiced by smallholder farmers. Mixed cropping of cereals and legumes is widespread in the tropics (Molatudi & Mariga, 2012) because legumes used in crop production have traditionally enabled farmers to cope with erosion and with declining levels of soil organic matter and available N (Scott et al., 1987). The common crop combinations in intercropping systems of Tanzania and Africa are cereal-legume, particularly maize-cowpea, maize-soybean, maize-pigeon pea, maize-groundnuts, maize-beans, sorghum-cowpea, millet-groundnuts, and rice-pulses (Beets, 1982; Rees, 1986). It is popular because of its nutritional complimentarity (Edje, 1990). The features of an intercropping system differ with soil, local climate, economic situation and preferences of the local community (Steiner, 1982). In crop rotation, legumes contribute to a diversification of cropping systems and as N_2 -fixing plant, it can reduce the mineral N fertilizer demand.

According to Huang et al. (2006) systems that intercrop maize with a legume are able to reduce the amount of nutrients taken from the soil as compared to a maize monocrop. When nitrogen fertilizer is added to the field, intercropped legumes use the inorganic nitrogen instead of fixing atmospheric nitrogen and thus compete with maize for nitrogen (Kutu & Asiwe, 2010). However, when nitrogen fertilizer is not applied, intercropped legumes will fix most of their nitrogen requirements from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi et al., 2007). Improving performance of maize/legume intercrops can significantly benefit the smallholder (SH) farmers by increasing yield on a limited amount of land, reducing risk of total crop failure, and maximizing the efficiency of labour utilization (Huang et al., 2006). In addition, some of intercropping systems help to stabilize soil nutrient levels, which will keep yields sustainable into the future (Kutu & Asiwe, 2010). Intercropping has negative impact especially harvesting two crops from within one field may be more challenging than harvesting the different crops from separate fields (Thobatsi, 2009). Further, Farmers who traditionally use herbicides to protect their maize plants from competition may face problems if their intercrops are susceptible to the herbicides (Scholl & Nieuwenhuis, 2004). In this case, farmers may have fewer options for herbicide-based weed control, or may have to completely abandon this strategy (Maqbool et al., 2006). Generally, intercropping may not help farmers with very low soil fertility problems because does not rehabilitate poor land successfully (Thobatsi, 2009). Therefore, intercropping systems are deliberately designed to optimize the use of spatial, temporal, and physical resources both above- and belowground, by maximizing positive interactions (facilitation) and minimizing negative ones (competition) among the components (Ndakidemi, 2006). The understanding of the efficient cereal-legume cropping system would be one of the solutions of maximizing land use, spreading economic risk and improving soil productivity through nitrogen fixation.

3. Impact of Cereal-Legume Cropping Systems on Weeds, Diseases, Insects and Water Use Efficiency

Cereal-legume cropping system is one of the traditional farming which control weeds in the small scale farms. This occurs when the competitive ability of the component crops population is higher than the dominant weeds (Dimitrios et al., 2010). For example a study by Belel et al. (2014) indicated that cereals and cowpea reduced striga infestation significantly due to unfavourable cover conditions created by the intercropped crops. Intercropping system helps to reduce weeds population once the crops are established due to increased leaf cover (Dimitrios et al., 2010). Thayamini et al. (2010) reported weed suppression in maize-groundnut and maize-bean intercropping as an integrated weed management tool. Intercropping show weeds control advantages over sole crops because the chemical control is difficult when the crops have emerged especially when a dicotyledonous crop species is combined with a monocotyledonous crop species. Some intercropped species produce toxic chemicals (allelopathy) which suppress growth of weeds (Belel et al., 2014). On other hands, intercrops may provide yield advantages without suppressing the growth of weeds below levels observed in sole crops if intercrops use resources that are not exploitable by weeds or convert resources into harvestable materials more efficiently than sole crops (Thayamini et al., 2010). Intercropping such as wheat-canola-pea has great suppressive effect on weeds compared to sole crop, indicating some type of synergism among crops within intercrops with respect to weed suppression (S. S. Rana & M. C. Rana, 2011). Generally, the weed suppressing ability of intercrop is dependent upon the component crops selected, genotype used, plant density adopted, proportion of component crops, their spatial arrangement and fertility moisture status of the soil (Belel et al., 2014; S. S. Rana & M. C. Rana, 2011; Dimitrios et al., 2010).

