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Agroforestry
Small Landholder's Tool for Climate Change Resiliency and Mitigation

Edited by Gopal Shukla, Sumit Chakravarty, Pankaj Panwar and Jahangeer A. Bhat

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Published in London, United Kingdom







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http://dx.doi.org/10.5772/intechopen.87650
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First published in London, United Kingdom, 2021 by IntechOpen
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, 5 Princes Gate Court, London, SW7 2QJ, United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

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p. cm.
Print ISBN 978-1-83962-729-3
Online ISBN 978-1-83962-730-9
eBook (PDF) ISBN 978-1-83962-731-6

Meet the editors

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Jahangeer A. Bhat, Ph.D., is a former head of the Department of Forestry, College of Agriculture, Fisheries and Forestry, Fiji National University, Republic of Fiji Islands. Dr. Jahangeer has worked as a counsellor, mentor, and coordinator for forestry academic programmes. He has been instrumental in developing HE and TVET streams of forestry and allied programmes and worked closely in accreditation with the Fiji Higher Education Commission and forestry stakeholders. Before joining Fiji National University, he worked for HNB Garhwal University, Srinagar, India, and has 11 years of research and 8 years of teaching experience with a publication record of more than 60, including research articles, review papers, conference papers, and books of national and international repute. Dr. Jahangeer reviews research articles for several scientific journals and has handled research projects in his capacity as Principal Investigator and Co-Principal Investigator. His major interests lie in emerging issues in forestry including conservation of biodiversity, traditional knowledge of plants, and sustainable management of forest resources. His focus of research is vegetation ecology, ethnobotany, and evaluation of ecosystem services, forest plant biodiversity, climate change, and socio-cultural issues in forestry. Dr. Jahangeer is currently working at the College of Horticulture and Forestry, Rani Lakshmi Bai Central Agricultural University, Jhansi, India.

Contents

Preface

Forests absorb carbon from the atmosphere and store it in the tissues of the plants. Because forest soils typically have a lot of soil organic matter, they are one of the most important carbon sinks. However, in our rush to develop and produce more food, we have reduced the amount of forest cover. Reduced forest cover has resulted in increased global warming and climate change, both of which are impacting crop production and human life. Cyclones, polluted air, receding glaciers, and erratic rainfall are all common occurrences. Agricultural production is necessary, but it must be done in harmony with the environment. This is possible if we can use agroforestry to mimic the forest on farmlands. Agroforestry is the production of food, fodder, timber, fiber, and other products in a cost-effective and environmentally sustainable manner. These systems are also appropriate for small landholders who are primarily cultivators. This book was designed to share success stories and agroforestry techniques for small landholders for climate change resiliency and mitigation. This book is divided into six chapters, each of which discusses climate change and agroforestry from the perspective of various authors from around the world.

The first chapter discusses *Dusung*, a humid tropic traditional agroforestry practiced in Indonesia. The researchers estimated the traditional agroforestry system's sustainability index and divided it into four categories/sustainability indices. Traditional agroforestry is used for economic, ecological, and socio-cultural purposes as well as for greenhouse gas mitigation and adaptation through carbon sequestration. These sustainability indices can assist in the development of agroforests. The development of agroforests with low sustainability index values can be prioritized.

The second chapter discusses traditional agroforestry systems and their contribution to biomass and carbon stock at various altitudes. The research was conducted at altitudes ranging from 286 to 2800 meters above mean sea level. Agrisilviculture, agrihorticulture, and agri-horti-silviculture are three common agroforestry systems that have been studied. The chapter authors quantify the biomass and carbon stock of each component and system. They also summarize the best agroforestry system and trees for biomass production and carbon stock based on their research.

The role of Zimbabwe's small landholder's agroforests is the subject of the third chapter. The chapter discusses the depletion of forest resources because of deforestation in Zimbabwe, as well as its impact on the climate. The chapter promotes the use of a landscape approach to climate change adaptation. According to the author, agroforestry is a compelling option available to small landholders in Zimbabwe as a nature-based intervention against climate change.

