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Sustainable Agriculture: Agroforestary for Enhanced Soil Fertility and Food Security

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Abstracts

In the past four decades the global cereal production has increased mainly resulting from greater inputs of fertilizer, pesticides, new crop strains, water and other technologies of the 'Green Revolution which are essential for global political and social stability and equity. But doubling food production and sustaining food production at this level are huge challenges for the sustainability of food production and of terrestrial and aquatic ecosystems and the services they gives to the society. Agricultural practices determine the level of food production, sustainability and largely the state of the global environment. The present agricultural practices that have greatly increased global food supply have had adverse impacts on the environment and on ecosystem services are calling for the need for more sustainable agricultural methods. Sustainability implies maintain high yields in the face of major shocks' and agricultural practices that have acceptable environmental impacts. This review paper examines how and why agro-forestry would be the best alternative for sustainable agriculture and food security. Different researches are explain that agro-forestry is highly efficiency to insure agricultural sustainability through enhancement of soil fertility, plant nutrients (n, p, k, mg, ca, s), organic matter, soil carbon sequestration, retention of soil moisture, regulate soil temperature and climate change. It also help for food security via increased crop productivity, ensuring nutrition security and balanced diet, diversified crop production, boost income generation, and other multi functional value. To achieve such a scenario particularly in the developing countries knowing the multiple benefits of agro-forestry and expanding the agro-forestry system is not only an important for enhanced soil fertility and food security, but it is the question of sustaining life on the earth.

Keywords: sustainability, agriculture, agro-forestry, soil moisture, soil carbon sequestration, plant nutrients (N, P, K, Mg, Ca, S), food security, income generation.

1. Introduction

1.1 Backgrounds

Agricultural revolution is the source of civilization which is changing rapidly especially since the end of World War II with the advancements of science, shifting consumer preferences, globalization, environmental impacts, population growth and frictions in subsidy regimes (IISD, 2007). Green agricultural revolution caused for the increment of world food production by 145%, in Africa by 140%, Latin America by almost 200% and in Asia by 280%. During this time the total agricultural area has expanded by 11% from this the industrialized countries, agricultural area has fallen by 3% and the developing countries has risen by 21% in (FAO 2005).

In many developing countries, agriculture is still the most backbone of the economy but its sustainability fall in threat due to inefficient use of input such as chemical fertilizer, machinery, insecticides and herbicides which led to considerable environmental harm, loss of habitats, loss of biodiversity and their valuable environmental services (UNEP/ CBD/SBSTTA, 2010). The idea of sustainability came to public attention after a 1972 report, "Limits to Growth. And the term "sustainable development" achieved international public importance through the 1987 World Commission on Environment and Development report of Brandt land. Following the two reports the need to monitor the progress towards sustainability has received proper recognition especially since the United Nation Conference on environment and development held in Rio Janeriro in 1992 (Anja Yli-Viikari, 1999).

The agreement on a universally accepted definition of sustainable agriculture is proved unclear in relation with the question such as; can anything be sustainable in quickly changing world? how on earth are we going to feed 2 billion more people by 2050 as climate change depletes the land and water available?, can human activity successfully maintain itself and its goals without exhausting the resources on which it depends? (UNEP/CBD/SBSTTA, 2010).

There is a growing evidence to suggest that the modern agricultural approach to agricultural growth has reached critical environmental limits and that the aggregate costs in terms of lost or foregone benefits from environmental services are too great for the world to bear (Ruttan 1999; MEA 2005; Kitzes *et al*,2008). It is crucial in helping to lift people out of poverty and hunger in rural areas by any alternative form of sustainable agriculture, not only at national level, but also globally (European Union, 2012).

According to Preston Sullivan (2003) sustainability can be observed and measured interims of the three pillars of sustainability which are

- Environmental (there is no bare ground, clean water flows, wildlife is abundant, fish are abundant, the farm landscape is diverse in vegetation ,etc).
- Social (The farm supports other businesses and families in the community, dollars circulate within the local economy, the number of rural families is going up, young people take over their parents' farms and continue farming).
- Economic (The family savings or net worth is consistently going up, the family debt is consistently going down, the farm enterprises are consistently profitable from year to year, reliance on government payments is decreasing.

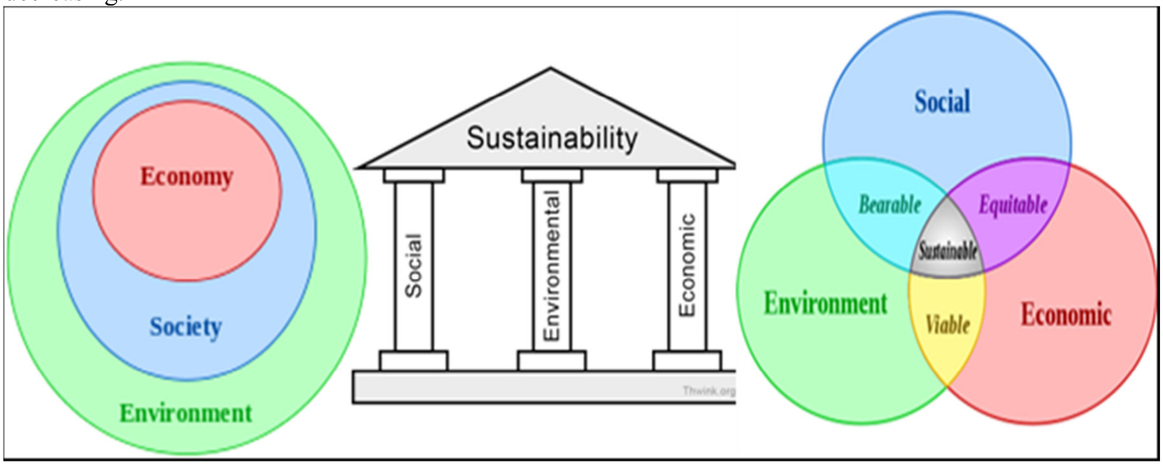


Fig: - 1 the major pillars of sustainability

The three pillars of sustainability can express in any of the three ways, which are interdependent, and in the long run none can exist without the others. But the effort that has been implementing in these sectors is failing to solve the problem, because most effort is focused on only one or two pillar at a time. For example, the United Nations Environmental Programme (UNEP), the environmental protection agency's (EPA) of many nations and environmental NGOs focus on the environmental pillar. The World Trade Organization (WTO) and the Organization for Economic Cooperation and Development (OECD) focus mostly on economic growth, and to some extent gives attention to social sustainability, like war reduction and justice (Thwink.org on Voice America, 2016).

At the end of the 1990s, increased international concern about environmental issues has made Kyoto Protocol and emphasis on the environmental service functions of alternative land uses. Therefore sustainable agriculture via agro-forestry is very important and the timely response to the decline in the quality of the natural resource base associated with modern agriculture and has prompted major adjustments in conventional agriculture to make it more environmentally, socially and economically viable (Rachel, *et al.* 2012). Agro forestry practices have existed since the very beginning of plant domestication and it is practiced by more than 1.2 billion people worldwide (FAO, 2013).

❖ There are three types agro-forestry practices based on the type of components.
  - Agrisilviculture - crops (including shrubs/vines) and trees.
  - Silvopastoral - pasture/animals and trees
  - Agrosilvopastoral - crops, pasture/animals and trees (Nair, 1985).

The system has characterized by intentional, intensive, interactive, integrated, productive, sustainable and adoptive production due to the capacity of its various forms to offer multiple alternatives and opportunities to enhance farm production and income, promote environmental services, aesthetic values and agro-ecotourism (Beer.J *et al,* 2003 and Hosny El-Lakany, 2004 and World Agro-forestry Centre, 2014***)***.

Objectives of the paper

1. To review the issue of sustainable agriculture from the context of agro-forestry practices
2. To assess the role of agro-forestry to soil fertility enhancement
3. To review the food security impact of agro-forestry
4. To forward the necessary recommendations about the significant of agro-forestry for sustainable farming and food security.

