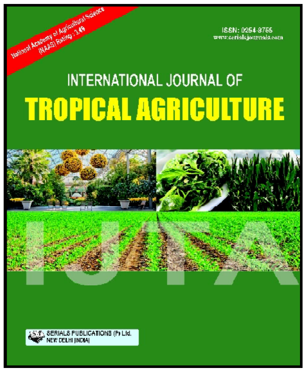

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Role of Trees and Woody Vegetation in Soil Fertility Enrichment and Food Security in Dryland Agroforestry as a Climate-Smart Agriculture Strategy

Antony Joseph Raj

Department of Land Resource Management and Environmental Protection, College of Dryland Agriculture and Natural Resources, Mekelle University, Mekelle, Tigray, Ethiopia
E-mail: drajr.aaidu@gmail.com

Abstract: Globally 40 per cent of the land cover area is classified as drylands which supports 2.5 billion people. It is reported that 90 per cent of drylands are in developing countries and 10 per cent of drylands are severely degraded and need immediate attention. The potential of trees to bring improvements in nutrition, income, housing, health, energy needs, and environmental sustainability in the dryland areas has guided ICRAF's mission, with the presence of trees being the principal component of an "evergreen agriculture". Within the array of benefits brought by trees, an important element is the positive effect of trees on soil properties and consequently benefits for crops. In this scenario, agroforestry systems have been indicated as one of the more promising alternatives to achieve a more sustainable agriculture, especially for poverty reduction, food security and maintaining environmental services. Trees and woody vegetations are widely incorporated in various dryland agroforestry systems practiced in agricultural landscapes around the world. Trees and woody vegetations for soil fertility improvement in agroforestry are *Leucaena leucocephala, Sesbania* spp., *Faidherbia albida, Calliandra calothyrsus, Erythrina* spp.*, Pithecellobium dulce*, *Flemingia* spp., *Cassia siamea, Albizia amara*, *Albizia lebbeck*, *Albizia procera*, *Albizia saman*, *Dalbergia sissoo*, *Acacia cyanophylla, Acacia nilotica*, *Acacia tortilis*, *Acacia senegal*, *Acacia auriculiformis*, other *Acacia* spp., *Prosopis cineraria*, *Prosopis juliflora*, *Inga jinicuil. Casuarina equisetifolia* (symbiotic with the actinomycete *Frankia*) has found extensive use to consolidate sandy coastal soils and has the ability to fix atmospheric nitrogen.

Key Words: dryland, dryland agroforestry, food security, ecosystem services, soil fertility improvement

1. AGROFORESTRY INTRODUCTION

Agroforestry is a system of land management which seems to be suitable for the fragile ecosystems of the developing world. It combines the protective characteristics of forestry with the productive attributes of both forestry and agriculture. Agroforestry is a new name for the old practice of growing trees on farmland [1] & [2]. Farmers have been practising agroforestry for thousands of years by combining trees with crops or animals. When land is scarce or when soil has a low fertility or is sensitive to erosion, agroforestry techniques offer considerable benefits for long term agricultural sustainability. Agroforestry can help to make small farms more productive by increasing family income [1] & [2]. Attaining Millennium Development Goals (MDGs) is the greatest challenge of our generation and it will bring benefits to everyone, including greater economic abundance, peace and security to all people on the earth. A clear vision is evolving that articulates how agroforestry research and development can contribute materially to achieve these goals and aspirations [3].

Farmers have integrated trees in their farming systems for centuries. Agroforestry is an ancient land use practice and modern science involving the deliberate management of trees on farms and in surrounding landscapes [1] & [2]. Agroforestry systems vary greatly in tree species mix, complexity, configuration and input requirements, producing a wide range of products and services. With appropriate technical and institutional support, the practice of agroforestry can contribute to rural food and health systems and help to buffer households against health and nutrition shocks. By combining the strengths of agriculture and forestry, agroforestry opens up promising new prospects for the future of rural communities [1] & [2].