The fourth chapter looks at potential climate-smart farming practices that could help farmers adapt to local climate change and variability in South Africa's Limpopo Province. The chapter also discusses field studies on Moringa oleifera and Vachellia karroo conducted in the province, as well as their potential as a feed source for livestock farmers.

The fifth chapter discusses the benefits of agroforestry in terms of combating land degradation. Agroforestry plays a role in soil moisture conservation, water quality improvement, soil health management, soil fertility, soil conservation, climate change mitigation, and ecosystem services and thereby helps with land improvement.

The final chapter begins with a discussion of farm forestry and climate as well as information on the carbon storage potential of various agroforestry systems. The policy on agroforestry in various countries is compiled in this chapter, as are the activities being undertaken to promote agroforestry. There is also a discussion of the implications of agroforestry policy reforms. There are also three case studies on agroforestry in Niger, China, and Indonesia.

This book provides an overview of the various small agroforestry systems that exist around the world and are maintained and managed by small landholders. These agroforestry systems benefit landowners by providing a source of income while also sequestering carbon, making them a cost-effective tool for combating climate change. We believe that researchers, agroforesters, and students will find this book useful in their research and extension efforts.

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Chapter 1

Designation of Traditional Agroforestry Clusters for Handling Climate Change Based on the Sustainability Index in the Archipelago

Jan Willem Hatulesila and Gun Mardiatmoko

Abstract

Many people already understand that the impact of climate change is directly related to forestry, agroforestry, and agricultural crop production, as well as the preservation of biodiversity in small islands, which supports the local community's economy by producing various types of plants. According to studies, the dynamics of climate change directly impact the availability of food and island communities' readiness to maintain local economic resources. Therefore, agroforestry clusters can be determined based on the agroecological conditions directly related to the distribution of plant species, such as their ecological, conservation, landscape, and economic aspects. Furthermore, the area of land and the composition of the types of agricultural crops grown were taken into account based on the form of cluster analysis variables, in the villages on the small island of Maluku, which are only in the good (average sustainability index score is 89.2) and moderate (average sustainability index score 69.7) categories. Agroforestry also contributes to climate change mitigation and adaptation, therefore, to determine the magnitude of the contribution of agroforestry in absorbing carbon, it is necessary to measure biomass using non-destructive and destructive methods.

Keywords: sustainability index, traditional agroforestry, local wisdom, biomass, sasi, masohi

1. Introduction

The adequate management of the biodiversity and biological resources of natural products in a sustainable manner is one of the efforts used to maintain their benefits in such a way that they do not cause damage to the ecosystem. The application of a forest management system is based on the principle of sustainability by increasing the overall land yield. This is also achieved by sequentially combining the production of agricultural crops (including trees), forest plants, and animals on the same land unit, using management methods that are culturally appropriate to local residents, are a feature of the traditional agroforestry [1].

Environmental damage occurs due to biophysical or ecological related global climate change, such as resource depletion, deforestation, and agricultural and forestry land degradation in rural landscapes. Ecosystem diversity is similar to the landscape, which consists of various patches and corridors (such as rice fields, moor, crops, grazing fields, lakes/reservoirs/poolponds, plantations, mixed gardens, residential areas, rivers, irrigation channels, village roads, footpaths, *etc*. Therefore, the diversity of agricultural landscapes (agrobiodiversity), forestry (Agro-forestry), fisheries (Agro-Fishery), and livestock (Agro-Silvopasture) supports biodiversity when facing climate change as a central issue.

Agroforestry has two main functions, namely (1) Socio-economic function, which reflects human efforts in trying to meet their needs in the social and economic fields. It is generally, in the form of forest products, food plants, animal husbandry, *etc*. (2) Environmental function, in the form of components, is inseparable from agroforestry and acts as a system that includes hydrological, ecological, and conservation functions. This is usually the form of services, quantified using existing parameters, such as using agroforestry functions to prevent soil erosion through land cover and canopy strata, storing groundwater reserves, and using carbon binding to reduce greenhouse gas emissions, and conserving or protecting certain flora and fauna.