2. Result and Discussion

2.1 Soil fertility enhancement in agro forestry

Soil is the thin layer covering the entire earth's surface, except for open water surfaces and rock outcrops, which interacts dynamically with the lithosphere, atmosphere, hydrosphere, and biosphere, collectively forming pedosphere or it is the sum total of all the organisms, soils, water and air. The soil is not only seen as a substrate for crops but also as a key-component of the ecosystem services supply chain. In organic farming systems, soil fertility is defined as the "ability of a soil to provide the conditions required for plant growth" .The function and relevance of soils in agro ecosystems has been recognized in the context of sustainable management, soil quality, soil resilience or soil conservation, and protection of local or regional agro ecosystems (Stockdale *et al.* 2002). Thus, Larson and Pierce (1994) suggest the concept of soil quality, "represented by a range of physical, chemical and biological properties of the soil within its particular environment that together provide a medium for plant growth and biological activity, regulate and partition water flow and storage in the environment, and serve as a buffer in the formation and destruction of environmental hazardous compounds.

Table: -1, Soil Category and Related Functions

Indicator category	Related soil function
Chemical	Nutrient Cycling, Water Relations, Buffering
Physical	Physical Stability and Support, Water Relations, Habitat
Biological	Biodiversity, Nutrient Cycling, Filtering

Source: - Doran, J.W. and T.B. Parkin (1996) and Jelte van't Foort,*et al,* (2012)

Fertile soil has an abundance of plant nutrients including nitrogen, phosphorus and potassium, an abundance of minerals including zinc, manganese, boron, iron, sulfur, cobalt, copper, magnesium, molybdenum, and chlorine and an abundance of organic matter**,** therefore restoring the productive capacity and life support processes of soil via sustainable natural resource management using agro forestry system is very necessary (Patiram and B.U. Choudhury, 2000).

Table 2: Soil properties beneath trees and open field

Available nutrients at two soil levelis (kg/ha)	Under *Prosopis cineraria*	Under *Prosopis juliflora*	Open field
N: 0-15 cm	250	203	
15-30 cm	193	212	196
P: 0-15 cm	22	10	8
15-30 cm	10	5	4
K: 0-15 cm	633	409	370
15-30 cm	325	258	235

Source Aggarwal, 1980 cited in Young, A (1988).

Nutrients (mg/kg)	Under *Prosopis glandulosa*	Beyond canopy
NO—N	195	62
P04—P	7.7	0.8

Source: Virginia, 1986 cited in Young, A (1988).

Table 2 reveals that how agro-forestry ensures sustainable agriculture via increment of soil fertility, nutrient uptake, timing of nutrient release, and nutrient retrieval; production of a range of different qualities of plant litter, improve soil physical structure, water-holding capacity, exudation of growth-protection from erosion, modification of extremes of soil temperature, reduction of acidity, climate regulating and other important services (Young, A .1988).

The tree roots serve for fertility and nutrient cycling by enriching the soil with organic matter and nitrogen under the canopy,maintaining the soil biomass and improving of nutrient cycling through root production and turnover; reducing leaching losses through the uptake of mobile nutrients; pumping up nutrients from subsoil layers to the top soil; improving soil penetrability for crop roots; fixing atmospheric N; creating appropriate conditions for the development of mycorrhizal and rhizospheric microorganisms (N-fixing and P-solubilising) (Felker, 1978, Schroth , 1999, Jelte van 't and Foort, *et al*,2012).

2.1.1 Retention of soil moisture

Soil water is an important water source for vegetation development. Changes of soil water may greatly affect tree species diversity and forest canopy structure. The water storage capacity of soil depends on its depth and capacity to retain water under gravitational drainage, vegetation type, and evapo-transpiration. Getting a better understanding of the interactions between vegetation, soil and water flux is central to environmental management for more water yield in water-limited environments (Chao Wang, et al, 2013). Soils under natural forests tend to be relatively porous because trees loosen the soil and accumulate more organic matter with high infiltration rates. Forest plays significant role in the soil water amount, by reducing surface runoff and increase the amount of water that percolates into a soil.

The soil water retention capacity is closely related to soil properties such as texture, bulk density, porosity, soil organic carbon content, and so on. Especially there is a significant linear positive relationship between averaged soil water content and soil organic matter content (Chao Wang, et al, 2013). Thus, agro forestry influences the water retention capacity in forest sites, and in turn increases the overall water storage capacity (Lüscher and zürcher, 2003).

Sarah (2002) found that shrubs affect soil properties through soil-vegetation interaction that resulted in higher infiltration rate and greater soil water retention capacity than in inter- shrub areas after rain. Zhang et al. (2011) found forested ecosystems had greater soil water retention capacity than shrub ecosystems because of the thick humus. Similar results were found by Wang et al. (2008), who discovered that the top soil layer under high vegetation cover, as with the highly organic fine-grained soils and litter layer, reduced the thermal conductivity and increased the water infiltration and water hold capacity, altering the active soil-water-heat relationship.

There is positive correlation between increases soil water content and the increase of soil organic matter (Chao Wang, et al, 2013). Agro forests play a crucial role in runoff generation, on the one hand, by affecting hydrological processes such as precipitation interception and evapo transpiration (Eagleson, 2002).

Table.3 Runoff and soil loss under different land use systems of Sikkim

Land use	Runoff (L/ha)	Soil loss (kg/ha)
Agricultural field of maize	6427	122
Large cardamom plantation	6989	66
Natural forest	5581	12
Barren land	8097	166

Source Sharma et al., (1992)

Agroforestry checks soil erosion through the cover effect, where hedge pruning are laid along cropped alleys. They reduce runoff, increase infiltration and reduce soil loss through their barrier effect. Dense ground forest vegetation (grass, cardamom, herbs, shrubs) under large cardamom plantation with shade trees on hill slopes more than 35% in Sikkim, arrests the flow of water, reduce the soil erosion and soil remains almost undisturbed (Patiram et al., 1996).

2.1.2 Reduction of Excessive Soil Temperature

The temperature of soil is one of the important factors affecting plant growth is controlled by many factors. These are air temperature, amount and intensity of precipitation reaching the soil, depth and duration, shade of living cover, depth of litter, water content of the soil, humus content of the soil, snow cover, wind velocity, color of the soil, and structure of the soil. Forest shade of the crowns and partly from the insulation of the forest floor usually reduces the maximum soil temperature and increase the minimum soil temperature with the depth of the soil (MacKinney, 1929). The influences of forest vegetation on freezing of soil are of great importance because soil under a forest usually remains soft when that in the open is frozen to considerable depth. The distance beyond the edge of the forest's influence on the soil temperature is about the same as the distance of the influence on radiation (Breman and Kessler, 1995).

Several studies suggest in the agro forestry system the tree shade increases understory herbaceous productivity because of the reduction of temperature and evapo-transpiration. There is some evidence that extreme heat negatively affects crop establishment and subsequent growth (Bernhard-Reversat, 1982, Ong and Monteith, 1985; Peacock et al., 1990; Mclntyre et al.,1993).Solar irradiance was reduced by 45 to 65 percent under Acacia tortilis and Adansonia digitata (Belsky et al., 1989). Only about 20 % of total radiation reached the understory of A. tortilis and Balanites aegyptiaca at midday in a Sahelian savanna **(**Akpo and Grouzis**,** 1996).

In semi-arid Kenya, soil temperatures 5 cm below the surface were at least 5–9°C lower under trees than in the open grassland, both at the beginning of the growing season and when grass cover was at a maximum. The difference between locations decreased with soil depth (Belsky et al., 1989).Soil temperature was also substantially lower under Vitellaria and Parkia trees than in the open (Jonsson, 1995). An almost leafless crown of F. albida resulted in a soil temperature decrease of up to 10°C at 2 cm depth (Van den Beldt and Williams, 1992). In northern Senegal, air temperatures under and outside tree canopies differed by 6°C at maximum temperatures (Akpo and Grouzis, 1996). In addition, the variation of soil temperatures at 10 cm depth during the day was lower under canopies (3°C) than in full sunlight (9°C). Maximum and minimum air temperatures are moderated by tree crowns because of reduced solar radiation during daytime and reduced reflection of infrared radiation at night (Dancette and Poulain, 1969).

According to Van den Beldt and Williams (1992) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) using vertical artificial screens showed that the effect of shade on soil temperatures contributed to better millet growth during seedling establishment. They argue that root damage due to high temperature rather than water deficits caused differences in millet performance, and that crops would not be able to take advantage of the greater soil fertility around F.albida trees without the moderated temperature associated with them.