Agroforestry systems are designed to produce a range of productive benefits including food, fodder, fuelwood, fibres, wood, pole, etc as well as protective benefits such as reducing soil and water erosion; improving soil fertility status; improving water quality and yield, flood control, biodiversity conservation, microclimate modification, carbon sequestration, climate change mitigation, aesthetic value, etc. [4]. Agroforestry systems take advantage of trees for many uses, to hold the soil, to increase fertility through nitrogen fixation, or through bringing minerals from deep in the soil and depositing them by leaf-fall, to provide shade, construction materials, foods and fuel. Agroforestry practices are *intentional* combinations of trees with crops and/ or livestock which involve *intensive* management of the *interactions* between the components as an *integrated* agroecosystem. These four key criteria - intentional, intensive, interactive and integrated - are the essence of agroforestry and are what distinguish it from other farming or forestry practices. To be called agroforestry, a land use practice must satisfy all of the following four criteria/ four "I" words [5].

2. ORIGIN OF AGROFORESTRY

The scientific rediscovery of agroforestry dates back to the mid-1970's but the roots of agroforestry tradition go much, deeper. The main taproot of agroforestry lies embedded in the traditional agroforestry practices of farmers all over the world. Forerunner of modern agroforestry within the scientific land use specializations are several [6]. From classical forestry view, agroforestry developed and grew out of the taungya method of reforestation, first developed in Burma toward the close of the 19th century. At an outpost of the British Empire in 1806, U Pan Hle, a Karen in the Tonze forests of Thararrawaddy Division in Myanmar (Burma), established a plantation of teak (*Tectona grandis*) by using a method he called "Taungya", and presented it to Sir Dietrich Brandis, the Governor. From this beginning, the practice became increasingly widespread. It was introduced into South Africa as early as 1887 [7] and was taken, from what was then Burma, to the Chittagong and Bengal areas in colonial India in 1890 [8].

The wider implications and potentials of the Taungya approach were first recognized by [9] and others at the University of Ibadan in Nigeria. King coined the name "Agrisilviculture" to refer to what later came to be called agroforestry. The most significant single initiative that contributed to the development of agroforestry came from the International Development Research Centre (IDRC) of Canada. In July 1975, the IDRC commissioned John Bene, to lead a study to identify the critical priorities for tropical land use and to assess the interdependence between forestry and agriculture in low-income tropical countries and propose research leading to the optimization of land use in developing countries.

The publication in 1977 of a report entitled *Trees, Food and People* [10] by the Bene Commission concluded that the top priority for tropical forestry lay in "agroforestry", the term coined by the commission to refer to the new field of interdisciplinary endeavour. In short, there was a shift in emphasis from forestry to combined production systems which would integrate forestry, agriculture and/or animal husbandry in order to optimize tropical land use [10]. This initiates led to the establishment of International Council for Research in Agroforestry (ICRAF) in 1977 started its work in The Hague and later in July 1978, ICRAF moved to its present headquarters in Nairobi, Kenya.

ICRAF joined the Consultative Group on International Agricultural Research (CGIAR) in 1991 to conduct strategic research on agroforestry at a global scale and was renamed as the International Centre for Research in Agroforestry (ICRAF). In 2002, the Centre acquired the brand name the 'World Agroforestry Centre'. However, the 'International Centre for Research in Agroforestry' remains as legal name. World Agroforestry Centre reflects the fact that Centre is now recognized as the international leader in agroforestry research and development.

3. DEFINITIONS OF AGROFORESTRY

- It was the Bene Commission that proposed the first widely accepted definition: "Agroforestry is a sustainable management system for land that increases overall production, combines agricultural crops, tree crops and forest plants and/or animals simultaneously or sequentially, and applies management practices that are compatible with the cultural patterns of the local population" [10].
- Reference [11] defined agroforestry as "a land use system that integrates trees, crops and animal in a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable to the farmers".
- The following definition was suggested by ICRAF and was increasingly used in ICRAF publications and thus achieved wide acceptability. "Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, bamboos, palms, 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. In agroforestry systems there are both ecological and economical interactions between the different components" [12].
- "The deliberate growing of woody perennials on the same unit of land as agricultural crops and/or animals, either in some form of spatial mixture or sequence. There must be a significant interaction (positive and/or negative) between the woody and non-woody components of the system, either ecological and/or economical" [2].
- "An intensive land management system that optimizes the benefits (physical, biological, ecological, economic, social) arising from biophysical interactions created when trees

and/or shrubs are deliberately combined with crops and/or livestock" [13].

