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Roles of eco-friendly low input technologies in crop production in sub-Saharan Africa

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Abstract: The global population doubled in the past decades and the situation is more serious in sub-Saharan African Countries. This also resulted in increased demand for biofuels, land, water, and increased pressure of prices of agricultural products, land, and water. Regardless of this it has been possible to increase per capita world food production by 24% and 40% by the adoption of green revolution technologies such as high yielding cultivars, fertilizers, pesticides, and irrigation water. However, these technologies have their own drawbacks, which may be attributed to their adverse effect on human health, environment, and escalating prices of agricultural inputs, especially fertilizer. On the other hand, there are technologies which have been proved to be effective in addressing these problems. As a result, it is demanding to look for these alternative eco-friendly agricultural technologies that can be used along with modern practices to tackle the challenge in a sustainable manner. These eco-friendly technologies may include intercropping, alley-cropping, agroforestry, cover crops, composting, and vermin-composting. Hence, depending on the suitability and availability of the technologies it is possible to address both food security and environmental problems simultaneously by

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PUBLIC INTEREST STATEMENT

In the past decades, it has been possible to increase food production to meet the global food demand that aroused the following population increase. However, the increase in food production during this time was impossible without the use of agrochemicals (pesticides, herbicides, etc), high yielding crop cultivars, and fertilizers. On the other hand, unwise use of these agrochemicals including fertilizer had a serious consequence on the environment and human health in some parts of the world. Regardless of this, there are alternative technologies that can boost crop yield avoiding adverse effect on the environment and humans. The technologies are low cost, environmentally friendly, and accessible even to low income farmers. The ecologically sound and cost-effective technologies include intercropping, alley-cropping, agroforestry, cover crops, composting, and vermin-composting. Hence, depending on the suitability and availability of the technologies it is possible to address both food security and environmental problems simultaneously by integrating these technologies along with modern techniques such as inorganic fertilizers, irrigation, and improved varieties.

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integrating these technologies along with modern techniques such as inorganic fertilizers, irrigation, and improved varieties in a sustainable manner.

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**Keywords:** green revolution; eco-friendly; environment; global population; vermi-composting; fertilizer

1. Introduction

The global population doubled in the last century (Wik et al., 2008). Despite this with green revolution technologies, which involved the use of high inputs such as seeds of high-yielding cultivars, fertilizers, pesticides, and irrigation water it has been possible to increase per capita world production by 24% and 40%. This approach, involves the use of high-level inputs referred to as high external input agriculture (HEIA), and the high-level inputs are difficult to be accessed by the majority of the world population as it needs high capital investment and well functioning economic and physical infrastructure for effective implementation (Pretty 1999, as cited in Graves & Waldie, 2004).

Further, at a current rate of growth, the world population is projected to reach nine to ten billion in 2050 (Wik et al., 2008). As a result, to feed the growing world population which will require doubling the production by 2050 in turn attributed with an increase in demand for biofuels, which could further increase pressure on inputs, prices of agricultural produce, land, and water (Hosam et al., 2010). Worsening the situation in Sub-Saharan Africa also the increasing population pressure has contributed to the land shortage, which in turn led to a decline in crop growth, yield, and soil fertility (Gruhn et al., 2000). For instance, in Ethiopia, the population is growing at a fast rate, while land available for agricultural production is limited and the use of higher-yielding crop varieties and fertilizer has been found to be critical to meet the national food demand (Beyene et al., 2008).

Consequently, traditional practices needed for soil fertility improvement such as slash and burn, crop residues, and animal manures are no more effective in improving soil fertility status and replenishing the lost nutrients either by crop removal or through erosion and this is combined also with an insufficient supply of inorganic fertilizers particularly in sub-Saharan Africa (Gruhn et al., 2000) resulting in a decline in crop yield and fail to meet the growing food demand.

On the other hand, though there are success stories by adopting the green revolution in combating rural food insecurity, the green revolution has its own drawbacks in that it adversely affects human health and the environment (Menale & Zikhali, 2009). Further, modern agricultural techniques are characterized by using of an excessive amount of fertilizer, which is subject to loss through erosion exacerbating the environmental pollution problems (Rodriguez et al., 2004). Consequently, agricultural intensification and expansion have destroyed biodiversity and habitats, driven wild species to extinction, accelerated the loss of environmental production services, and eroded agricultural genetic resources essential for food security in the future (Hosam et al., 2010).

Moreover, the adverse effects of utilizing high external agriculture input are thus, mainly associated with environmental and ecological effects ultimately resulting also in health problems (both humans and animals) (Garg & Garg, 2006; Hosam et al., 2010; Weil, 1990). Similarly, untimely and inappropriate application and usage of pesticides, which impose unnecessary cost and cause damage to consumers, wildlife, etc. are another case in point (Weil, 1990). Further, pesticides and other chemicals impose serious and extensive environmental damages and which in turn cause health risks. Long-term research results revealed that continuous use of inorganic fertilizers under continuous cultivation can lead to soil quality deterioration (Ano & Ubochi, 2007; Saha et al., 2010).
Hence, the combined use of organic and inorganic nutrient sources has been suggested to address such problems.

However, presently, the adverse effects of heavy fertilizer use on the environment are confined to some developed countries and a few regions in developing countries (Gruhn et al., 2000; Weil, 1990). On the contrary, in many developing countries input, i.e. commercial fertilizers and chemicals markets are unreliable, inefficient, and out of reach for subsistence cultivators or smallholder farmers (Tripp, 2006).

In short, it is becoming argumentative whether to use modern inputs or to adopt low external input technologies (Tripp, 2006). Hence, especially in sub-Africa judicious use of inorganic fertilizer along with organic fertilizer is a demanding issue to boost crop productivity. Moreover, attempts should also be made to integrate the inorganic, i.e. use of chemical fertilizers with other organic soil fertility improvement techniques, which will be discussed later in detail.

Besides, low external input technology (LEIT) may benefit poorer rural households who are unable to afford purchased inputs (Tripp, 2006). Therefore, the application of locally available nutrients at higher rates through low external input agricultural techniques combined with optimal use of external nutrients appears to be the most appropriate strategy in the existing economic environment (Jagera et al., 2003).

To sum up, above all nowadays concerns about the environment are growing and different lessons learned from the limitations of high external input technologies in addressing the issue of food demand especially in industrialized nations. However, the right technological solutions combined with the right policy directions for the future can effectively contribute to a sustainable and equitable global food system. A new global food system should assure that everybody has access to sufficient food and that poverty should be reduced significantly without doing damage to the natural environment (Hosam et al., 2010) and looking for more ecologically friendly and sound technology options is a pressing demand. As a result of these, the use of nonrenewable inputs such as pesticides and fertilizers that can damage the environment or harm the health of farmers and consumers is minimized and more emphasis is placed on the use of such techniques as for example, intercropping, agroforestry, cover crops, or animal manure. Hence, the drawbacks of using excess chemicals and success stories of low input technologies and different types of technological options will be discussed in the following section.

2. Adverse effects of overapplication of agrochemicals
In general, agricultural practices, which involve area-wide intensive agriculture with high inputs such as fertilizer, pesticides, irrigation, have a negative impact on biodiversity, soil, climate, water, landscape, rural culture, etc. (Oppermann, 2010).