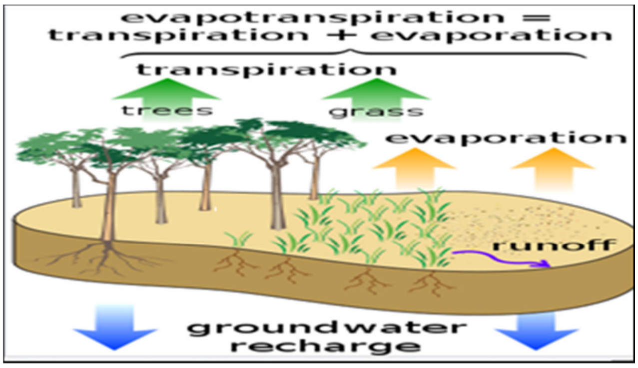


Fig:-2 Evapotanspiration, evaporation and ground water recharge

Water cycle of the earth surface shows the individual components of transpiration and evaporation that make up evapotranspiration, and other related process such as runoff, ground water recharge and balanced soil temperature. Also Agro forestry reduces wind velocity in certain conditions. Wind velocity reduction was responsible for a 15–20 percent decrease in overall water consumption and decreased evapotranspiration**,** which positively contribute for soil temperature (Dancette, 1966).

2.1.3 Improvement of organic matter (OM)

Of all the effects of trees, that of maintaining soil organic matter levels through the supply of litter and root residues is the major cause of soil fertility improvement. Soil improvement under trees and agro-forestry systems is in great part related to increases in organic matter, whether in the form of surface litter fall, soil carbon or, roots exudates in the rhizosphere which substrate for a vast range of organisms involved in soil biological activity and interactions, with important effects on soil nutrients and fertility (Rachel C.et al, 2012).

Trees in agro-ecosystems can be present in an infinite number of arrangements and species, greater diversity of species is more favorable of space above and below the soil, and the variation in the characteristics of the litter produced can maintain a greater level of soil biodiversity, with positive effects on fertility (Sharma et al., 1997).

Trees producing litter rich in Ca were associated with soils with greater PH, exchangeable Ca, and percent base saturation, as well as greater rates of forest floor turnover and greater diversity and abundance of earthworms, also trees contribute to carbon accumulation in soils, but in some type of trees species such as Pinus lower PH that produce acidifying litter (Rachel C.et al, 2012).

The processes by which trees in the agro forestry maintain or improve soil OM

- Effects of tree shading on microclimate
- Photosynthetic fixation of carbon and its transfer to the soil via litter and root decay,
- Providing favorable conditions for the input of nutrients from rainfall and dust
- Control of erosion by combination of cover and barrier effect
- Soils under trees have favorable structure and water holding capacity, through organic matter maintenance and root action
- Provision of a range of qualities of plant litter, woody, and herbaceous
- Growth promoting substances
- The potential through management of pruning and relative synchronizations of timing of release to nutrients from litter with demand for their uptake by crops.

Table: 4. Soil organic carbon, nitrogen and N-mineralization rate in different agro forestry

Agro forestry systems	**Org. C (%)**	**Nitrogen (%)**	**N-mineralization rate (ug N/g /14 days**
Albizzia + cropland	1.13 ± 0.03	0.25 ± 0.02	19.0 ± 6.7
Non-N-fixing trees+ cropland	0.90 ± 0.07	0.20 ± 0.01	8.0 ± 2.8
Alnus + large cardamom	2.01 ± 0.10	0.30 ± 0.02	35.5 ± 4.0
Natural forest + large cardamom	3.56 ± 0.46	0.51 ± 0.03	54.0 ± 8.9

Source Sharma et al., (1992)

The table above shows the N2-fixing species conserves fewer nutrients compared to non-N2-fixing species and hence, contribute more of these elements in their litter which results greater cycling (Sharma et al., 1994). This provides better production potential for associate crops in the stands with N fixers (Sharma et al., 1997).

Table: 5. Bulk density (g cm–3) of the ecosystems studied

	Under canopy		Outside canopy	
Ecosystem	0–5 cm	5–10 cm	0–5 cm	5–10 cm
NF/native forest	1.17 ± 0.09	1.48± 0.08	1.55 ± 0.08	1.65 ± 0.05
WPE/well preserved Espinal	1.19 ± 0.05	1.44 ± 0.05	1.34± 0.06	1.55 ± 0.04
GE/good Espinal	1.27 ± 0.06	1.44 ± 0.05	1.38± 0.05	1.55 ± 0.05
DE/degraded Espinal	1.34 ± 0.05	1.50 ± 0.03	1.43± 0.04	1.55± 0.03
VDE/very degraded Espinal	1.40 ± 0.08	1.45 ± 0.05	1.43 ± 0.07	1.53 ± 0.03

Table: 6 Effects of organic matter on soil fertility

Primary effect of OM	**Consequences**
Physical effect, binding of particles, plant root improve structural stability balance medium and large pores,	Improve root penetration, erosion resistance and moisture properties, water holding capacity permeability aeration
Chemical effects Nutrient source, balanced supply, not subject to leaching with slow partly controllable, release	Including better responses to fertilizers, on acidifying source of N ,mineralization of P in available forms
Complexing and enhanced availability of micro nutrient. Increase cation exchange.	Better retention of fertilizers nutrients
Improve availability of P through blocking of fixation sites	
Biological effects, provision of favorable environment for N fixation. Enhance faunal activities	

Source: Mun Oza,et al, (2007).

Table 5 table 6 shows the effects of organic matter on soil fertility under different ecosystem i.e. under natural forest (NF) in the 0–5 cm layer there was 73% reduction in soil organic carbon content outside the canopy compared with under the canopy. Similarly, in the other agroforestry systems at the same depth there was between 28 and 40% less SOC outside the canopy compared with under it. In short the soil organic content, microbial biomass, respiration rate, and light fraction are greater under the canopy than outside the canopy (MUN˜ OZa,et al, 2007).

2.1.3 Soil carbon sequestration

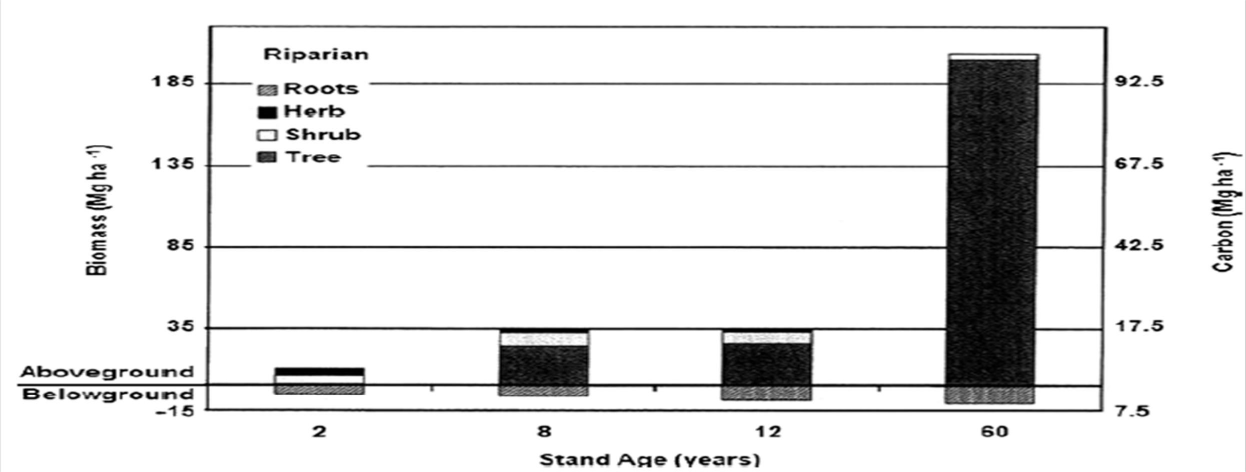
Carbon sequestration is the process of removing C from the atmosphere and depositing it in a reservoir. It is well known that tree based systems contribute to reductions in atmospheric CO2 and offset CO2 emissions through three main mechanisms, namely: C sequestration, C conservation, C substitution (UNFCCC, 2007 and Nair et al. 2009). The role of trees reduces the global carbon accumulation adversely affects the climate and contributes to the soil fertility by supporting vegetation growth. Besides the above benefit carbon sequestration role of plants has economic value via payments for mitigation of greenhouse gas emissions to reduce climate change (Rachel.C, 2012).