4. TREES AND WOODY COMPONENTS IN DRYLAND AGROFORESTRY

Drylands refers to areas where there is a shortage of water, defined as 25 to 50 per cent less of the evapotranspiration demand or an aridity index less than 0.65. Globally 40 per cent of the land cover area is classified as drylands which supports 2.5 billion people. It is reported that 90 per cent of drylands are in developing countries and 10 per cent of drylands are severely degraded and need immediate attention. One third (1/3) of trees in drylands are threatened and one sixth (1/6) of trees in dryalnds are endangered or critically endangered [14]. Arid or dryland environments are diverse by land forms, soils, fauna, flora, water balance and human activities, while water is a common scare commodity. Much of rainfall is lost by evapotranspiration and as a result, ground water is recharged only by seepage through soil profile. However, it is a common phenomenon in arid zones of the world that ground water is frequently used at the rate that exceeds recharge. Tropical agriculture including agriculture in arid tropics, particularly subsistence agriculture is vulnerable, as farmers do not have adequate resources to adapt to climate change. Fuelwood shortage is a major problem in most parts of the semi-arid and arid tropics and agroforestry potentials in fuelwood production are well documented. Similarly, desertification and fodder shortage, which are the other major land use problems in this zone, could be addressed to some extent through the agroforestry approach [15]. Land use options that increase livelihood security and reduce vulnerability to climate and environmental change are necessary. Traditional resource management adaptations, such as agroforestry systems, may potentially provide options for improvement in livelihoods through simultaneous production of food, fodder and firewood as well as mitigation of the impact of climate change [16]. Agroforestry in drylands may play a significant role in mitigating the atmospheric accumulation of greenhouse gases [17]. It also has a role to play in helping farmers adapt to climate change.

Table 1
Major Characteristics of Dry Regions (Arid and Semi-Arid) [1]

S. No.	*Factors*	*Description*
1	Climate	Hot/ cold; one or two wet seasons and at least one long dry period; rainfall 1,000 mm
2	Vegetation and soils	Savannas with low or medium-high trees and bushes; thorn scrub and steppe grasslands; Vertisols, alfisols and entisols
3	Geographical spread	Semi arid and arid parts of Indian subcontinent
4	Main land use systems	Arable farming, extensive ranching or nomadic pastoralism, perennial crop husbandry towards the more humid areas, forestry
5	Main land use andecological problems	Drought (in areas with less rainfall), soil fertility decline caused by over cultivation, over grazing, degradation of deciduous woodland, fuelwood/ fodder shortage, population increase
6	Major agroforestry emphasis	Fuelwood/ fodder production, soil fertility improvement, windbreaks and shelterbelts, food production, sustainable natural resource utilization, value chain

One of the key components in any agroforestry system, including drylands, is the multipurpose trees (MPTs). MPTs are woody perennials which are deliberately kept or grown in a land use system to produce multipurpose products and benefits. Reference [18] defined precisely "multipurpose trees" (MPTs) to mean "tree species that are grown to provide more than one significant crops or functions on the farm. On small farms, this can often mean, for instance, that the farmer uses both wood and leaves from the same tree". The trees and woody plants in an dryland agroforestry system are not necessarily planted. Instead natural regeneration of trees may be protected or mature trees may be deliberately left in the fields or pastures.

In dryland agroforestry, particular attention is placed on multipurpose trees and perennial shrubs. The most important of these trees are legumes because of their ability to fix nitrogen and thus make it available to other plants [19]. Considerable knowledge on properties of trees is necessary to incorporate them in agroforestry systems such as size and form of the canopy, root system, climatic adaptation of the species, adaptation to various soils and stresses and suitability for various agroforestry practices. The trees and woody plants can be planted in dryland agroforestry in different ways viz. individual trees, scattered trees, lines of trees with crops, strips of trees along contour and waterways, boundary lines, living fences, windbreaks, shelterbelts, terrace planting on hills, wood lots, etc. The role of trees and woody vegetation in dryland agroforestry includes [4]:

- Source of fruits, nuts and edible leaves to humans
- Source of fodder to livestock animals
- Source of non-edible materials including resin, tannin, insecticides and medicinal products
- Source of construction materials, posts, lumber and thatching
- Source of fuel
- Beautification and shade
- Soil conservation and improvement of soil fertility
- Water quality improvement
- Climate amelioration
- Carbon sequestration and climate change mitigation