Cereal-legume cropping systems also control insects and diseases by provision of barrier that prevent the spread between the host and parasite. This has been reported by Seran and Brintha (2010) on bud worm and corn borer infestation in sole maize being greater than in maize intercropped with soybean. Another study by Thayamini et al. (2010) indicated that the average percentage of maize stalk borer infestation was significantly greater in monocropped (70 percent) than in intercropped maize-soybean. Cereal-legumes intercropping enhance the abundance of predators and parasites, which in turn prevent the build-up of insects and disease, thus minimizing the need of using expensive and dangerous chemical insecticides and fungicide (Sekamatte et al., 2003). Mixed crop species can also delay the introduction of diseases by reducing the spread of disease carrying spores and by modifying environmental conditions so that they are less favorable to the spread of certain pathogens (S. S. Rana & M. C. Rana, 2011). Therefore the simplification of cereal-legume cropping systems can affect the abundance and efficiency of the natural enemies or predators, which depend on habitat complexity for resources. Changes in environment and host plant quality lead to direct effects on the host plant searching behavior of herbivorous insects as well as indirect effects on their developmental rates and on interactions with natural enemies (S. S. Rana & M. C. Rana, 2011).

Cereal-legume cropping systems improve water use efficiency which leads to increases the use of other resources because of the early high leaf area index and higher leaf area which conserve water (Ogindo & Walker, 2005). Thayamini et al. (2010) indicated high water use efficiency in intercrops than sole crops under water limiting conditions hence leading to higher grain yields. This is because intercropping increased light interception, reduce water evaporation, and improve conservation of the soil moisture compared with maize alone (Ghanbari et al., 2010). The total water requirement of intercrop does not increase much compared to sole cropping. For example, a study by Rana and Rana (2011) showed that the water requirement of sole sorghum and intercropping with red gram was almost similar (584 and 585 mm, respectively). Therefore, the total water used in intercropping system is almost same as in sole crops, but yields are increased hence water use efficiency of intercropping is higher than sole crops.

4. Biological Nitrogen Fixation (BNF) in Cereal-Egume Cropping Systems

Dinitrogen (N_2) gas represents almost 80% of the earth's atmosphere and it is not directly available to plants (Davidson et al., 2007). BNF is the process whereby a number of species of bacteria use the enzyme nitrogenase to convert atmospheric N_2 into ammonia (NH_3), a form of nitrogen (N) that can then be incorporated into organic components, e.g. protein and nucleic acids, of the bacteria and associated plants (Davidson et al., 2007; Postgate, 1998). The process is coupled to the hydrolysis of 16 equivalents of ATP and is accompanied by the co-formation of one molecule of H_2 (Chi Chung et al., 2014). The overall reaction for BNF is:

$$N_2 + 8\ H^+ + 8\ e^- \rightarrow 2\ NH_3 + H_2 \tag{1}$$

The conversion of N_2 into ammonia occurs at a cluster called FeMoco, an abbreviation for the iron-molybdenum cofactor. The mechanism proceeds via a series of protonation and reduction steps wherein the FeMoco active site hydrogenates the N_2 substrate (Hoffman et al., 2013). The natural process of BNF offers an economic means of reducing environmental problems and improving the internal resources compared with the production of nitrogen fertilizer by industrial fixation (Aydinalp & Cresser, 2008). Intercropping legumes with non-leguminous crops can result in competition for water and nutrients (People et al., 1989). However, it has been shown that when mineral N is depleted in the root zone of the legume component by the non-leguminous intercrops, N_2 fixation of legumes will be promoted. Legume-*Rhizobium* symbiotic system is the most important biological nitrogen fixation (BNF) process in nature (Peoples et al., 1995), providing about 65% biosphere's available nitrogen for use including the agricultural system (Lodwig et al., 2003). N_2-fixing systems can thrive in soils poor in N and that they are a source of proteins and provides N for soil fertility. Typical environmental stresses faced by the legume nodules and their symbiotic partner (*Rhizobium*) may include photosynthate deprivation, water stress, salinity, soil nitrate, temperature, heavy metals, and biocides (Walsh, 1995). For such constraints to be controlled, legume crops can contribute (or fix) substantial quantities of N into the soil. BNF is important in legume-based cropping systems when fertilizer-N is limited (Fujita & Ofosu-Budu, 1996), particularly in SSA where nitrogen annual depletion was recorded at all levels at rates of 22 kg ha^{-1} (Smaling et al., 1997) and mineral-N fertilization is neither available nor affordable to smallholder farmers (Mugwe et al., 2009). Therefore, the rates of N_2 fixation tend to be highest when plant-available mineral N in the soil is limiting but water and other nutrients are plentiful. Also mineral nutrients may influence N_2 fixation in legumes and non legumes at various levels of the symbiotic interactions: infection and nodule development, nodule function, and host plant growth (O'Hara, 2001). Robson (1978) summarized the nature of the interaction between nutrient supply and combined nitrogen on legume growth as a means for estimating symbiotic sensitivity to their supply or concentration. He highlighted that Co and Mo are required in high amounts for symbiotic nitrogen fixation for host-plant growth than Cu, Ca and P. Although there is an experimental evidence for specific requirements for 11 nutrients (B, Ca, Co, Cu, Fe, K, Mo, Ni, P, Se and Zn) for symbiotic development in some species of legume, only four of these elements (Ca, P, Fe and Mo) appear to cause significant limitations on the productivity of symbiotic legumes in some agricultural soils (O'Hara, 2001). High rates of N_2 fixation in some agricultural soils are commonly achieved because most cropping systems are dominated by cereals that utilise large quantities of soil mineral N (Peoples et al., 2002). Keeping in mind the importance of biological nitrogen fixation process in cereal/legume cropping systems, this will help to utilize the fixed nitrogen to its full potential.

5. Nitrogen Transfer from Legumes to Cereal Crops

The movement of biologically fixed nitrogen from legume to the cereal crop is not well known although; evidence suggests that associated non-legumes may benefit through N-transfer from legumes (Fujita et al., 1992). This N-transfer is considered to occur through root excretion, N leached from leaves, leaf fall, and animal excreta if present in the system (Fujita et al., 1992). The limited studies carried out within SSA suggested that N_2-fixed by a leguminous component may be available to the associated cereal in the current growing season (Eaglesham et al., 1981), known as direct N transfer (Stern, 1993). Further, Eaglesham et al. (1981) showed that 24.9 percent of N fixed by cowpea was transferred to maize crop.