Based on the above functions the role of land use systems in stabilizing the CO2 levels and increasing the carbon (C) sink potential has attracted considerable scientific attention in the recent past, especially after the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Agro forestry practices have been approved as a strategy for soil C sequestration under afforestation and reforestation programs and under the Clean Development Mechanisms of the Kyoto Protocol (Watson et al. 2000; IPCC 2007; Smith et al. 2007). The systems have spread over one billion ha in diverse eco regions around the world. These woody perennial-based land use systems have relatively high capacities for capturing and storing atmospheric CO2 in vegetation, soils, and biomass products.

According to the intergovernmental panel on climate change, AFS offer important opportunities of creating synergies between both adaptation and mitigation actions with a technical mitigation potential of 1.1–2.2 Pg C in terrestrial ecosystems over the next 50 years. Additionally, 630 million ha of unproductive croplands and grasslands could be converted to agroforestry representing a C sequestration potential of 0.586 Tg C/yr by 2040 (1 Tg = 1 million tons). The total C storage in the aboveground and belowground biomass in an AFS is generally much higher than that in land use without trees (i.e. tree-less croplands) under comparable conditions.

Adoption of agro-forestry practices has greater potential to increase C sequestration of predominantly agriculture dominated landscapes than monocrop agriculture (Lee and Jose 2003; and Nair 2003; Morgan et al. 2010). Within agroforestry systems C can be stored in above- and below-ground biomass, soil, and living and dead organisms. The quantity and quality of residue supplied by trees/shrubs/grass in agro-forestry systems enhance soil C concentration (Oelbermann et al. 2006).

The amount of carbon fixed in silvopastoral systems is determined by the tree/shrub species, density and spatial distribution of trees, and shade tolerance of herbaceous species (Nyberg and Hogberg, 1995; Jackson and Ash, 1998). Soil C sequestration potential is much greater in alley cropping than in mono cropping agronomic systems. In addition to C sequestered by trees, windbreaks provide additional C sequestration due to improved crop and livestock production and energy savings (Kort and Turnock 1999). Indirectly, windbreaks reduce fuel use for heating and thereby reduce CO_2 emissions.



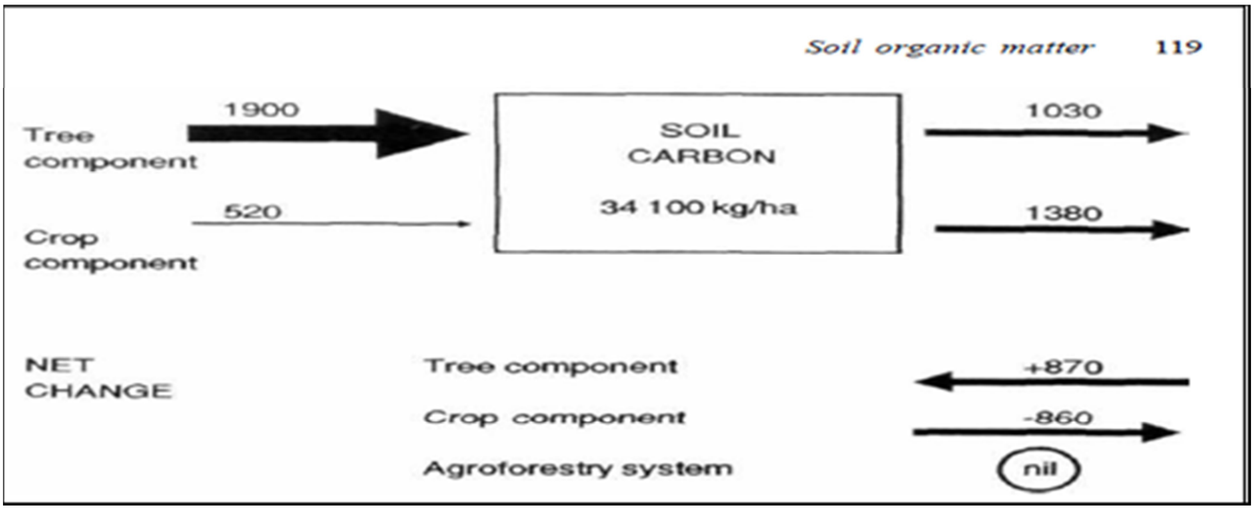


Fig:-3 Biomass and Soil C Sequestration Potential
Source Nair *et al*. (2010)

As fig 3 the above- and below-ground biomass and carbon of 2-, 8-, 12-, and 60-year-old riparian stands in South Carolina, USA (Giese et al. 2003). Trees store about 50–60% of the C in the above-ground biomass whereas pasture grasses store only 10% above-ground, the rest being allocated below-ground (Houghton and Hackler 2000; Sharrow and Ismail (2004). The table above clearly indicating roots of the perennial vegetation in silvopastoral systems shifts C deeper into the soil profile compared to conventional pastures or row crops. Paudel et al. (2011) observed significantly greater percentages of C in soils under a cotton wood (P. deltoides Bortr. ex Marsh.) and grass silvopasture compared to maize-soybean rotation in Missouri.

Literature reveals incorporation of agro-forestry by introducing improved plant stock and implementing improved and intensive management techniques, could be enhanced C sequestration on the land base in a short period. Well designed and managed AFS can be effective CO2 sinks, especially with the use of perennial crops and fast growing tree species (Nair et al. 2010).

2.1.5 Enhancement of plant nutrients (N, P, K, Mg, Ca, S)

Plant nutrient is concerned with the cycling of plant material, agroforestry is necessarily concerned with the complete range of plant nutrients: the major nutrients, nitrogen, phosphorus and potassium; the secondary nutrients, calcium, magnesium and sulphur; and the trace elements or micronutrients, of which about seven are required for plant growth. There is much current interest in the potential role of agroforestry in the mitigation of nutrient depletion. One of the main tenets of agroforestry is that trees enhance soil fertility, the capacity of the soil to provide essential nutrients for plant growth (Young,A 1990).

Agro forestry and Nutrient Cycling

Agroforestry systems promote more closed nutrient cycling than agricultural systems by:

1. To increase gains from symbiotic fixation, through the use of nitrogen-fixing trees
2. To enhance uptake of other nutrients released by rock weathering through the deep root systems of trees.
3. To reduce nutrient fixation on clay minerals and increase availability, through release from organic compounds.
4. To lead to more closed nutrient cycling, improving the ratio between plant uptake and leaching loss, through two mechanisms:
   A. uptake by tree root systems and associated mycorrhiza, with recycling as litter;
   B. synchronizing: the timing of mineralization with that of crop nutrient requirements, through controlling the quality, timing and manner of addition of plant residues.
5. To provide a balanced nutrient supply, as organic residues, thereby reducing the likelihood of micronutrient deficiencies.
6. To reduce nutrient losses from erosion (discussed in Part II, a demonstrated potential of large magnitude (Young.A, 1990).

Table: - 7.Agroforestary role for plant nutrients

Nutrient	% in leaf	Potential nutrient return in leaf litter or pruning's (kg/ha/yr)
Nitrogen	2.0-2.0	80-120
Phosphorus	0.2-0.3	8-12
Potassium	1.0-3.0	40-120
Calcium	0.5-1.5	20-60

Available nutrients at two soil levelis (kg/ha)		Under *Prosopis cineraria*	Under *Prosopis juliflora*	Open field
N:	0-15 cm	250	203	
	15-30 cm	193	212	196
P:	0-15 cm	22	10	8
	15-30 cm	10	5	4
K:	0-15 cm	633	409	3|70
	15-30 cm	325	258	235

Nutrient return through stem flow, trough fall and rainwater at

Source	N	P	K	Ca	Mg
Stem flow	0,17	**0.02**	0.71	**0.84**	0.10
Trough fall	8.39	0.89	31.28	35.19	5.03
Total	9.56	0.91	31.99	35.93	5.13
Rainfall	4.33	0.43	7.80	9.96	4.77
Contribution of 1+2 (3-4)	5.23	0.48	24.19	24.97	0.63

Source Young.A (1990)

Table7 refers the nutrients build up in top soil (0-15 cm) in the sole tree stand and under agro-forestry systems (**Dhyani,** 1998)

Table:-8 Agro forestry systems for nutrient exchange

Agro forestry systems	**Exchangeable nutrients (me/100 g)**					
Tree + crop	**Total N (%)**	**C/N**	**Ca2+**	**Mg2+**	**K+**	**Avail P (ppm)**
Alder	0.23	7.1	2.91	2.05	0.41	12.1
Albizia	0.20	8.0	3.02	4.46	0.39	18.1
Cherry	0.15	9.6	2.11	1.90	0.23	10.5
Mandarin	0.17	9.2	2.52	2.00	0.27	11.8
Sole crop	0.11	12.2	0.53	0.51	0.19	5.8
Mean	0.19	8.6	2.51	2.46	0.29	11.67
Sd (±)	0.04	1.61	0.83	1.28	0.08	3.39
CV (%)	23.2	18.63	33.23	51.90	27.02	31.80

Source: - Patiram and B.U. Choudhury (2000)

In the table 8 the total content of N was higher in soil tree stand as compared to agroforestry systems in top soil (0-15 cm). The table above shows the role of agro forestry trees on soil nutrients. For instance the total amount of nutrients (kg/ha/yr) through trough fall contributed 98% of all the nutrients, because of larger quantity of water passing through this compartment. More amounts of the Ca and Mg contributed by trough fall as compared to N, P, and Mg.