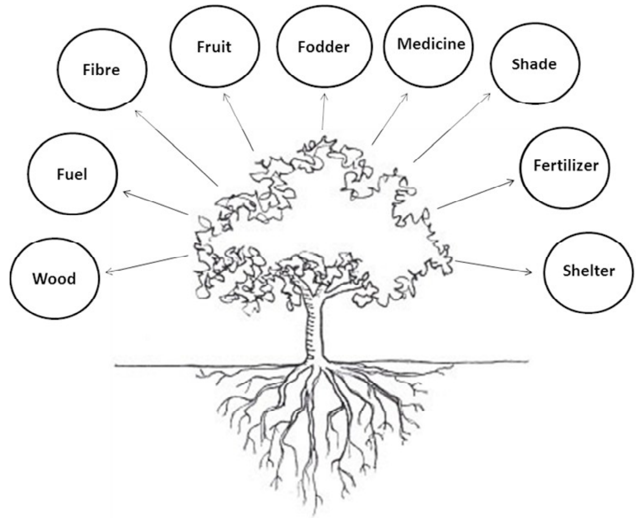

Figure 1: Benefits of Multipurpose Trees (MPTs) in Drylands [20]

5. NITROGEN FIXING TREES/ FERTILIZER TREES IN DRYLAND AGROFORESTRY

Trees play the important and most dominant roles in dryland agroforestry systems. Better emphasis is given trees and woody plants which are indigenous in nature and have the capability to fix atmospheric nitrogen. Selection and management of MPTs influence the success of any dryland agroforestry system [21]. The nitrogen fixing trees (NFTs) besides their 'N' fixing ability provide protein rich foliage which can be used for fodder and green manuring. More than 650 tree species are known to fix nitrogen but limited number of NFTs, which are adapted to harsh dryland conditions, can be incorporated in dryland agroforestry. The most important nitrogen fixing fertilizer trees used in agroforestry for the arid and semi-arid regions are *Faidherbia albida, Leucaena leucocephala, Acacia nilotica*, *Acacia tortilis*, *Acacia senegal*, *Acacia auriculiformis*, *Acacia cyanophyll,* many other *Acacia* spp., *Prosopis cineraria*, *Prosopis juliflora*, *Inga jinicuil*, *Sesbania* spp., *Calliandra calothyrsus, Erythrina* spp., *Pithecellobium dulce*, *Flemingia* spp., *Cassia siamea, Albizia amara*, *Albizia lebbeck*, *Albizia procera*, *Albizia saman*, *Dalbergia sissoo* [21]. *Casuarina equisetifolia* (symbiotic with the actinomycete *Frankia*) has found extensive use to consolidate sandy coastal soils and has the ability to fix atmospheric nitrogen.

The use of nitrogen-fixing trees to improve soil fertility has received much attention in systems containing widely scattered trees such as *Faidherbia albida* in the arid and semi-arid tropics, and in hedgerow intercropping in the sub-humid tropics, where *Leucaena leucocephala* and *Gliricidia sepium* may rapidly increase soil fertility [22]. However, benefits have only been found where the soil is fertile and there is sufficient rainfall and labour [23]. In the semi-arid tropics, hedgerow intercropping has not met with the success initially anticipated as the fertility improvements obtained have failed to offset competition for water and nutrients [24]. Similarly, Reference [25] reported that less than one per cent of the nitrogen fixed by *L. leucocephala* trees was taken up by sorghum in agroforestry systems under nitrogen-limiting soil conditions.

NFTs do not depend solely on soil nitrogen, but "fix" nitrogen through symbiotic microorganisms that live in root nodules and convert atmospheric nitrogen into a plant usable form. This form of nitrogen is known as "green manure" and is a nutrient that helps plants, such as food crops, to grow. There are two basic types of N-fixing systems found in trees, based on two different symbiotic microorganisms.

- Bacteria of the genus *Rhizobium* inoculate trees in the families Fabaceae and Ulmaceae
- Actinomycete of the genus *Frankia* inoculates several other families like Betulaceae, Casuarinaceae, etc.