The current impact of climate change that threatens all bio-ecology and natural resources has encouraged people worldwide to carry out processes of mitigation and adaptation to deal with the occurrence of various natural disasters. This is because of the degradation of natural resources, pollution, and loss of biodiversity which disturbs and increases the vulnerability of health systems to damages, thereby reducing resilience. All forms of agricultural systems on large and small islands in Indonesia are sensitive to climate change variations [2].

The sustainability of ecosystems, especially in small islands, is determined by the land's biodiversity. In Asian society, including Indonesia, traditional farming practices known as agroforestry have been passed down from generation to generation. They have been proven to be able to develop and fill the context of sustainable agricultural development. Applying a forest management system based on the principle of sustainability increases the overall land yield. This is achieved by combining the production of agricultural crops (including tree crops), forest plants, and animals on the same land unit. Furthermore, various methods and management efforts are culturally applied as appropriate local populations for the current traditional agroforestry [3].

Agroforestry models have become a prioritized choice in cropping systems because they have several advantages compared to forestry and agricultural systems (monoculture). This advantage can be seen from the multiple products produced throughout the management of both wood and non-timber, including environmental services. The development of an agroforestry system is dependent on the structure of the constituent components. A decrease is experienced in the annual crop products when the agroforestry system component dominates the number of trees. Therefore, silvicultural action in agroforestry is the key to success. In addition, the agronomic regime chosen also has a positive correlation to tree development. The spatial dynamics in an agroforestry system are determined by how these constituent components use existing resources. It is important to ensure a balance between the interests of trees and seasonal plants using the resource sharing system. Agroforestry dynamics directly affect seasonal crop cultivation, with some able to provide support for seasonal crop cultivation throughout the year. However, it needs to be noted that other agroforestry models have limitations, therefore, the presence of seasonal crops can only be carried out at certain times, such as during the rainy season.

The land's carrying capacity can be represented by the condition or level of fertility of the site. Therefore a fertile land tends to possess a better carrying capacity and vice versa. The principle of the agroforestry model in terms of land management that needs to be understood is the addition of other plants or trees as a single system with various components [4]. In agroforestry systems, the fallow period is highly dependent on spatial dynamics, which tend to depend on the type of constituent. The selection of constituent tree species in an agroforestry system needs to consider the characteristics or basic information, such as physiognomy, distribution, and application of silvicultural recipes.

Agroforestry can be grouped into two systems, namely simple and complex [3]. In a simple agroforestry system, trees are intercropped with one or more seasonal crops. Meanwhile, a complex agroforestry system permanently involves various types of trees that are intentionally or naturally planted. The main characteristic of complex agroforestry is its physical appearance and the dynamics similar to forest ecosystems, therefore, it is also known as agroforest. Generally, they are massive mosaic forests that consist of several 1–2 ha plantations owned by individuals or groups and located far from their homes and village boundaries.

2. Traditional "*Dusung*" agroforestry patterns in the Maluku Islands

The traditional land-use practices by communities in Maluku Province in terms of culture and customs are proven to answer ecological, economic, and socio-cultural problems, such as the land use pattern known as *dusung*. This process is used to plant short-term subsistence agricultural crops (vegetables, tubers, and spices), fruit crops (*Durio* sp., Lansium sp., *Myristica* sp., *Mangifera* sp., *Nephellium* sp., *etc.*), and forestry plants (*Pterocarpus* sp., *Paraserianthes* sp., *Anthosephalus, Alstonia* sp., *etc.*) in the long run. The condition of small islands in Maluku is geophysically undulating to hilly areas and dominated by dry land agro-ecosystems. The developed agricultural pattern is a "multi cropping" or "mixed" agroforestry system obtained by combining tree crops, such as plantation, industrial and forest plants in several strata. Food crops are also obtained as intercrops, usually carried out by the community at the end of the rainy season and into the dry season as a form of practice building *dusung.*