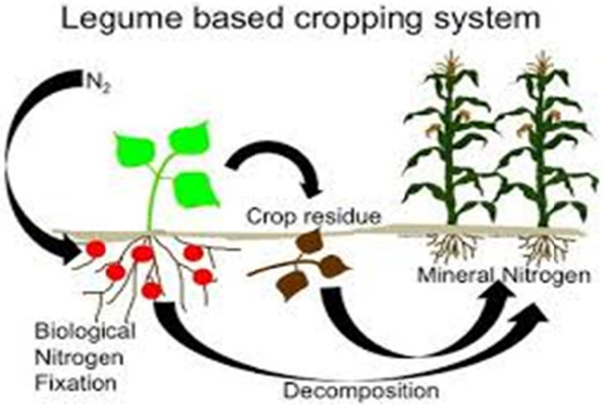

Figure 1. Legume-based cropping systems

Source: https://www.google.co.tz/search?q=cereal-legume+cropping+systems

However, Ofori and Stern (1987) and Danso et al. (1993) reported that there is little or no current N transfer in cereal-legume intercropping system. In addition, Fujita et al. (1992) reported that benefits to the associated non-leguminous crop in intercropping systems is influenced by component crop densities, which determine the closeness of legume and non-legume crops, and legume growth stages. In crop mixtures, any species utilizing the same combination of resources will be in direct competition because most annual crop mixtures such as those involving cereals and legumes are grown almost at the same period, and develop root systems that explore the same soil zone for resources (Reddy et al., 1994; Jensen et al., 2003). Controlled studies showed a significant direct transfer of fixed-N to the associated non-legume species (Eaglesham et al., 1981; Stern, 1993; Ndakidemi, 2006). In mixed cultures, where row arrangements and the distance of the legume from the cereal are far, nitrogen transfer could decrease (Giller et al., 1991). Research has shown that competition between cereals and legumes for nitrogen may in turn stimulate N_2 fixation activity in the legumes (Hardar-son & Atkins, 2003). The cereal component effectively drains the soil N, forcing the legume to fix more N_2. Despite claims for substantial N-transfer from grain legumes to the associated cereal crops, the evidence indicate that benefits are limited (Giller et al., 1991). Benefits are more likely to occur to subsequent crops as the main transfer path-way is due to root and nodule senescence and fallen leaves (Ledgard & Giller, 1995). Therefore, it is important to develop clear understanding on how the fixed nitrogen becomes available to non-leguminous crops in the cereal-legumes intercropping systems.

6. Nutrients Uptake and Partitioning in Plants

Mineral nutrients are usually obtained from the soil through plant roots, but many factors can affect the efficiency of nutrient acquisition (Hell & Hillebrand, 2001). First, the chemistry and composition of certain soils can make it harder for plants to absorb nutrients. The rate of nutrient uptake by roots depends on the concentration of the particular nutrient at the root surface, root properties or plant species, and requirement of the plants (Paul et al., 2005). The nutrients may not be available in certain soils, or may be present in forms that the plants cannot use (Hell & Hillebrand, 2001). Soil properties like water content, pH, and compaction may exacerbate these problems. Figure 2 indicates the maximum availability for the majority of nutrients are at pH = 6.5 *i.e.* under slightly acidic conditions while the availability of metal cations (mostly microelements) increases with acidity, with the exception of Molybdenum (Fageria & Baligar, 2008).