The use of trees, especially NFTs in dryland agroforestry and dryland silvopastoral systems, is receiving considerable attention recent days. The use of NFTs in dryland agroforestry systems in tropical regions is attractive as a source of N and organic matter needed in the rehabilitation of nutrient depleted soil [27]. Nitrogen fixing fertilizer trees under dryland agroforestry practices maintain or improve soils by the processes described below:

Table 2
Nitrogen Fixing Woody Actinorhizal Plants [26]

Family	*Genera*
Betulaceae	*Alnus*
Casuarinaceae	*Allocasuarina*, *Casuarina*, *Gymnostoma*
Coriariaceae	*Coriaria*
Elaeagnaceae	*Elaeagnus*, *Hippophae*, *Shepherdia*
Myricaceae	*Comptonia*, *Myrica*
Rhamnaceae	*Ceanothus*, *Colletia*, *Descaria*, *Kentrothamnus*, *Retanilla*, *Talguena*, *Trevoa*
Rosaceae	*Cercocarpus*, *Chamaebatia*, *Cowania*, *Dryas*, *Purshia*

- Fixing atmospheric nitrogen and providing in plant available form
- Deep nutrient capture from sub-soils through roots
- Addition of organic matter, nitrogen and other nutrients to the topsoil through leaf fall
- Addition of nitrogen and other nutrients to soil by decaying roots
- Reduction in losses from soil, leading to more closed cycling of organic matter and nutrients
- Improvement of soil physical conditions
- Improvement of soil chemical conditions
- Affecting soil biological processes and conditions

Analysis of soils from under *Faidherbia albida* indicated a remarkable fertility gradient from bare soil to soil under foliage and protein yields of millet near trees were increased 3-4 fold [28]. Leguminous trees such as *Acacia cyanophylla* are commencing to have an important agroforestry role in areas with 250-400 mm rainfall. Significant accumulations of

Table 3
Nitrogen Fixing Woody Leguminous Plants [26]

Sub-family	*Species*	*Percentage Fixers*	*Representative NFT Genera*
Caesalpiniaceae	1,900	23	*Chamaecrista*, *Cordeauxia*
Mimosae	2,800	90	*Acacia*, *Albizia*, *Calliandra*, *Enterolobium*, *Leucaena*, *Mimosa*, *Paraserianthes*, *Pithecellobium*, *Prosopis*
Papilionaceae	12,300	97	*Cajanus*, *Dalbergia*, *Erythrina*, *Flemingia*, *Gliricidia*, *Pterocarpus*, *Robinia*, *Sesbania*, *Tephrosia*

organic C, N, Ca, Mg, P and K have been measured in the surface soil beneath Prospopis canopies in natural ecosystems [29], due partly to transport of these elements from lower depths and to biological nitrogen fixation. It has been estimated the biological nitrogen fixation (BNF) of *Leucaena leucocephala* ranges from 300-550 Kg N ha^{-1} yr^{-1} through various studies, *Casuarina equisetifolia* ranges from 60-110 Kg N ha^{-1} yr^{-1}, *Sesbania rostrata* ranges from 83-109 Kg N ha^{-1} yr^{-1}, *Sesbania sesban* ranges from 43-102 Kg N ha^{-1} yr^{-1}, *Gliricidia sepium* 13-108 Kg N ha^{-1} yr^{-1}, *Inga jinicuil* 35-40 Kg N ha^{-1} yr^{-1}, *Acacia mearnsii* 200 Kg N ha^{-1} yr^{-1}, *Faidherbia albida* 20 Kg N ha^{-1} yr^{-1} and *Albizia lebbeck* 94 Kg N ha^{-1} yr^{-1} [2] & [30].

6. SOIL FERTILITY IMPROVEMENT IN DRYLAND AGROFORESTRY OF ARID AND SEMI-ARID LANDS

In spite of erratic and unevenly distributed rainfall in drylands, agriculture is the mainstay of rural populations, and mixed crop-livestock, mixed livestock-crop farming, and livestock farming, form the spectrum of economic activities. In general rainfall appears to be governing factor for evolution of traditional agroforestry systems. On the basis of rainfall, four types of major traditional agroforestry systems can be classified as presented in Table 4 in arid regions of Western Rajasthan in India [31]. The tree and woody plant density of the agroforestry system forming species is also clearly governed by rainfall regime. Data indicated that with decrease in rainfall, the density of trees and woody component of the system decreased substantially and as well as the productivity of arable crops and grasses were declined.