The combination of plants in *dusung* agroforestry is characterized by several forms of land use, which are also different in each agroecosystem because they have *dusung* types from the simplest composition to the more complex ones. The cropping pattern of annual crops is the main business, while forest plants are secondary. The main types of perennial crops are coconut (*Cocos nucifera*), cloves (*Eugenia aromatica*), nutmeg (*Myristica fragrans*), sago (*Metroxylon sago*) and fruit trees such as durian (*Durio zibetinus*), langsat (*Lancium* sp), duku (*Lancium domesticum*), advocate (*Anona muricata*), gandaria (*Buea macrophylla*), mangosteen (*Garcinia manggostana*), mango (*Mangifera* spp) and guava (*Eugenia jambolana*), *etc.* Furthermore, there are several types of forestry plants, such as samama wood (*Anthosepalus macrophylla*), pule (*Alstonia scholaris*), salawaku (*Paraserianthes falcataria*), forest guyawas (*Duabanga mollucana*), and community planted wood such as teak (*Tectona grandis*), titi (*Gmelina mollucana) and lenggua (Pterocarpus indicus).* Annual crops are dominated by cassava (Manihot utilisima), sweet potato (*Xanthosoma sagittifolium*), taro (*Calocasia esculenta*), bananas (*Musa* spp), peanuts (*Arachis hypogea*), corn (*Zea mays*), *etc*.Vegetable plants cultivated are genemo (*Gnetum gnemon*), spinach (*Amarantus* sp), long beans (*Vigna sinensis*), mustard greens (*Brasisca* sp), eggplant (*Solannum tuberesum*), cucumber (*Cucurbita* sp), tomato (*Solannum lycopersicum), etc.*

The cultivation process adapted by the local community, led to a change in secondary forest which was covered by a very dense plant canopy comprising of various bird species, and various types of insects as indicators of a forest ecosystem few years later. The *dusung* farming pattern is shown in **Figure 1.**

The *dusung* farming pattern is still well-practiced, and till date, where the traditional agroforestry with the archipelago's geographical conditions can maintain the ecological and ecosystem functions. Furthermore, biophysical conservation efforts used to cultivate various plants are maintained and function as a buffer zone for water management and soil conservation. The *dusung* farming pattern also provides social sustainability where there is the customary practice of "*sasi,*" which prohibits harvesting before time and economic sustainability. The yields of various types of plants can be sold to the sub-district or district market. In addition, the *dusung* management is carried out together, starting from land preparation to harvesting called "*masohi.*" Generally, there are several *masohi* systems, namely: (1) *Masohi Bilang*: in this masohi the first person individually invites another to help in carrying out the job at the initial stage, (2) *Masohi Balas*: the second person replies to the first to help carry out a job. In other words, there is an exchange of the same work assistance in the implementation of the construction of the *dusung* on the two lands belonging to that person, (3) *Masohi Kumpul*: several people work together by taking time to carry out a job. More than 10 people sequentially carried out this activity.

This activity ended after all the landowners that participated in the "masohi gathering" had finished the work of producing *dusung.* Therefore, in this case, there was no known work wage, rather there was the exchange of labor assistance in the work of the hamlet [5]. *Dusung* is a traditional conservation system where the regulatory pattern is applied in the village due to the management and utilization of natural resources and the environment. Furthermore, the vegetation that forms in this pattern forms layered canopy strata from various types of plants that have economic value and productivity (multi-cropping). A social value guarantees and improves the need for foodstuffs and the quality of life for rural communities, especially those below the poverty line. For instance, the availability of local energy (firewood) and the ecological value of the diversified forest and agricultural products. Furthermore, there are conservation values associated with improving environmental quality with the provision of products and services in a sustainable manner. In order to measure the extent of the role and function of the *dusung* agroforestry pattern in the Maluku islands, a study needs to be carried out on the following: (1) the pattern's diversity on the island of Ambon, (2) its analysis according to small island agroecological conditions, (3) determining the sustainability index, from the ecological, conservation, landscape, economic and policy implementation aspects and (4) determining the cluster pattern according to the yield sustainability index value in the Maluku islands. Therefore, by examining the profile of the

Figure 1.
Dusung *pattern agroforestry use.*

agroecological zone as a buffer for the ecosystem in the archipelago from the coast to the mountains, the traditional agroforestry formed in the Maluku Islands needs to be maintained and preserved from generation to generation and sustainably.