2.2. Agro-forestry for ensuring food security

One of the most serious challenges faced by policy and decision-makers in many developing countries is food security. It may have different meanings for different people. The International Conference on Nutrition (ICN), held in Rome in 1992, defined food security as "access by all people at all times to the food needed for a healthy life" (FAO/WHO, 1992). Essentially, in order to achieve food security a country must achieve three basic aims,

1. Ensure adequacy of food supplies in terms of quantity, quality and variety
2. Optimize stability in the flow of supplies
3. Secure sustainable access to available supplies by all who need them (FAO/WHO, 1992).

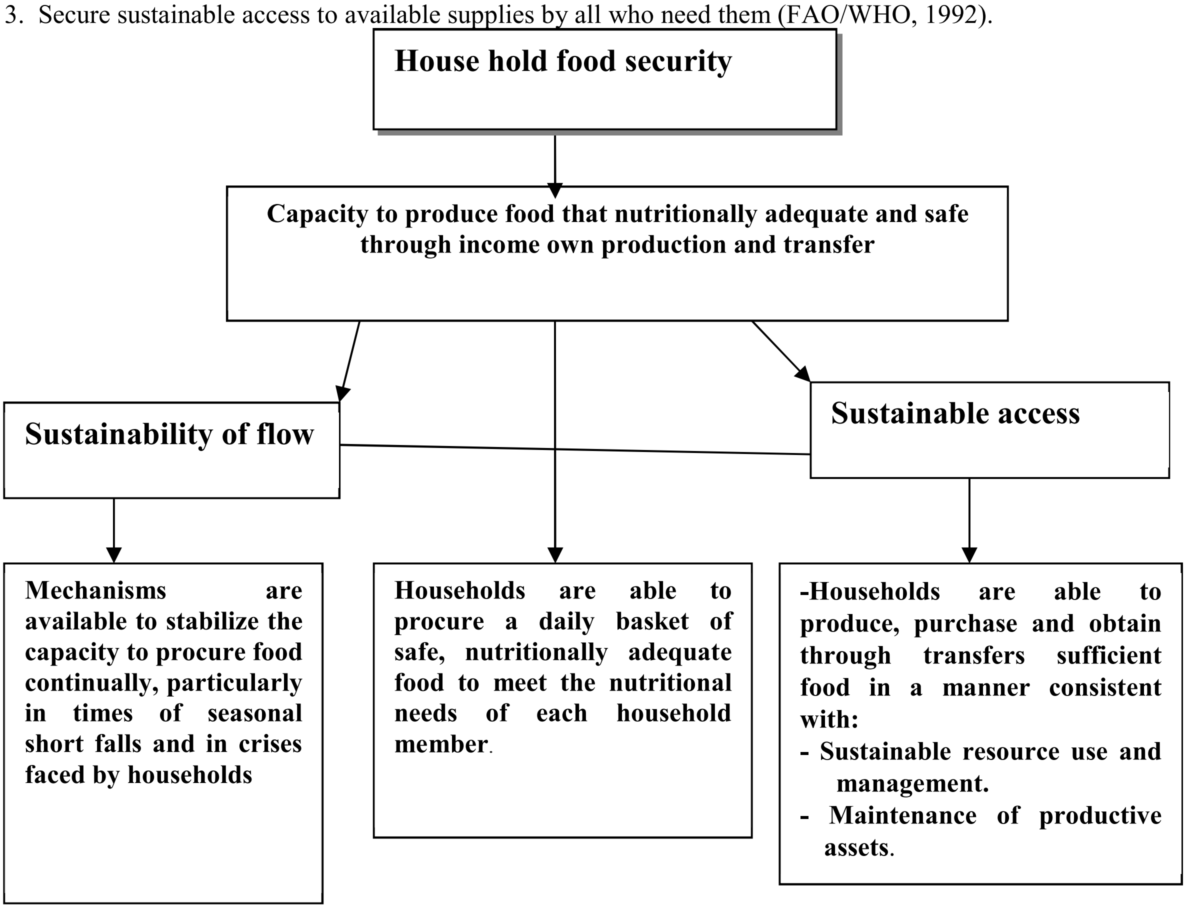


Fig: 4. the normative dimensions of household food security
Source adopted from Frankenberger *et al,* (1993).

Table:-9 Average annual food production and its rate of growth for sub-Saharan Africa, 1961-1975 to 1991-1994

Crop	Mean 1961-1965		Mean 1971-1975		Mean 1981-1985		Mean 1991-1994	
	Production ('000 tonnes)	Growth rate (%)	Production ('000 tonnes)	Growth rate (%)	Production ('000 tonnes)	Growth rate (%)	Production ('000 tonnes)	Growth rate (%)
Wheat	900	3.2	1 300	1.2	1 500	-3.4	2 200	-0.4
Rice, paddy	3 600	3.8	5.2	4.5	6 600	2.9	10 800	3.3
Cereals, total	32 700	1.3	39 300	3.6	45 600	2.5	59 800	2.5
Roots and tubers	49 700	3.3	66 000	3.2	77 800	2.9	113 500	2.5
Pulses, total	3 200	3.7	4100	2.0	4 400	-1.8	5 900	0.3
Oil and crops	3 900	2.0	4 200	1.8	3 900	-0.4	5 000	3.2

Source FAO, (1995)

Table:-10 Average annual exports and imports of basic food staples for sub-Saharan Africa, 1961-1965 to 1991 - 1993

Crop Group	Mean 1961-1965			Mean 1971-1975			Mean 1981-1985			Mean 1991-1994		
	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade	Imports	Exports	Net trade
Cereals, total	2000	700	-1300	3836	1906	-2930	9254	646	-8607	11667	671	-10996
Pulses, total	66	190	124	51	213	161	116	122	6	219	128	-91
Oilseeds	23	2 383	2 360	53	1308	1255	61	430	369	103	368	265

Source FAO, (1995)

Table:-11 Food available for consumption for sub-Saharan Africa, 1961-1965 to 1991-1992 (`000 tones)

Crop group	Mean 1961-1965	Mean 1971-1975	Mean 1981-1985	Mean 1991-1992
Cereals and cereal products, including beer	27 920	34 393	47 046	60 937
Starchy roots and products	38935	50147	60693	85335
Pulses and products	2 420	3 059	3 504	4 721
Oil crops and products	1 594	2 269	3 236	4 294

Source, FAO, (1995)

Table:-12 Estimates and projections of chronic under nutrition in developing regions

Region/year (three-year average)	Total population (millions)	Undernourished	
		Percentage of total population	Person millions)
Sub-Saharan Africa			
1969-71	268	38	103
1979-81	357	41	148
1990-92	500	43	215
2010	874	30	264

Source: FAO, (1996)

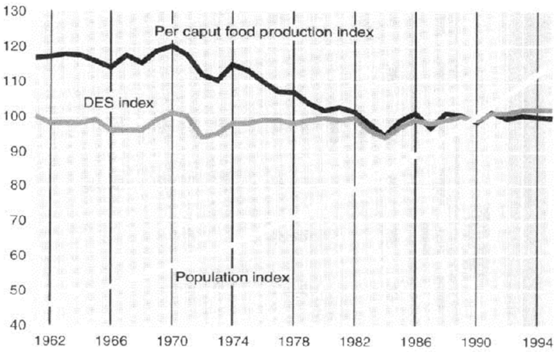
Table:-13 Per capita dietary energy supplies: 1969-1971, 1979-1981 and 1990-1992