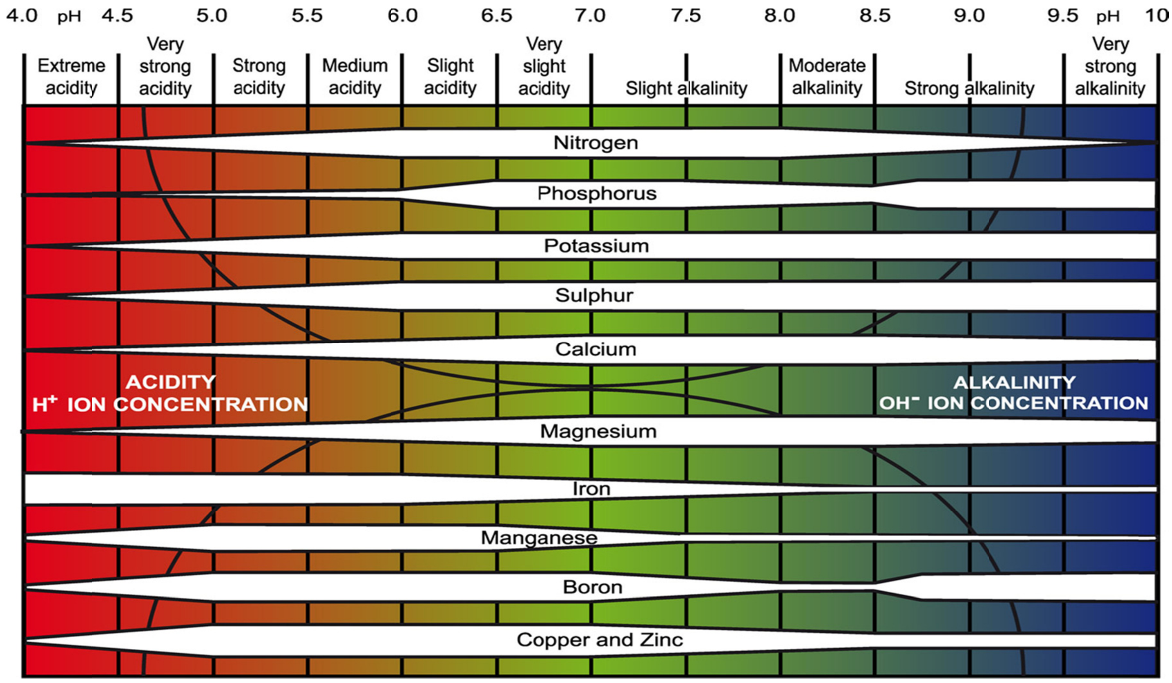

Figure 2. The influence of soil pH on nutrients availability

Soil pH has direct effect on nutrients availability; maximum availability and growth are achieved near neutral pH range (Figure 2). Second, some plants possess mechanisms or structural features that provide advantages when growing in certain types of nutrient limited soils (Jones & Ljung, 2012). In fact, most plants have evolved nutrient uptake mechanisms that are adapted to their native soils and are initiated in an attempt to overcome nutrient limitations. One of the most universal adaptations to nutrient-limited soils is a change in root structure that may increase the overall surface area of the root to increase nutrient acquisition or may increase elongation of the root system to access new nutrient sources (Jones & Ljung, 2012). These changes can lead to an increase in the allocation of resources to overall root growth, thus resulting in greater root to shoot ratios in nutrient-limited plants (Lopez-Bucio, 2003). The plant species are assumed to have different rooting and uptake patterns, such as cereal/legume intercropping system, more efficient use of available nutrients may occur and higher N-uptake in the intercrop have been reported, compared to monocrops (Fujita & Ofosu-Budu, 1996). Dahmardeh et al. (2010) reported that maize-cowpea intercropping increases the amount of nitrogen, phosphorus and potassium contents compared to monocrops of maize. Despite the beneficial effects of the intercropping to the cereal crops, it may also accelerate soil nutrient depletion, particularly for phosphorous, due to more efficient use of soil nutrients and higher removal through the harvested crops (Mucheru-Muna et al., 2010). Recent efforts on replenishment of soil fertility in Africa have been through the introduction of legumes as intercrop and/or in rotation to minimize external inputs (Sanginga & Woomer, 2009). Since plants are non-motile and often face nutrient shortages in their environment; they use mechanisms in an attempt to acquire sufficient amounts of the macro- and micronutrients required for proper growth, development and reproduction (Vance, 2001). These mechanisms include changes in the developmental program and root structure to better "mine" the soil for limiting nutrients, induction of high affinity transport systems and the establishment of symbioses and associations that facilitate nutrient uptake (Beyer, 2010). Together, these mechanisms allow plants to maximize their nutrient acquisition abilities while protecting against the accumulation of excess nutrients, which can be toxic to the plant (Vance, 2001). It is clear that the ability of plants to utilize such mechanisms exerts significant influence over crop yields as well as plant community structure, soil ecology, ecosystem health, and biodiversity. Therefore, the plant tissues analysis can be useful to diagnose plant nutritional problems and monitor effectiveness of a soil fertility improvement through maize-legume cropping systems and fertilization.