3. Models and concepts of *Dusung* farming

The concept of *dusung* is a modification of an ever-changing ecosystem due to the formation of new agricultural activities with greater benefits. In terms of ecology and economy, *dusung* (traditional agroforestry) is more complex than a monoculture system because it is local in nature and need to be in accordance with the ecological and socio-economic conditions of the area. *Dusung* is used as a land system with specific productivity objectives capable of improving rural communities' welfare over a prolonged period. It is the "Science and Art" of planting trees and other plants on available land both inside and outside the forest to produce various objects and services for individuals and the general public. It is also a method used to manage forests and their environment on community land to achieve a better socio-economic condition for the rural population and overcome environmental problems, erosion, and soil fertility deterioration. *Dusung* is a traditional pattern of natural resource use (forest), which shows local wisdom of sustainable management of natural resources and their ecosystems. The traditional conservation process in its regulatory pattern runs and applies in rural communities (*Negeri*) with proper management and utilization. In *dusung* farming pattern, the vegetation that forms a layered canopy strata pattern has a productivity value throughout the year (multi-cropping). The *dusung* pattern is a traditional land use system in the form of local wisdom similar to agroforestry [6], as shown in **Table 1.**

The *dusung* farming pattern is a modification of a new ecosystem with greater agricultural benefits, such as (1) ecologically maintaining the quality of natural resources and the whole agroecosystem, which includes animals, plants, and microorganisms. The plants have various root depths, crown heights, and canopy spacing. It also comprises of different requirements for temperature, light intensity, soil,

No	Farming pattern	Region	Agroforestry concept
1	Fruit crops and root crops	Maluku Tengah, Maluku Utara	Agrisilviculture
2	Planting spices and tuber crops	Maluku Tengah, Maluku Utara	Agrisilviculture
3	Mixed perennial crops dominated by coconut, nutmeg, and cloves	Maluku Tengah, Maluku Utara	Agrisilviculture
4	Mixed perennial crops dominated by coconut and cacao	Maluku Utara	Agrisilviculture
5	Mixed crop dominated by fruit trees	Maluku Tengah	Agrisilviculture
6	Walnuts and nutmeg	Banda island	Agrisilviculture
7	Coconut, tubers, and bananas	Maluku Tengah	Agrisilviculture
8	Cajuput, *Imperata cylindrica*, *Andropogon ambonensis*, and Bali cattle	Buru Utara	Silvopasture
9	Sago	Maluku Utara, Maluku tengah	Silviculture
10	East Nusa Tenggara tangerines	Island of Teon, Nila, Serua, Leti, Moa, Lakor, Kisar&Wetar	Agrisilviculture

Table 1.
Dusung *farming pattern in Maluku.*

air humidity, and land quality, (2) economically sustainable for farmers with the ability to meet all the necessities of life. The *dusung* system is regulated to produce all year round crops, such as coconut, cocoa, nutmeg, and walnuts as well as some are seasonal ones, including cloves, durians, duku, gandaria, *etc*., (3) fair and humane as *dusung* is capable of providing benefits to people without basic dignity of all living things, such as plants, animals, and humans. Regulations regarding business (picking up those that fall on the ground) and *sasi* (harvesting rules) contain elements of justice and humanity [6].