East African Country	Population(millions)	Per caput DES (kcal/day)			Annual growth rate/ %
	1990-1992	1969-1971	1979-1981	1990-1992	1969-1971 to 1990-1992
Ethiopia	51.4	1 700	1 810	1 620	-0.26
Kenya	24.4	2 200	2 150	1 970	-0.53
Uganda	18.1	2 300	2 130	2 220	-0.15
Somalia	7.7	1 810	1 870	1 590	-0.62
Tanzania, United Republic	26.9	1 740	2 280	2 110	0.90
Burundi	5.7	2 100	2 040	1 950	-0.35
Sudan	25.9	2 190	2 260	2 150	-0.08
Rwanda	7.3	2 040	2 090	1 860	-0.44
Sub-Saharan Africa	501	2 140	2 080	2 040	-
Africa	656.9	2 220	2 280	2 290	0.15
World	5 358.8	2 440	2 580	2 720	0.50

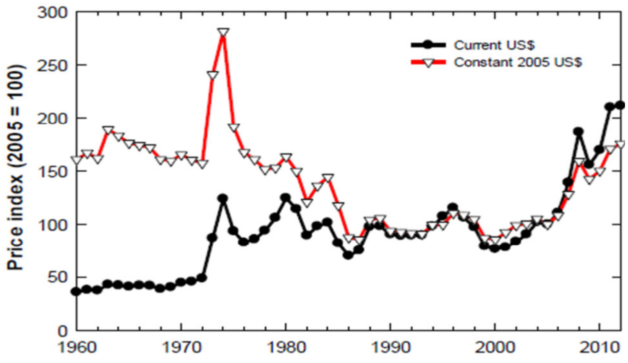
Source FAO, (1996)

The table 9 to 13 respectively shows that, the low average annual food production and its rate of growth, negative trade balance, small food available for consumption, rising chronically undernourished people from 38 to 43 percent between 1969 and 1992 and people with inadequate access to food doubled, rising from 103 million to 215 million in the same period.

In general the trends in population, food production and dietary energy supply for sub-Saharan Africa, expressed as indexes (1989-1991 base year = 100).



Source FAO, (1997)



Source: SDS net work (2015)

Fig: - 5, Per capital food production index

Fig: - 6 Global food price index

The fig,5 shows population, food production and per caput dietary energy supply/ food available for direct human consumption per person per day (DES) trends from 1961 to 1995, indicating that food production and DES have not kept pace with population growth.DES indicates the food available for direct human consumption per person per day.

The fig 6 indicates global food price index, (supply and demand) balances for agricultural products are tighter; the global food demand will continue to increase for at least another 50 years due to population growth and change of diet.

In recent decades, agricultural land that was formerly productive has been lost to urbanization and other human uses, as well as to desertification, salinization, soil erosion, and other consequences of unsustainable land management (Nellemann et al. 2009). The most likely scenario is that more food will need to be produced from the same amount of, or even less land. Indeed, for the last three consecutive years the record shows that total global agricultural land area has actually diminished (Nellemann,et al. 2009).

Beginning in 2006, international prices for basic agricultural commodities rose to levels not experienced in nearly three decades. The FAO's world food price index had risen to a record high in early 2011, topping the previous all-time high set in June 2008. The remarkable progress in global agricultural production in the second half of the last century has helped to break cycles of crop failures, food deficits and famines. However, as we move into the 21st century, the decline of food production in developing countries has been so worsening; for instance nearly 840 million people in the world suffer from under-nourishment most of them live in Asia and Africa.

In spite of these global trends there still are vast numbers of undernourished and malnourished people and at the same time there are a growing number of overweight and obese people in some countries. This can have severe life-long effects on the social, physical, and mental well-being of millions of young people. In general in the last four decades, agricultural production has come under increasing threat, due to the worsening climatic and environmental conditions, land, biodiversity, and forest and soil degradation, enhanced by a huge population pressure on limited resources.

Therefore investment in agriculture and rural development to boost food production and nutrition is a priority for the World (World Bank Group Agriculture Action Plan 2013–2015).

Also the growing food insecurity and deteriorating livelihood situations call for concerted and consorted actions at national and international levels to take advantage of the high potential of agro-forestry, among other systems, for promoting best land use practices.

In this regard agro-forestry has multiple socio-economic and environmental advantages in solving the problem of food and nutritional security requires a range of interconnected agricultural approaches, which includes improvements in staple crop productivity, ensure ecosystem services, enhance cultivation of a wider range of edible plants that provide fruits, nuts, vegetables, reduced insect pests and associated diseases, etc, for more diverse diets (Frison et al., 2011).

But little attention has been paid to the beneficial influence of integrating trees with the production of crops, livestock or a mixture of both in farming systems. The result has been the meaningless destruction of forests and trees with their negative consequences on food production in particular and environmental degradation in general (Aju, P. C.2014).

2.2.1 Increased crop productivity

Agricultural productivity is the amount of a single output per unit of a single input, or in terms of an index of multiple outputs divided by an index of multiple inputs (Barrett, et al, 2010). In the past growth in agricultural production in Sub-Saharan Africa was achieved by spreading out the amount of cultivated land, but today there is a very small scope for increasing the area for cultivation. Scholars in the field (Venkatesan & Kampen, 1998) suggest that raising agricultural production in the fixed land could only be achieved by raising the yield and productivity of farm labor, yet this obliges the innovation and adoption of appropriate farming system and technologies for developing countries.

The realization that trees can improve agricultural production and the development of farming systems that take advantage of this are still far from being widespread. But agro forestry has contributing significantly to the increment of productivity. Example maize yields have been proven to increase more than 200% in some cases when grown with nitrogen-fixing acacia species *Faidherbia* in Africa (Garrity et al. 2010: 201). Here the argument is that the soil and water conservation use of agro forestry is the joint between conservation and production which is essential for sustainable land use (Young, 1989). In Kenya alone, about 400 documented indigenous fruit tree species contribute much to food and nutritional security and livelihoods of rural communities, particularly during the periods of food shortage (De Leeuw *et al*. 2014: 42).

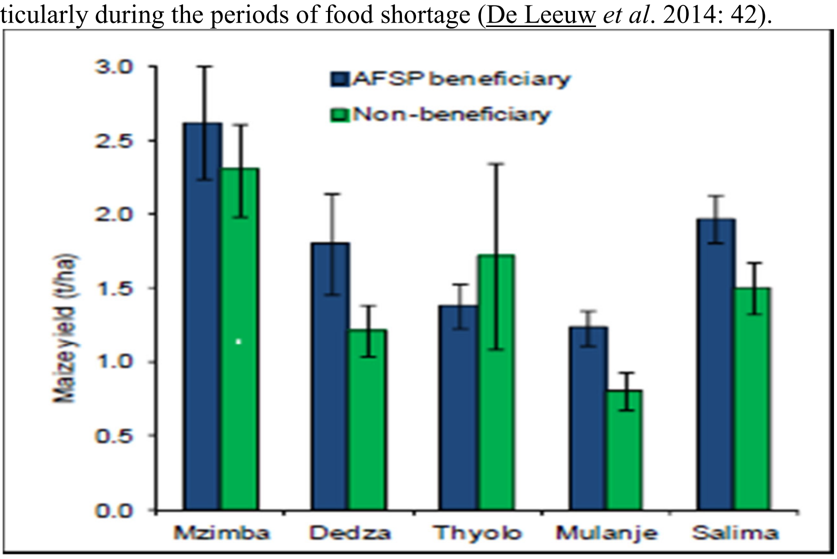


Fig: - 6 Maize yields in five districts in Malawi with and without the intervention of the Agro-forestry.
Source De Leeuw *et al*. (2014)

According to the fig 6 the maize yield in five districts in Malawi become higher for the farmers who are beneficiary of agro-forestry programe.