7. Legume Biomass Decomposition and Mineralization

Low soil fertility and nutrients mining are the main causes of decline in crop yield and productivity in Africa. Despite the prevalence of poor soils, fertilizers application rate in sub-Saharan Africa is only 9 kg ha^{-1} compared with global mean of 101 kg ha^{-1} (Camara & Heinemann, 2006) with high cost and limited access being cited as main contributing factors. The organic system favours the use of renewable resources and emphasizes the use of techniques that integrate natural processes such as nutrient cycling, biological nitrogen fixation and soil regeneration (Birech & Freyer, 2007). The magnitude of nutrient cycling is a function of (i) the biomass production, (ii) the nutrient contents and (iii) the decomposition rate (Lehmann et al., 2000). Decomposition is a complex process regulated by the interactions between organisms (fauna and microorganisms), physical environmental factors (particularly temperature and moisture) and resources quality (defined here by lignin, nitrogen and condensed and soluble polyphenol concentrations) (Swift et al., 1989). Fujita and Ofosu-Budu, (1996) reported that, the soil N may be replenished through decomposition of legume residues/ biomass. The nutrient accumulation within the biomass alone, does not give adequate information about the nutrient turnover, which is the relevant parameter for the magnitude of nutrient cycling. For this purpose, the biomass production has to be measured, which is more difficult for creeping legumes like Dolichos lablab in comparison with cereal crops (Lehmann et al., 2000). Further, there is evidence that the mineralization of decomposing legume roots in the soil can increase N availability to the associated crop (Dubach & Russelle, 1994; Schroth et al., 1995; Evans et al., 2001). However, litter decomposition is one of the key biogeochemical processes in forest ecosystems and it is estimated that the nutrients released during litter decomposition can account for 69-87% of the total annual requirement of essential elements for forest plants (Swift et al., 1989). The leaf litter decomposition in cropping systems is obviously easier than on the decomposition of any other parts of the plant because of the two reasons (Anderson, 1993). First, leaf litter decomposition is faster, and thus less time-consuming, especially in the tropics and subtropics (Harmon et al., 1999; Anderson, 1993). The decomposition of twig and stem litter takes significantly longer due to the higher content of more recalcitrant compounds contained in these highly lignified plant parts, and therefore long-term observations need to be considered (Harmon et al., 1999). Second, the concentration of nutrients contained in leaf litter is generally higher than in any other parts of a plant. Decomposition of legume crops is mainly determined by its chemical composition (Carbon to Nitrogen (C:N) ratio of the material) and on climatic conditions (Jama & Nair, 1996). Decomposition of residues takes place in two phases; the first phase is rapid which is controlled by C:N ratio and the second phase are slower controlled by lignin and polyphenol content of the residue (Jama & Nair, 1996). Marandu (2005) reported that, the rate of first phase decomposition is accelerated by high contents of soluble nitrogen in the residue. The critical levels of nitrogen below which the rate of decomposition is retarded are 18 to 22 mg/g (Mellilo et al., 1982). High lignin and polyphenol content of the residue retard the decomposition reducing nitrogen net mineralization while enhancing immobilization in the second phase. Determining the ratio of carbon to nitrogen (C:N) in the legume crop biomass is the most common way to estimate how quickly biomass N will be mineralized and released nutrients for use by the succeeding crop (Zhi-an et al., 2001). As a general rule, legume crop residues with C:N ratios lower than 25:1 will release N quickly. Values exceeding 30 parts carbon to one part nitrogen (C:N ratio of 30:1) are generally expected to immobilize N during the early stages of the decomposition process. Legume cover crops such as hairy vetch and crimson clover, when killed at flowering immediately before maize planting; generally will have C:N ratios of 10:1 to 20:1 (Ranells & Wagger, 1992). During decomposition, some materials will decompose fairly fast losing about 50% of their dry matter in 4-6 weeks (Wangari & Msumali, 2000). Residues with C:N ratios greater than