2.1. Effects of nitrogenous and phosphorus fertilizers
Leaching and run-off of surplus nitrogen (N) and phosphorus (P) into rivers, lakes, and inlets from agricultural watershed can cause environmental problems. Among these is eutrophication, which is present due to an excess accumulation of nutrients in the water that promotes the overproduction of algae. Excess surface algae deprive underwater plants of sunlight, which in turn alters the aquatic food cycle. The decomposition of dead algae by bacteria reduces the amount of oxygen in the water available for fish, which may potentially affect their survival (Gruhn et al., 2000; Weil, 1990).

Excess application of N fertilizers and manures is contributing to nitrate pollution. Nitrogenous fertilizers also contribute to N₂O, which is a greenhouse gas and may also contribute to the destruction of the stratospheric ozone when it is converted to nitric oxide (Byrnes, 1990). Further, mismanagement such as intensive use of ammonia-containing fertilizers another cause of soil acidification by decreasing the soil pH (Certini & Scalenghe, 2006; Eyasu, 2002; Foth, 1990).
Moreover, health-related problems are also found to be serious due to polluted water by excessive application of inorganic fertilizers especially N. Hence, the increased quantities of N and more particularly of phosphorus, in a water body, may enter from the run-off coming from the agricultural fields and the excessive concentration of nitrate in a polluted water is very dangerous as it may cause methemoglobinemia, the blue baby disease in infants, and other disease and stomach disorders in adults (Garg & Garg, 2006).

Contrary to these, at present time the problem in developing countries like Ethiopia is not serious as there is limited use of N and P fertilizers (Beyene et al., 2008). However, there is a potential of pollution due to the inappropriate use of such fertilizers i.e., untimely application or improper placement of the applied fertilizer. Hence, to avoid the long-term repercussion all stallholders should work hand in hand.

2.2. Pesticides and other Organo-chemicals
The application of pesticides according to spray schedules rather than as a last recourse in response to pest populations demonstrated to exceed economic thresholds is a case in point: imposing unnecessary costs and posing unnecessary risks to farm workers, wildlife, and consumers (Weil, 1990).

Abdollahi et al. (2004), who reviewed about the toxicity of pesticides, concluded that mechanisms of toxicity for most pesticides, including organophosphates, bipyridyl herbicides and organochlorines attributed to stimulation of free radical production, induction of lipid peroxidation, and disturbance of the total antioxidant capability of the body.

The harmful effects of synthetic organic insecticides and pesticides are enormous and they persist for a long time in the environment. Among these DDT is worth to mention having high toxic effects on aquatic life like fish due to water pollution and on birds eating such poisoned fishes, because of the high concentration of such toxic chemicals. Similarly, it is possible to assume human beings feeding such fishes are also easily victimized due to biomagnifications properties of the chemical (Garg & Garg, 2006).

Further, according to the review by Cocco (2002) most recent studies have hypothesized the role of DDT derivatives for excess risks of cancer of the reproductive organs. This hypothesis also still getting more acceptance as a role for high-level exposure to o,p’-DDE, particularly in post-menopausal ER+ breast cancer.

Organo-chemicals called chlorinated hydrocarbons used in agriculture, such as alderin, kepone, chlordane, methoxy, chlore, etc. are quite harmful due to their property of biomagnifications, which occurs in birds, animals, and human beings, and cause birth defects, neurological damages, etc. Another group of chemical compounds, of chemical compounds known as organo-phosphates such as parathion, malathion, diazonine, etc. if present in water can be directly absorbed through the skin, lungs, and gastrointestinal tract. Humans exposed to excessive amounts of chemicals like propoxer, carboxyl, and aldicarb, suffer from nausea, vomiting, blurred vision, etc. (Garg & Garg, 2006).

On the other hand, in developing countries like Ethiopia pest management relies heavily on cultivation methods and generally pesticides use on small farmers is limited. For instance, in Ethiopia commercial farms are the major users of pesticides and its usage dropped from 4100 Mt in the 1980s to 1,452 Mt in 1990s due to the closure of many state farms. Nearly, 60% of pesticides imports are herbicides during 1998–2002, while insecticide accounted for another 35% of imports (Beyene et al., 2008). Though, presently pesticide use is not a serious problem in our country the lessons learned from other developed nations and some developing countries by overapplication of such chemicals enable all the concerned bodies to give more emphasis to minimize the associated problems by overapplication of such chemicals.
3. Low external input agriculture

3.1. Concepts of low external input agriculture
According to some scholars the concept of low external input technologies includes a wide range of crop management techniques that use local inputs and resources and that take long-term environmental consequences into account (Tripp, 2006). Low input is not an appropriate basic criterion of sustainability; however, rather it is one of the several possible means of achieving the ends of sustainability (Weil, 1990).

3.2. Success cases by adopting low external input technologies
Success stories of adopting low external input agriculture such as integrated pest management, in different countries also indicated improvement in crop yield, household income or profit level, and reduction in the level of using chemicals.

Research conducted in Kenya on low input agricultural technologies also indicated a significant increase in yield and the possibility of realizing economic returns with relatively high application levels of compost (Jagera et al., 2003). However, the availability of material and labor inputs soon became limiting factors.

3.3. Constraints for adoption of low external input technologies
There are different factors, which affect the adoption of low input technologies in sub-Saharan African countries. For instance, under the Ethiopian condition in highlands of Ethiopia, research results also indicated the adoption of various low input techniques such as cover crops and crop residue incorporation related as much to farm size and availability of labor as to the conditions of the soil (Amede et al., 2001). Further, Menale and Zikhali (2009) indicated that the adoption of techniques such as cover crops and crop residue incorporation in the Ethiopian highlands depend on farm size and availability of labor, while adoption of compost technologies depends on livestock ownership. Thus, if there is no enough labor, it would be difficult to apply the technology to big farms. But, still there is a potential for resource-poor farmers with small farm size to adopt these technologies provided other biophysical conditions, which can influence the adoption of the technology are not limiting.

On the top of these, research results in Tanzania revealed that there is a lack of knowledge of effective means for soil improvements, like basic information about the farmyard manure application and compost preparation and poor extension services (Reyes, 2008).

4. Types of low external input technologies

4.1. Intercropping
Intercropping is growing two or more crops at the same time on a single field, which is an ancient practice still used in much of the developing world (Machado, 2009). Intercropping of legumes with cereals has great potential in organic farming for its potential for increasing and stabilizing yields, reducing weed pressure, and sustaining plant health (Huňady & Hochman, 2014). Further, Sullivan (2003) indicated that intercropping offers farmers the opportunity to engage nature’s principle of diversity on their farms. Spatial arrangements of plants, planting rates, and maturity dates must be considered when planning intercrops. Intercrops can be more productive than growing pure stands.

4.1.1. Benefits of intercropping
Intercropping of grain legumes and cereals is a promising idea in organic farming for its potential for increasing and stabilizing yields, reducing weed pressure, and sustaining plant health (Huňady & Hochman, 2014). Intercropping has several advantages over mono-cropping, which include greater land-use efficiency, greater yield stability, and increased competitive ability toward weed (Hailu, 2015). Different types of intercropping practices offer multiple benefits to farmers as compared to sole cropping. Hence, some of the major benefits obtained by intercropping are discussed as follows:
4.1.1. Improved environmental protection and soil fertility. One of the important aspects of intercropping systems is reducing the incidence of pests and diseases. Further, intercropping allows lower inputs through reduced fertilizer and pesticide requirements, which lower the risk of surface water or groundwater contamination in case of a heavy rain immediately after application (Lithourgidis et al., 2011). Hence, this minimize use of chemical pesticides that otherwise affect or pollute the environment.