- **Crop productivity increment role of agro forestry take place through**

- Maintaining soil organic matter and biological activity at levels satisfactory for soil fertility. This depends on an adequate proportion of trees in the system- normally at least 20% crown cover of trees to maintain organic matter over systems as a whole.
- Controlling runoff and soil erosion, thereby reducing losses of water, soil material, organic matter and nutrients.
- Maintain more favorable soil physical properties than agriculture, through organic matter maintenance and the effects of tree roots.
- Help to closed nutrient cycling than agriculture and hence to more efficient use of nutrients. This is true to an impressive degree for forest garden/farming systems. Trees can probably increase nutrient inputs to agro forestry systems by retrieval from lower soil horizons and weathering rock.
- The decomposition of tree and pruning can substantially contribute to maintenance of soil fertility. The addition of high-quality tree pruning leads to large increase in crop yields. The release of nutrients from the decomposition of tree residues can be synchronized with the requirements for nutrient uptake of associated crops. Also addition of high quality pruning to the soil at the time of crop planting usually leads to a good degree of synchrony between nutrient release and demand.
- They can check the development of soil toxicities, or reduce exiting toxicities-both soil acidification and salinization.

Indeed, in small scale agricultural production systems, trees outside forests management seems to hold a high promise as a bridge between food productivity and environmental protection, due to its capacity to restore the ecosystems and improve soil fertility (FAO, 2001).

2.2.2 Diversified crop production

As production and consumption decisions, there is also non separability between crop choice decisions in production and access to inputs for short or long-term investment by the farm household. In developing countries, like Ethiopia, farm households with limited cash income may not afford to acquire essential agricultural inputs due to flawed and imperfect credit markets. Consequently, farmers usually try to fill this gap by diversifying agriculture from merely food crop farming to other tree and cash crop planting practices (Geremew Worku Kassie, 2016).

In addition of diversifies crop production options for direct production of food, provision of rural employment and income, protective environmental functions (maintenance and restoration of soil fertility and soil improvement, erosion control) and maintenance of biodiversity AF system is rich in vitamins and sometimes even minerals, e.g. 40-100g of white cross berries (*Grewia tenax*) supply the daily iron requirements of an under eight-years-old child, enhancing the food and nutritional security of rural communities and can bring significant health, ecological and economic revenues (Hosny El-Lakany, 2007 and De Leeuw et al. 2014:). When soil becomes poor in plant nutrients, food production is impaired (AJU, P.C, 2014 and De Leeuw et al. 2014: p15).

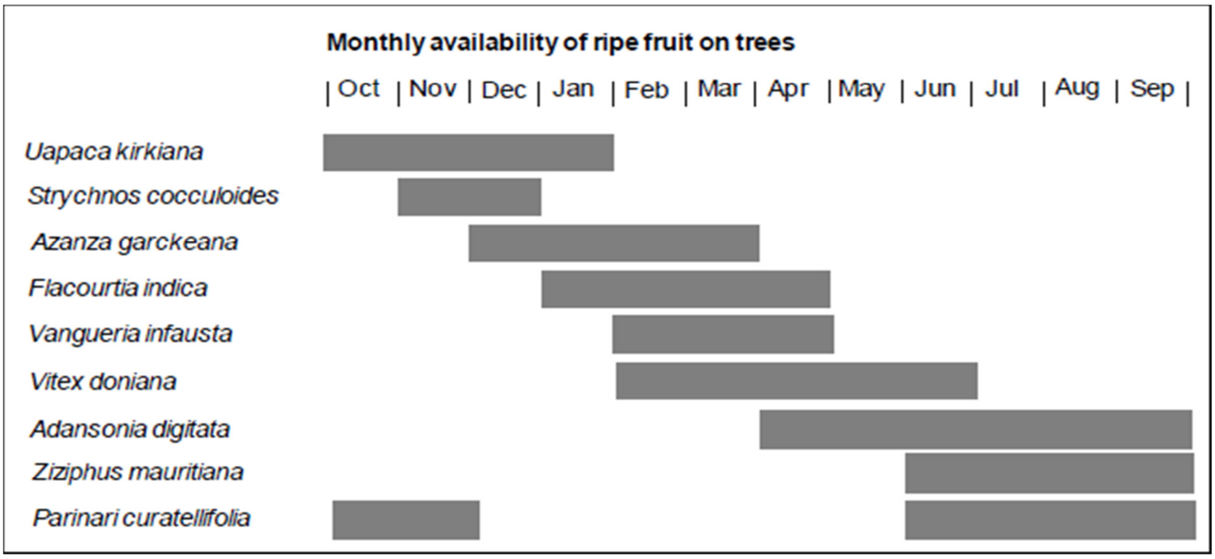


Figure:-7 A fruit tree 'portfolio' consisting of nine tree species fruiting at different times of the year, based on indigenous fruits in Malawi

Source: - Own formulation

Figure 7 shows duet to diversified production at least one species in the portfolio is ripe every month, even periods of hunger due to quiet period in the production of staple crops. Appropriate combinations of crops, animals and trees in agro-forestry systems can not only increase farm yields ,ensure food security, they can promote ecological and social resilience to change, because the various components of a system, and the interactions between them, will respond in differing ways to disturbances (FAO, 2013).

❖ **The major diversified products of agro-forestry**

- Food products (nuts, fruits, vegetables and mushrooms);
- Resins, incense, spices and condiments (nutmeg, cinnamon, cardamom);
- Industrial plant oils and waxes; timber
- Plant gums (Arabic frankincense, gum myrrh);
- Natural honey and bees wax;
- Animals and animal products (game, skins, bones).
- Medicinal plants etc. Therefore agro forestry system has very significant role in diversifying the crop productivity.

2.2.3 Ensuring nutrition security and balanced diet

During the past 50 years, the earth's population doubled to reach its current level of 7 billion and it is projected to exceed nine billion by 2050. Today world population is increasing by more than 80 million annually, at the same time 795 million people go hungry every day. Global agricultural output must expand by an estimated 60 percent to meet global food needs **(**FAO, 2016)**.** More than a billion of the world's poorest people rely on forests and trees to provide food, fuel and cash income (FAO, 2012). Forests are particularly important for food security and nutrition, as well as supplying fuel for cooking. Many components of the daily diet of rural families come directly from forest fruits, tubers, vines, mushrooms and leafy legumes, insects and animals harvested from forests. These provide important nutritional supplements that are a vital for food security (FAO, 2012).

However, food security is measured solely in terms of food energy, or calorie, production, losing sight of the fact that, by definition, food security includes secure access to the foods needed for a nutritionally balanced diet. Thus the contribution of forests and tree based ecosystem services to food security is often overlooked when food security is operational zed as access to calories alone, fruits, vegetables, and bush meat (Sunderland, T et al,2013). Forests and tree-based agricultural systems make essential contributions to human livelihoods and well-being through both the provision of direct and indirect ecosystem services (Arnold et al. 2011). Among the major uses of forest farming, NTFPs (none timber forest product) are a very important component of subsistence and livelihood activities throughout the world which are plants, parts of plants, fungi, and other biological materials harvested from within and on the edges of natural, manipulated, or disturbed forests. Suitable species or Shade-loving plants that are naturally adapted to grow under forest conditions are candidates for agro forestry. Examples of crops are gourmet, mushrooms like shiitakes (Lentinula edodes), berries, other fruits such as pawpaw (Asimina triloba), ramps (Allium tricoccum), and tree nuts such as walnuts (Juglans spp) and hickories (Carya spp) in the form of wood, fruit, nuts, and berries (Ken Mudge, 2009 and Jump up 2013 ginseng, decorative ferns, and pine straw (Gold, et al, 2000).

Agro forestry offers the possibility of improving food security by more effectively managing soil and water resources for the sustained production of annuals. It also offers a potential for overcoming many problems of seasonality of food availability by greatly extending the season when green fodder and food supplies are available. Trees and other perennials in the production system can help tide people over drought and pest attacks, etc., when annuals cannot survive (Campbell-Asselbergs, 1986).

The bush land, which is frequently fallow land or used for extensive livestock rearing, was long valued for the security it offered through containing less preferred fodder and wild seeds and roots which allowed for survival of both people and animals during what would otherwise be a disaster. Periodic droughts which have proven so catastrophic in recent times have been so severe because of the lack of this fall-back resource. Trees found in homesteads or farmlands are also frequently considered a living savings to be left to grow when not required but to be cut in times of need, thereby offering a more secure livelihood (Chambers and Leach, 1986).