4. Landscape sustainability index model: agroforestry pattern *Dusung*

The study was carried out in 8 villages of South Leitimur and Leihutu on Ambon Island. Data were obtained through site survey based on vegetation conditions formed from farming patterns of monocultures, semi-monocultures, and mixed plants that make up the *dusung* agroforestry. The sample selection is determined based on the spatial distribution of the landscape according to the representative land samples' location. The Land classification is determined based on the weighted parameter values from the researches.. The data taken in each sample include length and width of the land, area covered by stands, inventory of vegetation types according to potential, the grouping of plant types based on *dusung* farming patterns, and the layout of the planting system representing a mosaic landscape of *dusung* at various heights, such as flat, hills and mountains. The analysis is limited to the stand measurement model due to resource sharing as well as the climatic and growth factors that affect plant productivity, thereby making its survival possible. Furthermore, based on the land sample surveyed, information classification was carried out regarding the landscape conditions of the *dusung* agroforestry pattern for each respondent, such as the land owner (farmer) in each sample village location. This model is related to the development of the vegetation constituent components on the landscape, therefore, the model stratification approach is based on the ratio of the area of land for effective cultivation of plants to a suitable growing place. The stratification is divided into 3 classes, namely lowland *dusung* pattern, hilly and mountainous plains. The approach to growing places and distribution of tree species is based on the total number of land productivity according to the potential for each harvest season divided by the area of land. A regression approach is used to determine the relationship between the dependent and independent variables in accordance with the model class. The independent variable that has the main effect on the dependent makes the agroforestry system's key information. This information makes it easy to design and manipulate the actions intended to manage the agroforestry system. Therefore, the *dusung* agroforestry pattern model's determination with the distribution of productive plant species is alternatively carried out using an alternative design. Furthermore, to facilitate further analysis of the landscape model of the *dusung* agroforestry pattern in the agroforestry system, the land sample was divided into 3 clusters based on land area and composition of monoculture, semi-monoculture, and mixed crop types. They are also based on the landscape where they grow from the coast to the mountains, namely:

- Cluster 1 is located on an area of land with a composition of monoculture types of agricultural crops that occupy a landscape characterized by lowlands.

- Cluster 2 is located on an area of land with a composition of semi-monoculture farming types that occupy a landscape characterized by low to hilly lands.

DOI: http://dx.doi.org/10.5772/intechopen.96016

- Cluster 3 is located on an area of land with a composition of mixed types of farming, which occupies a landscape characterized by hilly to mountainous plains.

Until now, the production of types of plants in the *dusung* pattern is still contributing as a source of community income with several factors, namely (1) the potential for cultivated plants, (2) the production value of the harvest, (3) the area of *dusung* land ownership of the farmer and (4) the area of each village. The farming characteristics of the *dusung* pattern are used to carry out cluster analysis based on the division of the type of area and according to the potential of the *dusung* land by determining the variables as shown in **Table 2.**

Meanwhile, the Multidimensional Scaling (MDS) analysis was used to measure the sustainability index and sustainability level [7]. Furthermore, the MDS method can be used to determine the position of the point of sustainability, which is visualized through the horizontal and vertical axes. The point position can be visualized on the horizontal axis, in accordance with the value of the sustainability index using the rotation process. The sustainability index is the value of each dimension that describes its level [8], as shown in **Table 3.**

The value of each dimension's sustainability index can be visualized simultaneously in the form of a kite diagram. Similarly, the symmetrical diagrams of kites are determined by each dimension's sustainability index, namely economic, social, cultural, ecological, legal, institutional, infrastructure, and technology. The cluster approach can also be described through the spatial analysis of the *dusung* farming patterns formed in lowlands, hilly, and mountainous plains. Spatial descriptive research, with land units, are used for analysis or mapping. Furthermore, this research spatially and temporally describes land cover and its effects on small

Variable	Remarks
• Area of *dusung* land type in each sampling village	• The area of dusung land cover is obtained from the results of satellite image analysis (ha)
• The area of land owned by farmers	• Area of land that is privately owned by the family and leased (m^2 or ha)
• Total annual crop commodity produced	• Production capacity of each type of crop during the harvest season (kg/ha/yr)
• Total production of monoculture crops	• Production capacity of each type of crop during the harvest season (kg/ha/yr)
• Total production of mixed crop commodities	• Production capacity of each type of crop during the harvest season (kg/ha/yr)
• *Dusung* farmers' income contribution	• Average *dusung* farm income (IDR / year)

Table 2.
Forms of cluster analysis variables.