Intercropping improves soil fertility because legumes intercropped with cereals can enrich the soil by fixing the atmospheric nitrogen changing it from an inorganic form to forms that are available for uptake by plants. The nitrogen fixed through biological methods can partly or fully supply the demand for nitrogen (Huñady & Hochman, 2014; Lithourgidis et al., 2011).

4.1.1.2. Improved crop yield and reduced total crop failure. Intercropping can increase crop productivity as yield attained through intercropping out yield than the yield attained by the average of each component species grown in a monoculture (Bybee-Finley & Ryan, 2018).

Research results in Ethiopia also revealed that a higher total yield of intercropped maize and potato compared to sole cropping with land equivalent ratio (LER>1). Accordingly, the combined yield advantage in terms of total LER indices was greatest (1.58) in the cases of 1 maize: 2 potato intercropping arrangement, which might be attributed to more efficient total resource exploitation and greater overall production as opposed to the other intercropping treatments. This indicated that an additional 0.58 ha (58%) more area would have been needed to get equal yield to planting maize and potato in pure stands (Beyenesh et al., 2017). Similarly, intercropping research conducted in Jordan also indicated the superiority of yield of maize intercropped with potato with LER = 1.43 – 1.55 compared to sole crop yield (LER = 1) (Al-Dallan, 2009). Tamiru (2014) also reported that the total land equivalent ratio (LERtotal = LERmaize + LERharicot bean) significantly varied among the treatments of cropping pattern. Hence, intercropping of maize with haricot bean in a 1:3 ratio resulted in the highest total land equivalent ratio, 54% more efficient than growing both crops in the sole stand (Table 1).

Several research works revealed the role of intercropping on the improvement of crop yield (Punyalue et al., 2017; Sangakkara et al., 2003; Song et al., 2007; Xinru et al. 2016). For instance, Odhiambo and Ariga (2001), reported in Embawi, western Kenya significant effect of intercropping of maize with bean on yield and infestation of striga weed. Further, Xinru et al. (2016) reported that grain yield of chickpea and maize, fava bean and maize, soybean and maize, and rapeseed and maize were 38.2%, 32.6%, 34.0%, and 38.4% higher than their respective monoculture treatment regardless of the fertilization rate. Sangakkara et al. (2003) also reported a 32% significant yield improvement through intercropping compared to the control. According to Punyalue et al. (2017) significantly higher grain yield and crop residue dry weight were recorded for the maize/legume intercrops compared to maize sown after crop residue burning (Figure 1). Averaged over three years 53% higher grain yield was recorded for

| Table 1. Effect of row proportion of haricot bean in intercrop on the productivity of haricot bean crop and total land equivalent ratio of component crops (pooled data of two sites) |
|----------------------------------|------------------|-------------------|-------------------|-------------------|
| **Maize: Haricot bean row proportion** | **Grain (t/ha)** | **Land Equivalent Ratio (LER haricot bean)** | **Land Equivalent Ratio (LER maize)** | **Total land Equivalent Ratio (LERt)** |
| Sole haricot bean | 3.73a | | | |
| 1:1 | 1.64 c | 0.48b | 0.95 | 1.43ab |
| 1:2 | 2.07bc | 0.58ab | 0.82 | 1.40b |
| 1:3 | 2.68b | 0.73a | 0.81 | 1.54a |
| LSD(0.05) | 0.67 | 0.16 | NS | 0.11 |

Values within a column followed by the same letter are not significantly different at 5% probability level (Adopted from Tamiru, 2014)
intercropped maize compared to maize grown residue burning when the legumes were lablab and 33% higher with rice bean, cowpea, and mungbean.

Wheat intercropped with faba bean or maize maize produced significantly greater yield compared to sole wheat (p < 0.05) in 2004 (Table 2). Yield of wheat intercropped with faba bean or maize increased by 30% or 26%, respectively, compared to sole wheat. The yield of maize intercropped with faba bean or wheat was significantly greater than sole maize (p < 0.05) and increased by 39% and 49%, respectively (Table 2). However, compared with sole cropping, the yield of faba bean was only significantly increased when intercropped with maize (p < 0.05), whereas there was no yield increase in faba bean intercropped with wheat (Table 2).

Song et al. (2007) reported that wheat intercropped with faba bean or maize maize produced significantly greater yield compared to sole wheat (p < 0.05) in 2004 (Table 1). Yield of wheat intercropped with faba bean or maize increased by 30% or 26%, respectively, compared to sole wheat. The yield of maize intercropped with faba bean or wheat was significantly greater than sole maize (p < 0.05) and increased by 39% and 49%, respectively (Table 1). However, compared with sole cropping, the yield of faba bean was only significantly increased when intercropped with maize (p < 0.05), whereas there was no yield increase in faba bean intercropped with wheat (Table 1). Further, the same author reported that intercropping had the same effect on yields of wheat, maize, and faba bean in 2005 as in 2004. The yield of wheat intercropped with faba bean or maize was enhanced by 7% or 24%, respectively, compared with sole wheat. As in 2004, intercropping markedly increased the yield of maize intercropped with faba bean and wheat (by 46% and 34%, respectively) (Table 1).
Table 2. Grain yield of wheat, maize, and faba bean in different cropping systems in 2004 and 2005

|                | Yield (kg ha⁻¹) | Yield increase (%) | Yield (kg ha⁻¹) | Yield increase (%) |
|----------------|-----------------|--------------------|-----------------|--------------------|
| Wheat          |                 |                    |                 |                    |
| W              | 6,653 ± 567de   | -                  | 5,262 ± 229d    | -                  |
| W/F            | 8,395 ± 636 c   | 30                 | 5603 ± 751 cd   | 7                  |
| W/M            | 8155 ± 489 c    | 26                 | 6503 ± 195 c    | 24                 |
| Maize          |                 |                    |                 |                    |
| M              | 11,617 ± 2010b  | -                  | 15,226 ± 2191 b | -                  |
| M/F            | 16,217 ± 1056a  | 39                 | 22,233 ± 1594 a | 46                 |
| W/M            | 17,333 ± 2897a  | 49                 | 20,406 ± 3050 a | 34                 |
| Fababean       |                 |                    |                 |                    |
| F              | 5,112 ± 578 f   | -                  | 5,737 ± 282 d   | -                  |
| W/F            | 5,360 ± 663 ef  | 5                  | 5,781 ± 358 d   | 1                  |
| W/M            | 6720 ± 400 d    | 31                 | 6745 ± 1456 cd  | 18                 |

Means of three replicates ± standard error. Values in the same column followed by different letters are significantly different (p < 0.05). W Sole wheat; M sole maize; F sole faba bean; W/M intercropping of wheat and maize; W/F intercropping of wheat and faba bean; M/F intercropping of maize and faba bean. Adopted from Song et al. (2007)

According to Tamiru (2014) also intercropping of maize with haricot bean in 1:1 ratio produced the highest grain yield per plant compared to sole maize and intercropping of maize in 1:2 ratio. However, statistically similar total grain yield per hectare was obtained when intercropping maize in a 1:1 ratio with haricot bean compared to sole maize production (Table 3)

On the other hand, Graves and Waldie (2004) also indicated yield increments by intercropping of legumes with cereals are not always achieved. Further, research conducted by Molla and Getachew (2018) revealed that intercropping of maize with fenugreek, field pea, and haricot bean did not significantly (p > 0.05) affect the grain yield. According to the same authors, these higher differences between the sole and intercropping for maize grain yield and biomass would be associated with competition between the main and secondary crops in the intercropping for limited growth resources.