In semi-arid regions, agroforestry provides a means by which the imbalances brought about by deforestation may be redressed, environmental services restored, and productivity increased relative to that offered by traditional cropping systems [32]. In tropical semi-arid regions, there is substantial potential for increasing water use by implementing

Table 4
Traditional Agroforestry Practices in Arid Region of Western Rajasthan [31]

Rainfall (mm)	*Agroforestry Practice*	*Trees/Shrubs (No./ha)*	*Density of Prominent Tree Species (%)*
<200	*Ziziphus* spp. - *P. cineraria* - *Salvadora* spp. based	17.2	87.2 (65% *Ziziphus* spp.)
200-300	*Ziziphus* spp. - *P. cineraria* based	91.7	100.0 (91.7% *Ziziphus* spp.)
300-400	*P. cineraria* based	14.2	80.0
>400	*P. cineraria* - *A. nilotica* based	31.4	80.5

agroforestry as existing cropping systems often use less than half of the available rainfall due to substantial losses caused by evaporation from the soil surface, runoff and drainage [33]. Low rainfall use efficiencies occur primarily because the fraction of rainfall used for transpiration is low and the ratio of evaporation to transpiration is high when the crop canopy is sparse [34]. In agroforestry systems, runoff may be reduced by the barrier effect of closely planted tree rows, as outlined above, while deep drainage may be limited by water extraction by tree roots located beneath the crop rooting zone [35].

The presence of trees in the ecosystem can influence the nutrient content of the soil via its impacts on the soil structure and on the soil biology but also due to the particular functioning of trees. There are three levels of interactions. First of all, trees can be providers of new inputs for the nutrient cycle. For instance, tree canopies collect atmospheric depositions that are incorporated into the soil when the leaves fall. Also, deep roots of the trees can capture nutrients and minerals from the rock and the subsoil and pump it to the canopy so that it is an input in the nutrient cycle [36] & [37]. As well, certain tree species associate with nitrogen-fixing or phosphorus-solubilizing mycorrhizal or rhizospheric organisms and make these nutrients available for the plants of the entire ecosystem [38].

Secondly, trees can be active drivers in the nutrient cycling processes. Reference [39] studied the nitrogen cycle in agroforestry. In such agroecosystems, nitrogen is supplied to the topsoil by the fertilizer and/or the manure applied in the alleys [40], the biological fixation from atmosphere (N-fixing tree species) and the mineralization of organic matter (which is also influenced by the trees) (notably by root exudates, improved soil conditions and root turnover) [41]. According to [39], the problem is that nitrates are highly soluble and easily transported by runoffs and leaching through soil layers. They contaminate the water table and the rivers which make the water unsuitable for drinking and cause eutrophication of downstream ecosystems. To avoid such seepages, trees are helpful thanks to their "safety net", i.e. their vast root system that can uptake nutrients in the deeper soil layers where crop roots cannot take [42]. By actively capturing leached nutrients and pumping them back to the canopy and then, to the topsoil, the trees decrease the erosion and nutrient losses [38], help to maintain nutrient pool and the soil fertility [43], and improve the efficiency of nutrients use in the agroecosystems [44].

Finally, some tree roles in the nutrient cycle can be improved by human intervention. Litter fall and pruning by-products are major organic matter inputs and their decomposition releases nutrients in the topsoil [38] & [42]. But what the pruning by-products really matters to avoid nutrient losses at the ecosystem level [39] & [45]. If they are used as chipped wood or mulch, the nutrients are recycled in the agroecosystem. According to [39], in certain conditions and with particular species, tree prunings content in nutrients can meet crops requirements in N, Ca, Mg and K. In addition, root turnover can enrich soil with nutrients and notably with carbon [46] & [47] such as trees influence C/N ratio [48]. But the root management practices such as root prunings accelerate the root turnover and enhance the redistribution of nutrients through lateral roots [38]. In fact, the roots contain a lot of nutrients that travel easily along the whole root system. By pruning the roots, agroforesters induce root decomposition and the release of nutrients in the topsoil throughout the entire crop field.