Index Values (%)	Category	Remarks
0.00–25.00	Bad	Not sustainable
25.01–50.00	Less	Less sustainable
50.01–75.00	Sufficient	Sufficiently sustainable
75.01–100.00	Good	Good Sustainable

Table 3.
Assessment categories based on the index value of the sustainability status.

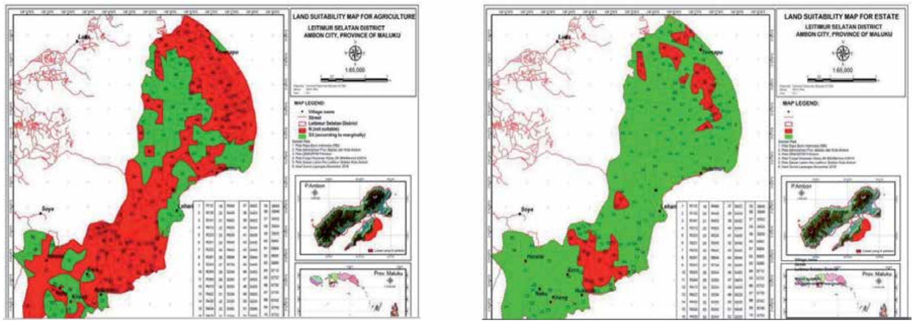

Figure 2.
Land suitability for agriculture and estate.

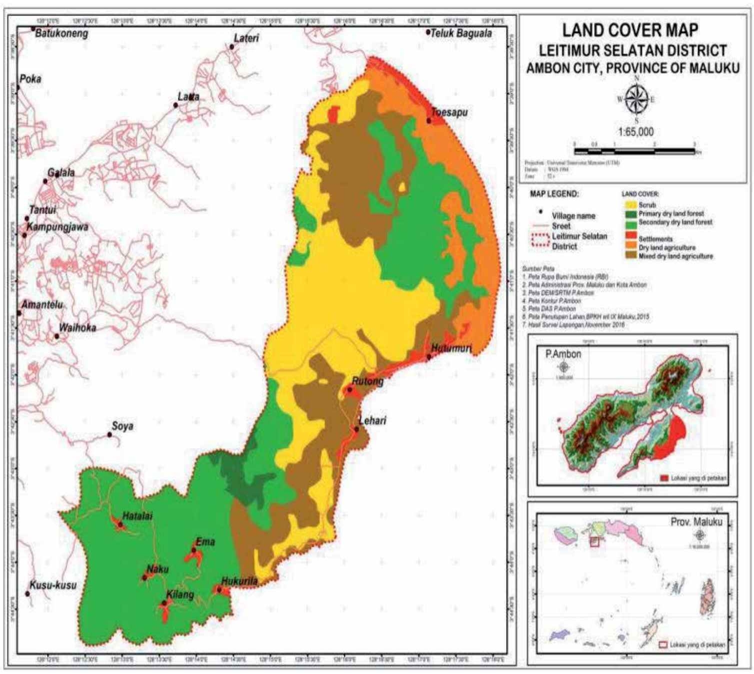

Figure 3.
Land cover in Leitimur Selatan District.

islands' protection function. Spatial analysis was processed using a Geographical Information System, with outputs including land cover maps and suitability maps for *dusung* agroforestry patterns as shown in **Figures 2** and **3**. Most of the villages studied were classified as good (score average 89.2) and moderate (mean score 69.7), with none in the poor and bad categories.