Intercropping is best practice with respect to bringing a more stable natural ecosystem. In areas where there is a problem of weather fluctuations which subject to extreme weather conditions such as frost, drought, and flood. Intercropping provides insurance against crop failure or against unstable market prices for a given commodity (Lithourgidis et al., 2011). Raseduzzaman and Jensen (2017) also indicated that climate change is adversely affecting crop yield and yield stability overtime in mono-cropping systems. As a result growing of two or more crop species in

Table 3. Effect of row proportion of Haricot bean in intercrop on the productivity of maize crop and total land equivalent ratio (pooled data of two Sites)

| Maize: Haricot bean row proportion | Grain yield per plant (g) | Total grain (t/ha) | Total land equivalent ratio (LERt) |
|-----------------------------------|---------------------------|--------------------|-----------------------------------|
| Sole maize                        | 116.7b                    | 3.68a              |                                   |
| 1:1                               | 131.4a                    | 3.49ab             | 1.43ab                            |
| 1:2                               | 104.5bc                   | 3.00b              | 1.40b                             |
| 1:3                               | 99.11c                    | 2.95b              | 1.54a                             |
| LSD(0.05)                         | 16.01                     | 0.56               | 0.11                              |

Values within a column followed by the same letter are not significantly different at 5% probability level (adopted from Tamiru, 2016)
the same field simultaneously increases resource use efficiency and crop productivity than the growing of crops in sole.

4.1.1.3. Ecological stability. Ecologists tell us that stable natural systems are typically diverse, containing many different types of plants, arthropods, mammals, birds, and microorganisms. In stable systems, serious pest outbreaks are rare, because natural controls exist to automatically bring populations back into balance. Planting crop mixtures, which increase farms cope biodiversity, can make crop ecosystems more stable, and thereby reduce pest problems (Sullivan, 2003).

Further, Lithourgidis et al. (2011) indicated that intercropping of compatible plants promotes biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment, which also increase the stability of the ecosystem.

4.1.1.4. Effect on soil biodiversity. According to Punyalue et al. (2017) soil biodiversity, determined at the time of maize flowering in the third season of cropping was enhanced by the maize/legume intercrops, with the abundance of soil animals closely correlated with crop and residue dry weight and N contents (Table 4). The abundance and richness of the soil macrofauna increased under maize/legume intercrops. The number of individual soil animals was 80 m−2 in maize sown after residue burning and three to five times as high in the intercrops.

According to Song et al. (2007) microbial biomass C (MBC) and biomass N (MBN) in the rhizosphere of sole wheat, fababean, and maize differed from each other in 2004. Microbial biomass C in the rhizosphere of sole fababean was significantly higher than sole wheat, whereas MBN in the rhizosphere was lower (p < 0.05). Microbial biomass C in the rhizosphere of wheat and fababean was significantly affected by intercropping, but had no effect in maize. In wheat, intercropping with fababean or maize strongly increased MBC (p < 0.05) compared with sole wheat. On the other hand, sole fababean had a higher MBC (p < 0.05) than fababean intercropped with wheat or maize. In contrast with MBC, MBN in the rhizosphere of wheat was significantly reduced (p < 0.05) when intercropped with fababean or maize compared with sole wheat (Table 5).

| Table 4. Soil biodiversity as influenced by intercropping of maize with lablab, rice bean, cowpea, mungbean |
|-------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Abundance of macrofauna groups (individual animals m−2) | Lablab | Rice bean | Cowpea | Mungbean |
|-------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Insects | 53.30y | 64.00y | 69.30y | 21.30x |
| Other arthropods | 10.70 | 42.70 | 10.70 | 26.7 |
| Earthworms | 341.70z | 186.70y | 192.00y | 250.70xy |
| Total | 378.70y | 293.30y | 272.00y | 298.70y |
| Arbuscular mycorhizal funji in the root zone (a,b) | 5.30y | 5.30y | 6.20y | 5.60y |

a) Different letters designate a least significant difference of 0.05.
b) Number of major species groups. For the purposes of this study, organisms were quantified in broad categories (eg ants, beetles, and centipedes) rather than by species.
* Significant at P, 0.05; ** significant atp, 0.01; NS indicates not significant at p, 0.05.
Adopted from Punyalue et al. (2017).
Table 5. Microbial biomass C, MBN, in the rhizosphere of wheat, maize, and faba bean in different cropping systems in 2004 and 2005

|          | 2004                  | 2005                  |
|----------|-----------------------|-----------------------|
|          | MBC (mg C kg\(^{-1}\) soil) | MBN (mg N kg\(^{-1}\) soil) | MBC (mg C kg\(^{-1}\) soil) | MBN (mg N kg\(^{-1}\) soil) |
| Wheat    | 169 ± 4 c             | 101 ± 4 a             | 203 ± 27 f             | 154 ± 5a               |
|          | W/F                   | 230 ± 13a             | 90 ± 5 b              | 316 ± 39a             | 106 ± 8bc             |
|          | W/M                   | 237 ± 2a              | 86 ± bc               | 274 ± 28ab            | 108 ± 15bc            |
| Maize    | 136 ± 4bc             | 73 ± 8 c              | 206 ± 13ef            | 95 ± 12bcd            |
|          | M/F                   | 164 ± 27bc            | 84 ± 8bc             | 243 ± 17bcd           | 101 ± 11bcd           |
|          | W/M                   | 158 ± 37bc            | 74 ± 10 c            | 228 ± 12cdef          | 84 ± 10d             |
| Fababean | F                     | 200 ± 11b             | 83 ± 3bc             | 301 ± 19a            | 101 ± 3 c            |
|          | W/F                   | 167 ± 15b             | 85 ± 10bc            | 212 ± 19ddef          | 100 ± 15bcd           |
|          | M/F                   | 164 ± 15 c            | 76 ± 10bc            | 254 ± 15bc           | 111 ± 4b             |

Means of three replicates ± standard error. Values in the same column followed by different letters are significantly different (p < 0.05).

W Sole wheat; M sole maize; F sole faba bean; W/M intercropping of wheat and maize; W/F intercropping of wheat and faba bean; M/F intercropping of maize and faba bean.

Adopted from Song et al. (2007)

4.2. Agroforestry

Agroforestry is a collective name for land-use system and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (Young, 1989). In agroforestry systems, there are both ecological and economical interactions between the tree and nontree components of the system. And different Agroforestry practices such as shifting cultivation, improved following, Hedgrow planting (Alley-cropping), shelterbelts (windbreaks), live fences, homegardens, etc. have been discussed by different researchers (Nair, 1993; Young, 1989).