A study in the *Faidherbia albida* parklands in Sudano-Sahelian zone of Africa, a region that suffers from soil fertility decline, food insecurity and climate change, revealed that presence of trees resulted in 35-55% larger available nitrogen close to tree crowns and compared with sole wheat and number of grains spike^{-1}, plant height, total above ground biomass and wheat grain yield were all significantly higher for wheat associated with *F. albida* compared with sole wheat [49]. Reference [50] compared the effects of *Leucaena leucocephala* fallow versus a bush fallow of an Alfisol in western Nigeria. After three years, during which *L. leucocephala* biomass was cut annually and returned to the soil as mulch, the cation exchange capacity and levels of exchangeable calcium and potassium were significantly higher in *L. leucocephala* fallow than in the bush fallow. In a study that gathered information from sites around the world, [51] found values for soil organic C stocks ranging from 6.9 to 302 Mg ha^{-1}. Despite the great amplitude of these values, attributed to the variation between systems, ecological regions, and soil types, the study revealed a general trend of increasing soil C sequestration in agroforestry when compared to other land-use practices, with the exception of forests. Although the ability of soils to accumulate C is generally related to characteristics that are little influenced by management, such as texture (clay soils typically accumulate more C than sandy soils), some management practices can influence soil C sequestration, particularly the insertion of trees in agricultural systems [52]. Soils in various sites studied by [53] in the African Sahel were not markedly different among each other in terms of their characteristics such as pH, bulk density, and particle size, such that variations in their C contents seemed to be related to the influence of trees. In eight years old alley-cropping systems with five different species, for example, the authors found that greater C content is nearer to the trees. However, the greater part of this C was found in the form of particles of size between 250-2000 μm, fractions that are considered to be large and less stable. In systems where trees where present for more than 30 years (parklands), there was a predominance of soil C in smaller fractions (<53 μm), which are more stable and thus represent a more "protected" form of C.

The most common agroforestry practices in the dryland tropics are silvopastoral systems/ woody perennials on rangelands and pastures, parkland system, tree woodlots, homegarden, improved fallows, shelterbelts and windbreaks, living fences, protein banks, plantation crops with pastures and livestock, multipurpose woody hedgerows, woody perennials for soil conservation and reclamation, apiforestry [14]. The choice of tree species for use in dryland agroforestry is likely to be based on a combination of product value, interactions with crops, availability and price of seedlings, management inputs, and the environmental services provided. Attention has recently turned to indigenous tree species, partly because of the perception that fast-growing exotic species are extravagant in their use of water [54], but also due to a realization of their value to local communities [55] and importance in providing environmental services, whilst moving the source of tree products away from natural forests [56]. Indigenous species may be less susceptible to attack by pests and have better survival rates, but often exhibit lower growth rates than exotic species providing wood of similar quality [57]. However, there is great potential for the improvement of the quality and growth rates of wild indigenous trees through domestication, genetic improvement, and development of suitable management strategies [56]. A study conducted at RRS, CAZRI, Bhuj, Gujarat with three tree species (*Azadirachta indica*, *Leucaena leucocephala* and *Acacia tortilis*) and two *Cenchrus* species showed that neem and subabul with *Cenchrus ciliaris* based AF system increased the wood biomass and fodder yield (321 and 303 kg/ha) [58].

7. AGROFORESTRY AND FOOD SECURITY IN DRYLAND AREAS

Significant progress in global agricultural production driven by green revolution in the Asian subcontinent in the second half of the last century helped to break cycles of crop failures, food deficits and wide spread famines. However, in recent past agricultural production has been hampered by changing climate, land and soil degradation, shortage of quality irrigation water. The problem is further magnified by the burgeoning population in the Asian and African countries. Agroforestry is one of the best opportunity and has great potential to increase food productivity in dryland areas. Agroforestry is an important option to provide food security to smallholding poor and marginal farmers and if properly implemented through national measures it can ameliorate food insecurity of a country on a larger scale [59].

Agroforestry research and development has emerged as a new and vibrant discipline over the past 25 years. The services provided by agroforestry practices to rural livelihoods as well as towards conservation of biodiversity have attracted wide attention among agroforestry and conservation scientists. It applies scientific principles to find practical solutions towards natural resource management and agricultural production problems [60] and subsequently, supports in improving food security of the vast rural population. There are various agroforestry practices made up of combination of several types of products, which are both subsistence and income generating, help the farmers to meet their basic needs and minimize the risk of the production systems and total failure [61]. Agrisilvicultural system is one of them in which there is a concurrent production of agricultural crops and trees in same piece of land either simultaneously or alternately. The agrisilviculture systems aim at production of enough foodgrains, timber, fodder, firewood and other products. Moreover, agrisilviculture practice helps in improvement of shifting cultivation practices through improving soil quality and reducing soil erosions. The system may include multipurpose trees, homestead plantation, alley cropping or hedgerow cropping [59].