25:1 decompose more slowly and their N is more slowly released. N release from green manure occurs slowly at or below 5 ^oC increases to a maximum at 30-35 ^oC and declines at a higher temperature, the release is also favoured by soil conditions that are neither exceptionally dry nor flooded (Seiter & Horwath, 2004). The intercrop legume may accrue N to the soil and this may not become available until after the growing season, improving soil fertility to benefit a subsequent crop (Ofori & Stern, 1987; Ledgard & Giller, 1995). According to Peoples and Herridge (1990) to maximize the contribution of legume N to a following crop, it is necessary to maximize total amount of N in legume crop, the proportion of N derived from N_2 fixation, the proportion legume N mineralized and the efficiency of utilization of this mineral N. Ammonia volatilization from legume residues may be high when they are left on the soil surface, but the losses do not appear to match those measured in some fertilized systems. Larsson et al. (1998) estimated that 17% of the N in alfalfa mulch was lost as ammonia within 30 days of placement. Janzen and McGinn (1991) measured 15% volatilization losses from a lentil (*Lens culinaris*) green manure when left on the soil surface, and Venkatakrishnan (1980) measured ammonia losses of 23% from a sesbania (*Sesbania rostra*) green manure after 63 days. Losses of N by ammonia volatilization from legume residues as well as fertilizers can be greatly reduced or eliminated by incorporating amendments into the topsoil (Janzen & McGinn, 1991; Larsson et al., 1998). It is worth noting that incorporating legume residues may reduce N losses through ammonia volatilization at the expense of increasing potential denitrification losses of N (Peoples et al., 1995). While there are not sufficient data to state conclusively that legume-N is less susceptible to ammonia volatilization than fertilizer N, there are a couple of mechanisms that would help explain such a difference. The temporary immobilization of N and the production of acidic products during cover-crop decomposition might reduce NH_3 volatilization losses. Moreover, the addition of green manures to flooded rice systems may have the effect of increasing the CO_2 in the floodwater, and reducing the pH and thus ammonia loss (Peoples et al., 1995). Data by Diekmann et al. (1993) are consistent with such a mechanism, where flooded rice fields experienced greater percent losses when receiving N from urea compared to N from green manures. The effect of plant tissue quality on decomposition and N mineralization rates has been well documented (Myers et al., 1994; Peoples et al., 1995; Fillery, 2001), but a great work remains to test and optimize different crop combinations appropriate to particular regions. Therefore, it is important to explore the most efficient legume biomass decomposition that would have great effects on soil fertility improvement in cereal/legumes cropping systems.

8. Grain Yields in Cereal-Legume Cropping Systems

One of the most important reasons for intercropping is to ensure that an increased and diverse productivity per unit area is obtained compared to sole cropping (Sullivan, 2003). Intercropping provides an efficient utilization of environmental resources, decreases the cost of production, provides higher financial stability for farmers, decreases pest damages, inhibits weeds growth more than monocultures, and improves soil fertility through nitrogen increasing to the system and increase yield and quality (Deveikyte et al., 2009). Land productivity measured by land equivalent ratio and monetary gain showed advantages of mixed cropping of cereals and legumes (Molatudi & Mariga, 2012). However, plants planted close together usually have an increased risk of diseases, high percentage of lodging and increased interplant competition for light, water and nutrients (Molatudi & Mariga, 2012). The number of plants that can be supported per unit area is largely dependent upon soil water availability. Grain yield is the most important outcome of cereal-legume crops and it depends on a number of yield components of cereal and legume. Several studies have shown that over time, average dry matter (DM) and grains yields are higher with intercropping than when each of the plant species in the mixture is grown as a monoculture (Vandermeer, 1989). In most parts of SSA, legumes are usually inter-cropped with cereals to improve land productivity through soil amelioration (Adeleke & Haruna, 2012). This is because the cereal-legume cropping systems help to minimize excessive loss of N while maximizing N use efficiency and meeting cereal-legume grain yields. However, there is no sufficient information on yields of using different cereal-legume cropping systems in Tanzania. Therefore, it is expected that, the success of cereal-legume cropping systems can have economic impact to smallholder farmers.

9. Land Equivalent Ratio (LER)

Land equivalent ratio is defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping (Waddington et al., 1989). Therefore it shows the efficiency of intercropping for using the environmental resources compared with monocropping. Land equivalent ratio (LER) can be used to assess land returns from the pure stand yields and from each separate crop within the mixture (Dariush et al., 2006). Muoneke et al. (2007) found that the productivity of the intercropping system indicated yield advantage of 2-63 percent as depicted by the LER of 1.02-1.63 showing efficient utilization of land resource by growing the crops together than separate planting. Further studies by Kipkemoi et al. (2001), Addo-Quaye et al. (2011), Osman et al. (2011), Raji (2007) and Samba et al. (2007) found that LER was greater than unity, implying that it will be more productive to intercrop cereal-legumes than grow them in monoculture. It is usually stipulated that the level of management must be the same for intercropping and sole cropping (Osman et al., 2011). The LER is interpreted based on the following criteria (Dariush et al., 2006).