According to Nair (1993) there are three major agroforestry systems with distinct practices. Hence, agri-silvi-culture systems encompasses home gardens, alley cropping, shelter belts and wind breaks, and multipurpose trees, while the silvi-pastore system includes trees on rangeland or pastures, river banks plantation with paster and animals. Further, the agro-silvo-pasture system includes agroforestry practices such as home garden with animals, multipurpose woody hedges, aqua forestry multipurpose woodland (Table 6).

Table 6. Agroforestry systems with possible agroforestry practices (adopted from Nair, 1993)

| Agroforestry systems          | Agroforestry practices             |
|------------------------------|-----------------------------------|
| Agri-silvi-culture system    | Home gardens                      |
|                              | Alley cropping                     |
|                              | Shelter belts and windbreaks       |
|                              | Multipurpose trees                 |
| Silvo-pasture system         | Trees on rangeland or pastures     |
|                              | River banks                        |
|                              | Plantation with pastures and animals |
| Agro-silvo-pasture system    | Home garden with animals           |
|                              | Multipurpose woody hedges          |
|                              | Aqua forestry                      |
|                              | Multipurpose woodland              |
Recently, global climate change has become a global challenge and the reduction of greenhouse gases emission is one strategy to address the problem. Pandey (2007) also indicated presently the emergence of evidence that agroforestry systems are promising management practices to increase aboveground and soil C stocks to mitigate greenhouse gas emissions. Thus, in addition to diversified products, income source, and soil improvement, protection of the soil from erosion they can also play important role in improving the microclimate of a given area, which in turn serves as a climate change impact mitigation strategy or measure.

4.2.1. Roles of Agroforestry practices
Agroforestry practices provide multiple benefits to a farmer level or the community at large. Hence, agroforestry systems support the production of a wide range of products: food (arable crops, vegetables, animal products, fruit, mushrooms, oils, nuts, and leaves); fuel (willow or hazel coppice, charcoal, fuelwood); fodder and forage; fiber (pulp for paper, rubber, cork, bark, and woodchip mulch); timber (construction and furniture making); gums and resins; thatching and hedging materials (spars, binders, and stakes); gardening materials (pea sticks, bean poles, fencing, hurdles); craft products (natural dyes, basketry, floral arrangements) recreation (agritourism, sport, hunting) (Smith, 2010).

In regions where the green revolution has not been able to make a dent or progress due to lack of soil fertility, agroforestry may hold promise. A useful path, complementary to chemical fertilizers, to enhance soil fertility is through agroforestry (Pandey, 2007).

Moreover, Nair (1993) indicated throughout the African continent farmers use windbreaks to protect crops, water sources, soils, and settlement on plains and gently rolling farmlands. Hedgerows of Euphorbia tirucalli protect maize fields and settlements in the dry savannas of Tanzania and Kenya. Tall rows of casuarinas line thousands of canals and irrigated fields in Egypt. In Chad and Niger, multispecies shelterbelts protect wide expanses of cropland from desertification.

Different agroforestry practices such as multistory tree gardening, woody perennials crop combinations, multistory tree gardens, hedgerow intercropping, windbreaks, and shelterbelts are a major method of reducing erosion. The function of trees and shrubs in agroforestry system is directly to increase soil cover, by litter and pruning, to provide partly permeable hedgerow barriers, to lead to the progressive development of terraces, through soil accumulation upslopes of hedgerows and to increase soil resistance to erosion, by the maintenance of organic matter, and their supplementary use is to stabilize earth structures by root systems, to make productive use of the land occupied by conservation works (Young, 1989).

The improved agroforestry practice is also known to play important role in attaining food security. For instance, research results in Tanzania indicated improved agroforestry secured enough food throughout the year for 40% of the households, while traditional practices did it only for 18% of the households, even if they were mainly cultivating food crops (Reyes, 2008).

According to Jamn nadass et al. (2013) maize yield improved by the adoption of Agroforestry food security program. This might be attributed to improved litter addition and improved N cycling through agroforestry system (Figure 2).

Agroforestry trees provide energy and nutritive requirement of the local diet. Nair (1993) reported fruit trees such as guava, rambutan, mango, and mangosteen, and other food-producing trees such as maringa olifera and Sesbania grandiflora, dominate the Asian home-gardens, indigenous trees that produce leafy vegetables (procarpus spp.), fruit for cooking (Dacryodes edulis), and condiment (Pentaclethra macrophylla), dominate the West African compound farms. Produce from these trees often provides a substantial proportion of the energy and nutritive requirement of the local diet.
Generally, the closed system in agroforestry enables the internal recycling of nutrients by accessing nutrients from lower soil horizons by tree roots and returned to the soil through leaf fall. Hence, agroforestry systems enhance soil nutrient pools and turnover and reduce reliance on external inputs (Smith, 2010). Thus, the materials from the tree component recycled improving the soil fertility and contributing to erosion control as can be seen in the following figure.

McNeely and Schroth (2006), who studied the impact of agroforestry practices on farm household income reported that gross income and net income analysis are more profitable for villages, which practiced agroforestry practices than control village farms, i.e. farm villages which did not practice agroforestry practices. Income from the sale of livestock, fruits, milk, and milk products was higher in project village as compared to control village whereas income from public services, wage labor was somehow the same.

Eventhough, there are many agroforestry practices offering different benefits to the farmers some of the most relevant agroforestry practices with this paper such as improved fallowing and alley-cropping will be discussed in this paper in detail.

4.2.2. Improved fallowing
An improved fallow is one of the agroforestry practice of a rotational system that uses preferred tree species as the fallow species (as opposed to colonization by natural vegetation), in rotation with cultivated crops as in traditional shifting cultivation. The reason for using such trees is the production of an economic product or improvement of the rate of soil amelioration, or both. Hence, an ideal fallow species would be one that grows fast and efficiently takes up and recycles available nutrients within the system, thus shortening the time required to restore fertility. In addition to soil-improving qualities, the need for economic products from the trees is also now recognized. The most clearly established include those species that are primarily identified by farmers (Acasia albida) as well as those selected and improved by scientists (e.g. Leucaena leucocephala) (Nair, 1993).

Improved tree fallow is intended to improve soil fertility as that of shifting cultivation but with the tree fallow consisting of planted species, selected for their soil enrichment capacity or useful products. Moreover, improved fallow is also expected to have a similar effect as that of shifting
cultivation for erosion control during the fallow, but with the danger of substantial erosion, and associated loss of carbon and nutrients, during the period of cropping. Moreover, it is indicated that improved fallow could have benefits similar to greater than natural fallows in shifting cultivation, but there is no research evidence (Young, 1989).

4.2.3. Alley cropping

Hodge et al. (1999) described alley cropping as an agroforestry practice intended to place trees within agricultural cropland systems. The purpose is to enhance or add income diversity (both long and short range), reduce wind and water erosion, improve crop production, improve utilization of nutrients, improve wildlife habitat or aesthetics, and/or convert cropland to the forest. The practice is especially attractive to landowners wishing to add economic stability to their farming system while protecting soil from erosion, water from contamination, and improving wildlife habitat.