Recently a collection of scholars published the results of a cross-sectional study that examined the role of forest foods in dietary intake and food security for forest-dependent households in eastern and southern Cameroon, an area rampant with food insecurity. The authors found that forest foods reduced the severity of food insecurity and yielded ample amounts of micronutrients. The data suggests that households who consume greater quantities of forest foods are less food insecure, with similar implications for forest communities throughout Cameroon. In South Africa, a similar report determined that a large portion of the population utilizes forest foods to sustain their livelihoods and alleviate poverty (Chambers and Leach, 1986).

2.2.4 Boost income generation

Most research on agro forestry has been conducted from the biophysical perspective, but nowadays economic and social aspects are gaining attention (Mercer and Miller, 1998). There are many opportunities for generating income from agro-forestry. For instance in Eastern Africa's dry lands various tree species are serving as source of incomes (De Leeuw et al. 2014: 41). Also in the United Kingdom, a range of timber/ cereal and timber/pasture systems has been profitable to farmers (State of the World's Forests, 2005).

❖ **The major income sources of agro forestry**

- Logs and Timber**:** - Income from harvesting timber and selling logs often provides the highest economic value in the AF system.
- Paid for services and products providing by AF such as recreational access, conservation reserve areas, clean water supplies, and storing carbon in trees.
- Non-timber Products: - forest is more than trees – they can be source of money from non-timber forest products, such as floral, medicinal, edibles, aromatics, mosses, vegetables, and gum trees, cotton wood that can be harvested and sold for pulpwood and evergreen boughs. Woody Floral product particularly good candidates for use in agro forestry systems because of their substantial markets, rapid growth, ease of integration into agricultural fields, and off-season labor requirements. Such as Decorative/Aesthetic, Craft and Dyes products are, Pine straw, Willow twigs, Vines, Bear grass, Ferns, Pine cones, Moss, and Native ornamentals are Rhododendron high bush cranberry (Viburnum trilobum) and Flowering dogwood (Cornus florida).
- Well-managed AF potentially produce high quality lumber, firewood and valuable forest products like maple syrup, ginseng, which are grown under shade increase the source of income.
- Pine straw may be another income-generating option from loblolly or long leaf pine plantations where there are markets.
- Tree canopies provide livestock with shade and wind protection and may contribute in increment of yield for additional income when the trees or tree products are harvested. The branches and leaves of some trees can be pruned from the trees and fed directly to livestock. Pine stands and nut and fruit orchards may be grazed to produce income before and while trees are bearing and growing.
- Some forest product companies may offer advanced purchase or lease agreements that provide annual

payments before the trees are harvested. Because these plantings also attract wildlife, hunting leases are a possible income source (Armitage, 1993 and Stevens, 1998 and Scott Josiah, 2000).

Agro forestry participants in semi-arid areas of Misungwi district of Tanzania annually had extra income than non-AF participants at average of 760 US$ (Stephen Manoni Maduka (2007). A study of coconut farmers in an area in Sri Lanka, for example, showed that intercropping increases net returns (Karunanayake, 1982). The growth in markets for some agro forestry products has recently been very rapid notably for fuel wood, charcoal and poles. All the above functions of agro-forestry classified as provision of non-wood products, timber provision, energy needs, water/hydrological cycle, air quality and environmental services, soil conservation and fertility amelioration (WAC, 2014).

3. Conclusion and Recommendation

Sustainable agricultural systems depend on agro-ecological processes that promote soil fertility and pest resistance through biologically acquired inputs, and social processes that generate knowledge and incentives for producing a variety of foods and fibers within locally affordable means. Forests are directly addressed within the 2030 development agenda, the Sustainable Development Goals, therefore sustainably managed forests, a stronger fight again desertification, a halt and reverse to land degradation, and a stop to biodiversity loss, sustain nutritious and invaluable food and medicinal sources (Nicole Graham, and Humanitas Global,2016).

As a result agro-forestry systems have been indicated as one of the more promising alternatives to achieve a more sustainable agriculture, in greater equilibrium with the environment (Rachel C,et al .2012). Agro-forestry practices are characterized by the coexistence or succession of trees and crops, which are particularly dependent on human action to remain stable (Jose, et al. 2004). Agricultural practices based on ecological principles (such as agro-forestry) can combine production with conservation of the remaining fragments of natural forests (Buck et al., 2006).

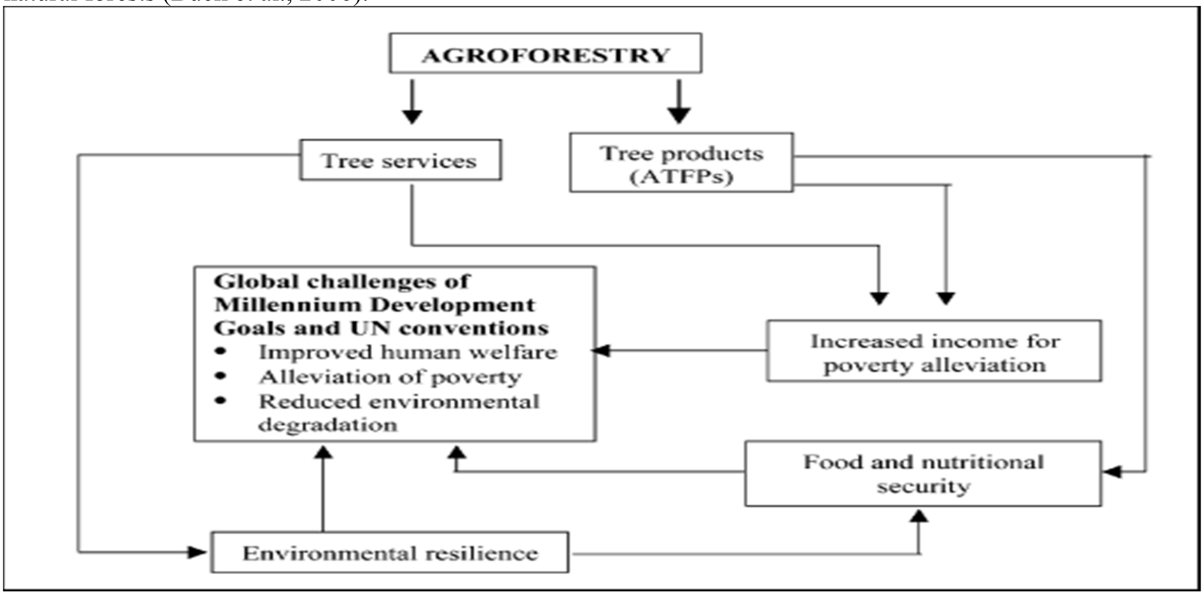


Fig:- 8 Over all function of agro forestry
Source: - WOCAT (2007)

In general agro forestry systems can be advantageous over conventional agricultural, and forest production methods. They can offer increased productivity, economic benefits, and more diversity in the ecological goods and services provided. Biodiversity in agro forestry systems is typically higher than in conventional agricultural systems. With two or more interacting plant species in a given land area, it creates a more complex habitat that can support a wider variety of birds, insects, and other animals. Depending upon the application, impacts of agro forestry can include:

- Reducing poverty through increased production of wood and other tree products for home consumption and sale
- Contributing to food security by restoring the soil fertility for food crops
- Cleaner water through reduced nutrient and soil runoff
- Countering global warming and the risk of hunger by increasing the number of drought-resistant trees and the subsequent production of fruits, nuts and edible oils
- Reducing deforestation and pressure on woodlands by providing farm-grown fuel wood
- Reducing or eliminating the need for toxic chemicals (insecticides, herbicides, etc.)

- Through more diverse farm outputs, improved human nutrition
- Providing growing space for medicinal plants in the situations where people have limited access
- Increased crop stability and income
- Multifunctional site use i.e. crop production and animal grazing.
- Typically more drought resistant.
- Stabilizes depleted soils from erosion (Central Queensland Forest Association,2013 and https://en.wikipedia.org/wiki/Agro forestry)

Thus, human action is central to regulate these interactions and enhance the productivity toward selected goals by converting physical, chemical and biological processes into beneficial inputs for crops and wood production (Jelte van 't Foort, et al,2012).

The reviewer recommend to realize this potential of agro forestay a better understanding is needed of how agro-forestry practice affects soil, water, plant, animal and atmospheric relations, and the roles of management in bringing about desirable outcomes.

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