LER > 1, indicates Intercropping to be more efficient than the Monocropping;

LER < 1, indicates a loss in efficiency due to intercropping;

LER = 1, indicates no difference in yield between the intercrop and monocrop.

Lithourgidis et al. (2011) proposed the simplest equation for computing LER; that is,

$$LER = \Sigma(Ypi/Ymi) \tag{2}$$

Where, *Yp* is the yield of each crop in the intercrop; *Ym* is the yield of each crop in the monocrop.

Generally, monoculture legumes have higher yields than those intercropped (Waddington et al., 1989).

However, *LER* cannot address the problem of assessment of yield advantage/disadvantage if the objective is to assess the yield advantage on the basis of the criterion, namely yield per plant. Mead and Willey (1980) reported that land equivalent ratio does not give the exact value of yields, instead, it represents the yield advantages or disadvantages of intercrops compared with sole crops and the time factor is less considered for crop maturity. A lot of maize-legume cropping systems have been done focusing on intercropping and monocropping but no research when maize-legume seeds inoculations have been used in intercropping. Identifying appropriate LER will help to indicate the efficient cropping system among the cropping systems which involves maize-legume (*Dolichos lablab* and *Phaseolus vulgaris*).

10. The Economic Benefits of Cereal-Legumes Intercropping over Sole Cropping

One of the advantages of cereal-legumes intercropping includes potential for increased profitability and low fixed costs for land as a result of a second crop in the same field (Thobatsi, 2009). Cereal-legumes intercropping system has higher cash return to smallholder farmers than sole cropping (Seran & Brintha, 2010). A study by Vijay et al. (2014) reported the maximum economic benefits or the highest net return were obtained when cereal crops and legumes were planted at the same time under intercrops system. Further studies by Ashish et al. (2015) and Osman et al. (2010) using benefit cost ratio (BCR) and monetary advantages index (MAI) revealed that maize-cowpea intercropping was found to be profitable than their sole crops and increase the income for smallholder farmers, and compensate losses due to uneven condition. Cereal-legumes intercropping could enhance total productivity of the system with low input investment by changing planting population and configuration (Ashish et al., 2015). Furthermore, intercrop can give higher yield than sole crop yields, greater yield stability, more efficient use of nutrients, better weed control, provision of insurance against total crop failure, improved quality by variety, also cereal as a sole crop requires a larger area to produce the same yield as cereal in an intercropping system (Matusso et al., 2014). Despite these multiple benefits, few studies have been done to highlight the effects of intercropping legumes with cereals on agricultural productivity and economic benefits. The study on legume-cereal intercropping system is needed to show the economic benefits and how it can meet the household food requirements.

11. Conclusions

Intercropping is an old practice used by subsistence farmers, especially under rain-fed conditions. Maize/legume intercropping system has become one of the solutions for food security among small scale maize producers due to unaffordability of chemical nitrogenous fertilizers and limited access to arable land. From the comparisons of typical cereal-legume systems and monoculture practices, this review suggests that sustainable agriculture involves the successful management of agriculture resources to satisfy changing human needs while maintaining or enhancing the environment quality and conserving natural resources. It relies greatly on renewable resources, and on-farm nitrogen contributions as achieved largely through biological nitrogen fixation. Intercropping provides a balanced diet, reduces labour peaks, and minimizes crop-failure risks. It has also been suggested that intercropping can reduce the adverse effects of pests (diseases, insects, and weeds), provide higher returns, ameliorate soil fertility and protect soil against erosion. Therefore, in order to feed the growing population steps toward greater agricultural sustainability through effective use and management of internal resources focusing on cereal-legume cropping systems should be given due consideration.

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