In alley cropping, usually legumes which can be used as green manure when pruned are used to substitute the fallow practice as the legumes can improve the soil while the land is being cropped. Hence, the legumes are pruned before planting the crop periodically to prevent shading and to apply the leaves pruned to be used as green manure to improve the fertility of the soil and allowing the land to be cropped for an extended period of time (Graves & Waldie, 2004).

4.2.3.1. Benefits of alley-cropping. Alley-cropping was found to offer enormous benefits to farmers. For instance, researchers who conducted research in many tropical countries indicated hedge-row planting (alley cropping) to be the most effective practices in controlling erosion (Nair, 1993; Young, 1989).

In addition to these, Nair (1993) indicated that one of the most important premises of alley cropping is that the addition of organic mulch, especially nutrient-rich mulch, has a favorable effect on the physical and chemical properties of soil, and hence on crop productivity. He also indicated the existence of promising results with regard to improvement in yield with alley-cropping practice.

4.3. Cover crops and green manures

Cover crops are simply plants, usually specific annual, biennial, or perennial grasses and/or legumes, growing and covering the soil surface (Card, 2011). On the other hand, green manure crops are crops that are grown and tilled into the soil while it is green (Card, 2011).

Further, green manure/cover crop or a combination of both has a high potential for biomass production and hence is considered the only practical and economic means to maintain and/or increase soil organic matter levels (Florentin et al., 2011).

Green manure/cover crops have different growth habits, duration, and characteristic. The different types of green manure/cover crops including Pigeon pea (Cajanus cajan L. Millsp.), Grey-seeded mucuna (Mucuna pruriens = Stizolobium cinereum), Jack bean (Canavalia ensiformis L. DC), Dwarf mucuna (Mucuna pruriens = Stizolobium deerlingianum Bort.), Sunnhemp (Crotalaria juncea L.), Pearl Millet (Pennisetum americanum L.), Forage sorghum (Sorghum sp.), Lablab (Lablab purpureus L., or Dolichos lablab L.), Forage peanut (Arachis pintoi L.), Creeping indigo (Indigofera endecaphylla L.), Tephrosia (Tephrosia tunicata L., Tephrosia candida L.), Leucaena (Leucaena leucocephala L. de Wit), Black Oats (Avena strigosa Schreb), White lupine (Lupinus albus L.), Oilseed radish (Raphanus sativus L. var. oleiferus Metzg), Hairy vetch (Vicia villosa Roth), Rye (Secale cereale L.), and Sunflower (Helianthus annuus L.) (Florentin et al., 2011). Hence, depending their availability and adaptability to the specific environment it is possible to use choosing among these.
4.3.1. Choice of cover crop and green manures

With regard to the selection of cover crops for a given area as far as any cover crop can adapt with the limit of existing climate and soil, foremost among the desired characteristics for selection is establishment vigor, persistence to the end of the required period and ease of eradication to make way for succeeding crop i.e., the main crop. For instance, in many tropics where dry impoverished soils exist, which need cover cropping cover crop choice is restricted to hardly, low growing species of legumes (like *luceana* spp.) because of their ease of establishment and spread, deep roots, and prospects of soil enrichment. Foregone legumes are generally much harder and better adapted to these conditions than are pulses (Edwards, 2005). Hence, the critical selection of varieties more adapted to the site of interest is vital for the success of the practice.

According to Monegat (1991) selection of green manure/cover crops should consider: 1. Rapid growth and good soil cover under prevailing soil and climatic conditions. 2. Production of a great quantity of green and dry mass, of the above-arts and roots. 3. Slow decomposition of dry matter produced.

Drought-tolerant grasses may be cultivated where long-term cover is appropriate or where erosion is a severe threat. For this purpose, species such as *chloris* sp. and *Cynodon* sp. have proven valuable (Edwards, 2005).

4.3.2. Roles of cover crops and green manures

Cover and green manure crops play many roles in agriculture. Cover crops protect the soil surface from wind erosion and the cover crop’s roots can hold soil in place against water erosion during heavy downpours (Card, 2011). Cover and green manure crops also can improve organic matter content, soil N status, and improved soil moisture and weed control (Bunch, 2012).

4.3.2.1. Improved soil organic matter. Cover crops increase organic matter content, which contributes to the improvement of soil structure (Bunch, 2012; Edwards, 2005; Singer et al., 2005). The availability of soil nutrients to crops, including those supplied by chemical fertilizers, can be improved as a result of improved organic matter by planting of cover crops or green manures. Particularly, in the case of phosphorus, in acidic soils, phosphorus may become four to five times more available to plants when surrounded by organic matter (Bunch, 2012).

4.3.2.2. Reduced soil erosion. Cover crops are found both in monocotelydons and dicotelydous species. The former botanical group, which comprises mostly cereals and grasses is doubly useful in soil erosion control, because in addition the direct role of their vegetation in shielding the soil surface against aggregative break down by raindrop impact, their fibrous root system binds the soil, thus increasing its resistance to entrainment to overland flow. On the other hand, the soil protection attributes of a dicotyledonous cover are due, overwhelmingly to the broad-leaf nature of this group of plants specifically their characteristically overlapping system of leaves geared to intercropping rainfall and minimizing splash (Edwards, 2005).

Singer et al. (2005) also indicated the role of cover crops, especially small grain crops in reducing erosion. Thus, in Iowa in three-year study, rye cover crops overseeded into no-tillage soybean reduced interrill erosion by 54% and rill erosion by 90% compared with no-tillage without cover crops. Oat cover crops reduced interrill and rill erosion by 26% and 65%, respectively. Similarly, they indicated that rye cover crops reduced nitrate losses by 96% while oat cover crops reduced losses by 75%.

4.3.2.3. Improved soil quality and soil fertility. Cover crops contribute to soil quality improvement principally through their decomposition by soil microbes. The products of decomposition, while generally adding to the soil in two specific ways, i.e. through soil physical conditioning and fertility building. The degree of enrichment depends on the quantity and quality of the biomass of the
cover crop. Cellulose rich plants or plant parts degraded more rapidly than if they were ligneous as is the nature of mature grasses. Hence, leafy portions of the shoot system degrade far more rapidly (Edwards, 2005).

4.3.2.4. Improve soil moisture. Cover crops or green manures add organic matter to the soil, which increases the infiltration of water into the soil and increases the water-holding capacity of the soil (Bunch, 2012). For instance, in one experiment carried out during a drought in southern Honduras, maize fertilized with chemical fertilizer died one month into the drought, maize fertilized with animal manure died about two months later, and maize fertilized with jackbean still managed to produce a rather small harvest (Bunch, 2012).

4.3.2.5. Increased nitrogen fixation. In most cases crops used as a cover or green manure are leguminous and have the capacity to improve soil N status through nitrogen fixation (Bunch, 2012; Florentin et al., 2011). Legumes, inoculated with their specific Rhizobium bacteria, will take nitrogen out of the air (present in the soil) and store it in their plant tissues via nodules on the roots of the legume. Some of this nitrogen is available as roots die, but the majority becomes available when the legume is tilled under (green manure) (Card, 2011).

4.3.2.6. Weed control. Cover crops play important role in the suppression of weeds (Bunch, 2012; Florentin et al., 2011; Singer et al., 2005). Moreover, the use of green manure/cover crops can also give additional economic advantage for the farmer by saving the labor for hoeing and to reduce the use of herbicides for weed control, lowering production costs, which otherwise total crop loss (Florentin et al., 2011).