The multipurpose trees can be planted in the drylands in several types of plantation geometry such as scattered, on the field bund or border, row plantation or strip plantation. Moreover, in the homesteads diverse products (fruits, vegetables, spices etc.), which are available year-round not only contribute to food security during the "lean" seasons but also ensure food diversity. The mixed tree-gardens represent a substantial unexploited potential for enhancing productivity and profitability [62]. Moreover, green manuring by leaves of trees in the hedgerow may add organic matter to the extent of 2.0 to 5.0 t/ha and 150 kg of N, 15 kg of P and 75 kg K per hectare annually [63]. This increased in soil fertility, subsequently enhanced the crop yield and improved the food security. A study of 1,000 farmers from 15 districts in Kenya found that tree fruits contributed 18 per cent of crop revenue, and tea and coffee contributed an additional 29 per cent of the revenue [64]. Reference [65] reported that in Zimbabwe indigenous fruits provided higher returns to labour than annual crop production. Similar reports of alternate sources of income and employment to the rural poor population through agroforestry are also highlighted by various workers from different parts of the world [66], [67] & [68].

Land degradation and desertification are two cardinal processes, which render agricultural lands unproductive and threaten food security in several parts of Asia [62]. Although trees are expected to improve soil fertility, the extent to which different agroforestry practices accomplish this depends on tree species, stocking level, growth rate and the input of litter [62]. It will be greatest where fast growing trees are integrated with a high density and adding the pruned materials into the soil thereby increasing the soil organic materials. Higher soil organic matter and available nutrients in tree-based agroecosystems can also increase yields in smallholder farming systems [69]. A study from Nepal on the impact of agroforestry on soil fertility and farm income showed that agroforestry intervention nearly doubled farm income per hectare from USD 800-1580 [70]. Similar report of increased crop production and generating additional income to the rural people is reported in Malawi of South Africa by improving soil condition through the intervention of agroforestry practice.

Fertilizer tree technologies of intercropping, relay cropping, improved fallows and biomass transfer, have been promoted as sustainable, low-input alternative or complimentary inputs to inorganic fertilizers in Malawi. The choice of the technologies is driven by the size of the land holdings and more benefits are associated with large land holdings [71]. Moreover, [72] have highlighted the impact of agroforestry adoption on livelihoods of farmers in Malawi, Mozambique and Zambia includes increase in crop yields, increase in income, increased savings resulting in change of wealth and soil improvement.

The tree components of the agroforestry system can contribute to increased food availability at the household level through four major pathways. First, the contribution of fodder supplement can increase the productivity of livestock. Higher productivity can result in greater food availability and/or higher incomes. Second, green leaf manure harvested and ploughed *in situ* and tree-crop-soil interaction can increase the soil fertility and result in improved productivity of food and non-food crops. Higher soil fertility is likely to increase the food/cash crop productivity and household income that will, in turn, contribute to food availability. Third, fruits and vegetables harvested from the tree component of agroforestry will directly contribute to improved dietary quality and micronutrient consumption, and indirectly, contribute through the sale of these items to the market for income in order to purchase food. Finally, the non-food tree outputs such as timber for housing and firewood for fuel contribute to income that can be used to acquire food. Indirectly, availability of fuelwood from tree components may also contribute to nutrition security by reducing the search for fuelwood which could increase time availability for child care [73]. Presumably, the increased cash income from non-food products can increase the resources spent on child care and health care of household members. This cash income along with food availability, can contribute to nutrition security if additional income is used to purchase nutritious food products.

Domestication of forest fruit trees and other species grown in agroforestry systems offers significant opportunity for livelihood improvement through nutritional and economic security of the poor in the tropics [74]. The important fruit trees in dryland areas of Africa with the potentials for domestication and meeting food security are *Cordeauxia edulis, Adanosania digitata* (*Baobab*), *Balanites aegyptiaca, Sclerocarya birrea, Vitellaria paradoxa, Carissa edulis, Cordia africana, Diospyros mespiliformis, Dovyalis abyssinica, Ficus sur, Ficus vasta, Ziziphus spina-christi, Xmenia americana, Zyzygium guineense, Grewia ferruginea, Mimusops kummel, Rhus natalensis, Tamarindus indica, Opuntia ficus-indica.* The wild edible plants form an important constituent of traditional diet in Sikkim Himalaya, where about 190 species are eaten and almost 47 species are traded in local market. Wild edible fruit species have high carbohydrate content [75] ranging between 32 and 88 per cent. Such fruit trees can be taken up for domestication in agroecosystems on priority action. Trees in agroforestry systems can provide host to globally valued products and thus support livelihoods locally. In Jharkhand, trees in agroecosystems are particularly valued as host to insects that yield marketable products such as silk [76], lac products [77] and honey [78].

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