In Africa, a particularly noxious weed is striga (Striga hermonthica), which can significantly reduce yields of maize, sorghum, and millet, and is a major concern for farmers in areas with low soil fertility. Hence, Striga control can be possible if a sufficient amount of biomass can be added to the soil if cover crops or green are planted in such fields (Bunch, 2012).

4.3.2.7. Improved yield. Cover/green manure crops can improve crop yield. Different researchers reported improvement in yield due to the use of Cover/green manure crops (Dreyfus et al., 1985; Sangakkara et al., 2003). For instance, Dreyfus et al. (1985) indicated in their two consecutive year results obtained by intercropping of S. rostrata with rice for using as green manure at Djibol. Further, they noted that the use of S. rostrata green manure doubled the grain yields in comparison with the control plots, which was due to the large inputs of nitrogen to the soil resulting from the incorporation of S. rostrata: shoot is responsible for most of the increase in the rice yield. However, one should not overlook two secondary effects of this green manure. Sangakkara et al. (2003) also reported a significant beneficial impact of the incorporation of the green manures on the biomass of maize three weeks later.

On the other hand, some researchers reported significantly higher yield on the subsequent crop for fallow than cover crops. For instance, Nielsen et al. (2016) reported that grain yield was significantly greater for the fallow treatment compared with the average cover crop treatment at both Akrob and Sidney (under both water treatments) for the 2012–2013 crop. The percent increase in yield was greatest (66%) for the dryland treatment at Akron and least for the irrigated treatment at Akron (10%). At Sidney wheat yield was 22% greater for the fallow treatment than for the cover crop treatment in the dryland situation and 20% greater for the irrigated situation.

4.4. Vermiculture biotechnology
Vermiculture is the culturing of earthworms. Vermiculture biotechnology involving the use of earthworms as versatile natural bioreactors for effective recycling of nontoxic organic wastes to the soil, resulting in soil improvement and sustainable agriculture (Palaniappan & Annadurai, 2007). According to Aalok et al. (2008): vermitechnology comprises three main processes: 1. Vermiculture—rearing of earthworms. 2. Vermicomposting—biodegradation of waste biomass in earthwormic way. 3. Vermiconversion—mass maintenance of sustainability of waste lands through earthworms.
Utilizable products and benefits of vermin-technology are waste biomass management, animal protein production, and organic pollution abatement, waste land conservation, land reclamation, production of worm-worked manure, soil fertility, and enhancement in plant production (Aalok et al., 2008).

Earthworms are invertebrates assigned to phylum Anelida, class chilopoda and order oligochaeta. Oligochaeta includes the major earthworms belonging to Megascolecidae, Lumbricidae, and other families. More than half the earthworm species of the world belong to Megascolecidae. The genus phrentinia alone has a large number of species. Both Megascolecidae and Lumbricidae are valuable to agriculture and are, therefore, intimately linked to human welfare, development, and progress. The commonly used species are Eiseria fretida, perionyx exavatus, Lumberies rubellus, Eudrillus spp. (Palaniappan & Annadurai, 2007).

Composting can be done either in pits or concrete tanks or well rings or in wooden or plastic crates appropriate in a given situation. It is preferable to select a composting site under ashaode, in the upland or an elevated level, to prevent water stagnation in pits during rains. Vermicomposting is set up by first placing a basal layer of vermibed comprising broken bricks or pebbles (3–4 cm) followed by a layer of coarse sand to a total thickness of 6–7 cm. To ensure proper drainage, a 15 cm moist layer of loamy soil follows. Into this soil, 100 earthworms are inoculated. Small lumps of cattle dung (fresh or dry) are then scattered over the soil and covered with a 10 cm layer of hay. Water is sprayed till the entire setup is moist but not wet. Less water kills the worms and too much water chases them away (Aalok et al., 2008).

The earthworms can be cultured on animal dung, poultry droppings and vegetables, and other kinds of biodegradable wastes. Thus, the excretion or cast of worm forms the needed organic fertilizer. Worms consume or feed the same weight of their body (0.5–0.6 g) and excrete the amount equal to the feed. In a similar fashion in one acre if 1 million worms exist they produce in that area about 500 Kg/day/acre. The worm cast contains all the nutrients in available form and in addition, a great deal of organic matter is provided to the soil, which makes it very productive (Palaniappan & Annadurai, 2007).

4.4.1. Effects of vermincomposting on crop productivity
According to Durak et al. (2017) yield and growth parameters were improved by vermicompost application when compared to control and conventional fertilization. As a result of this study, it was concluded that 300 kg vermicompost/da is a promising application in lettuce production for optimal yield and soil improvement (Figure 3).

**Figure 3.** The effects of different vermicompost applications on lettuce yield (kg m²) (adopted from Durak et al., 2017).
Further, Ansari (2008) reported that in two-year experiment the overall productivity of vegetable crops was significantly greater in plots supplied with vermin-compost at 6 tonnes per ha. Accordingly, vermicompost application at 6 tonnes per hectare significantly increased potato yields. Further, he indicated that the application of vermicompost at 4 tonnes per ha resulted in a considerably higher yield of spinach.

4.5. Crop rotation
Crop rotation is considered to be one of the oldest and most effective cultural control strategies. The planned rotation may vary from 2 or 3 year or longer period (Food and Agricultural Organzation of the United Nations [FAO], 2017). In short, there is temporal variation in different crops used for crop rotation. Crop rotation strategies differ in design. The land may be divided into sections and the crops assigned to specific sites. The sites are changed in subsequent growing seasons. Alternatively, the entire field is planted with one crop species in one season, followed by a different cultivar of the same species or different species, the next season (Acquaah, 2002).

Crop rotation has a wide range of benefits. The benefit from crop rotation includes protection against erosion, pests and diseases, weeds, and helps maintaining soil fertility (Acquaah, 2002; FAO, 2017).

4.6. Composting
Composting is a process that involves serious of processes to breakdown or decompose waste materials by the help of microorganisms in a warm, moist-aerated environment. The heat evolved during the decomposition process can be saved by the wastes gathered into a heap. The rise in temperature of the heaps foster the decomposition processes. Finally, at the end of the decomposition processes, compost or humus will be ready for use (FAO, 1987).

The waste materials such as plant residues, animal wastes, vegetable wastes, and weeds can be composted. First the waste materials are chopped into small pieces of 5–10 cm size and are dried to 40–50% moisture before stacking. Then, they are spread in layers of 10–15 cm thickness either in pits or in heaps of 1 m width, 4–6 m length, and 1 m depth. The heap is properly moistened with dung, using earth. A sufficient quantity of water is sprinkled over the heap to wet the composting materials to the level of 50% moisture. Periodically turnings, usually three times at 15, 30, and 60 days after filling, are given to aerate and the material is covered with a thin layer of soil of about 2–3 cm. Under the aerobic process of decomposition, losses of organic matter and nitrogen are heavy (40–50%) at the initial stage. The compost obtained by this method would have a composition of 0.8% N, 0.3%P, and 1.5%K2O (Palaniappan & Annadurai, 2007).

According to Inckel et al. (2002) a good composting process passes through 3 consecutive stages: 1. A heating phase (fermentation) 2. A cooling down phase 3. A maturation phase.

4.7. Compost making from parthenium weed
It is also possible to make compost from some noxious weeds such as parthenium. Composting parthenium involves cutting the parthenium plants into small pieces 10 cm by using a chaff cutter. This chopped material is spread to a thickness of 10 cm. Over the chopped materials inoculums, namely compost cultures (Trichoderma viridi, Fusarium sp.) is spread this to thickness of 10 cm. Over this layer, 0.5% is spread (5 kg urea/t urea of chopped materials). This has to be repeated till about 1 m height is obtained. Then plastering with mud is done. Periodical sprinkling of water is done to maintain 50–60% moisture. After 3 weeks a thorough mixing is given. In 40–45 days, the parthenium compost is ready for yield application. This compost contains 2.49% N, 0.73% P, and 1.37% K with a C: N ratio of 21:1. The same method is followed for other weed species also (Palaniappan & Annadurai, 2007).

4.8. Animal manure
Maruthi et al. (2008) reported that the poultry litter and the soil at the 1:3 ratios as manure for agricultural practice were found to be suitable for the seed germination and growth of four leafy
vegetables and can be safely used as fertilizer for the crop. Moreover, they indicted the use of poultry litter as manure helps in the reduction of solid waste at source and health problems generated due to indiscriminate disposal of litter will be reduced.

4.9. Integrated nutrient management
Integrated nutrient management is one aspect of sustainable agriculture, which entails the use of different types of soil fertility management measures organic (natural) as well as inorganic (manmade fertilizers). Thus, it is a practice, which keeps the soil as a storehouse for plant nutrients, so that plants will get a sufficient amount of plant nutrients and crop productivity increases without jeopardizing soil fertility of the future. And integrated nutrient management also relies on a number of factors, including balanced application of appropriate nutrient and conservation and transfer of knowledge about INM practices to farmers and researchers (Gruhn et al., 2000).

The integrated nutrient management strategies emphasize aspects like the reduction of nutrient losses from applied inorganic fertilizer; retention of soil nutrients; alternate or supplementary sources of nutrients and integrated nutrient management in different land-management systems (Palaniappan & Annadurai, 2007).

4.9.1. Effect of integrated nutrient management on crop yield
Some research results by different workers have revealed a significant effect of organic and inorganic nutrient sources on crop yield (Getachew et al., 2002; Wassie & Shiferaw, 2009). Getachew et al. (2002), who studied the effects of P fertilizer and farmyard manure on faba bean and some chemical properties in acidic nitosols of the central highlands of Ethiopia observed a highly significant (P ≤ 0.001) effect on total aboveground biological and seed yields of faba bean in 2003. Accordingly, they indicated that the application of FYM at a rate of 4 and 8 tons ha⁻¹ increased seed yields of faba bean by 7% and 25% in 2001, 14% and 30% in 2002, 67% and 90% in 2003, respectively. Furthermore, the mean yields of faba bean increased as the levels of the two interacting factors increased in which the highest mean yield was recorded from the interaction of 8 tons FYM ha⁻¹ and 39 kg P ha⁻¹.

4.10. Integrated pest management
Integrated pest management (IPM) is a sustainable approach to managing pests that combines biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks (Ebesu, 2003).

Acquaah (2002) elucidated that integrated pest management is a pest management strategy that combines the principles of other pest management systems, but with reduced emphasis on the use of chemicals, to reduce pest populations below levels that can cause economic loss. In this pest management approach, all strategies and methods are used as appropriate. Integrated pest management (IPM) strategy consists of site preparation, monitoring the crop and pest population, problem analysis, and selection of appropriate control methods (Ebesu, 2003). According to Acquaah (2002) steps in the IPM program include 1. identifying pests and beneficial organisms. 2. Knowing the biology of the pest and how the environment influences it. 3. Determining the tolerable pest population threshold. 4. Select the best method for pest management, if the economic injury is possible. 5. Select a pest control management method that will destroy pests without harming beneficial organisms (i.e. using resistant cultivars, altering planting time, and providing supplemental nutrition). 6. Developing a pest monitoring schedule. 7. Evaluating the pest management method and make appropriate adjustments.

5. Future perspectives
Human population is growing at a faster rate and the situation is more severe in most parts of the developing nations especially in Africa. There is a need to improve crop production in these areas of the world, which would not be realized without improving the low level of organic fertilizers and inorganic fertilizer usage. Gruhn et al. (2000) also indicated in contrast to developed countries, in
developing countries the use of inorganic fertilizer is low and there is less risk of environmental pollution. However, the low input usage resulted in a serious nutrient mining problem. Consequently, the ongoing reduction of plant nutrients may well lead to irreversible degradation and soil infertility unless steps are taken to improve soil management.

As dependence only on low input technologies to ensure long-term food security is successful. Moreover, in addition to the judicious application of inorganic fertilizers to reduce environmental pollution, governments should take the necessary steps to facilitate the widespread and responsible use of chemical fertilizers. At the same time, every effort should be made to improve the availability and use of secondary nutrients and micronutrients, organic fertilizers, and soil-conservation practices (Gruhn et al., 2000). In short, practicing integrated nutrient and pest management practices along with different low input technologies would address the problem of soil fertility, disease, and pest outbreak in a sustainable manner.

Similarly, with respect to chemical use in developing countries especially in our country, there is limited use of chemicals for the control of crop pests as the smallholder farmers most of the time use cultivation for its control (Beyene et al., 2008). Hence, even though, the usage of pesticides is not as such a serious problem in our country emphasis should be given to integrated pest management techniques, which avoid the related problems by using pesticides.

6. Conclusion

Green revolution technologies such as fertilizers, high yielding varieties, irrigation, chemicals, etc. helped much in increasing agricultural crop production that helped in supplying the global food demand of doubled global population in the last two decades. However, in Africa the situation was not like other parts of the globe because of poor access to high-level inputs such as fertilizers, improved seeds, etc.

On the other hand, the use of high-level inputs such as fertilizers and pesticides during the green revolution in developed and some developing countries were associated with adverse negative impacts on the environment, human and animal health. Hence, due to these problems different approaches have been suggested, which do not heavily depend on fertilizers and chemicals. These are also known as low input technologies and the concept behind low input technology is the integration of the modern scientifically best practices with technologies and with the practices of experienced farmers who have substituted fully or partially with purchased inputs with low inputs. Thus, the technology options include different low input technologies that have been tested for their effectiveness such as intercropping, agroforestry practices such as alley cropping, cover crop and green manures, crop rotation, integrated nutrient management, integrated nutrient management, composting, vermin-composting, etc. And they provide enormous benefit to the community and they are ecologically sound and economically.

On the other hand, the most pressing issue is to feed the growing population particularly in sub-Saharan African countries. Thus, in sub-Saharan countries, where there is low-purchased input usage, judicious application use of these inputs is needed. Moreover, integration of the inorganic fertilizers with organic fertilizers is needed to be emphasized to more sustainably improve soil and crop productivity in the country. Moreover, subsistence farmers, who cannot afford fertilizer better to adopt low-level inputs such as compost, animal manure, crop rotation, etc. to ensure food security and they should be given strong extension service. There should also be a policy, which prohibits overusage of agrochemicals and improves access to poor developing nations.

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