5. Agroforestry contributes to the mitigation and adaptation of greenhouse gases through carbon sequestration

Agroforestry contributes to climate change and GHG mitigation of various land-use models. Physically, agroforestry has a complex canopy arrangement with varying characteristics and root depths, thereby making it unique for the adaptation to global warming through its role in reducing landslides, surface runoff, erosion, and nutrient loss through leaching while maintaining the biodiversity of soil flora and fauna [9]. This agroforestry model combines trees with seasonal crops to ensure that their existence resembles a secondary forest. Although it does not absorb significant CO_2 in the air as a primary forest, land management through agroforestry can increase the absorption of CO, thereby mitigating climate change. Generally, there is a decrease in the world's primary forests due to the conversion of areas to other uses such as urban expansion, agricultural land, livestock, plantations, *etc*. Therefore, this agroforestry becomes one of the safety valves for forest sustainability, where residents can take advantage of forest and agricultural products to meet their basic needs. Agroforestry practices are considered potential in mitigating greenhouse gases (GHG), especially CO in the atmosphere. Agroforestry farming communities usually used the same land to cultivate a mixture of perennials, consisting of agricultural or fruit crops. The economic motive is the main objective, which means that the harvest income can be enjoyed at all times [10].

Conversely, multi-stratified land use is able to extract CO for photosynthetic purposes, which are stored in plant biomass for a relatively long time. Agroforestry also plays a role in adapting to climate change through the following processes (1) increasing resilience by mixing species with different resistance to temperature. In this process, a rise in temperature increases the number of species that can grow, and those likely to decline in growth with an equal amount of absorbed carbon, (2) increased resistance, which means that a rise in temperature increases the total productivity or absorption of the system disturbed to $CO_{2.}$ This is because there are various adjustments caused by mixed plants which have relatively different physiological characteristics, (3) migration, which means that to a certain extent, all elements or species in the agroforestry system are no longer tolerant to existing temperature changes, therefore, in some cases certain elements or types of the ecosystem moves to a more suitable place. This is directly or indirectly assisted by natural processes [2].

Therefore, biomass measurements are used to determine *Dusung's* ability to absorb carbon. Basically, there are two methods of measuring biomass, namely (1) the non-destructive method, which is used when the allometric formula and type of plant in the *dusung* pattern are known. Some examples of allometric equations that have been created in *dusung* are presented in **Table 4**, (2) a destructive method which aims to develop allometric formulas, especially for various tree

No	Tree species	Allometric formula	Source
1	*Coffea arabica*	(AGB) est. = 0.281 $D^{2.06}$	Hairiah *et al*, 2011 [9]
2	*Musa paradisiaca*	(AGB) est. = 0.030 $D^{2.13}$	Hairiah *et al,* 2011 [9]
3	*Myristica fragrans*	(AGB) est. = 134.353 $D^{2.424}$	Mardiatmoko *et al*, 2018 [11]
4	*Theobroma cacao*	(AGB) est. = 0.1208 $D^{1.98}$	Yuliasmara *et al*, 2009 [12]
5	*Bambusa sp*	(AGB) est. = 0.131 $D^{2.28}$	Priyadarsini, 1999 [13]
6	*Acacia mangium*	(AGB) est. = 0.1999 $D^{2.148}$	Pusat Litbang Konservasi dan Rehabilitasi, 2013 [14]
7	*Eucalyptus grandis*	(AGB) est. = 0.0678 $D^{2.5794}$	Pusat Litbang Konservasi dan Rehabilitasi, 2013 [14]
8	*Paraserianthes falcataria*	(AGB) est. = 0.0199 $(D^2H)^{0.9296}$	Mugiono, 2009 [15]
9	*Acacia auriculiformis*	(AGB) est. = 0.0775 $(D^2H)^{0.9018}$	Mugiono, 2009 [15]

Table 4.
Allometric equation of several types of plants in dusung.

species with specific branching patterns whose allometric equations understorey, seasonal plants and shrubs are generally unknown. In other words, the absence of allometric equations for the various types of plants in *dusung*, means that a destructive method of measuring biomass is necessary.

6. Conclusions

In conclusion, Maluku have long practiced traditional '*dusung*' agroforestry management patterns through local wisdom known as "*Sasi*" and "*Masohi*." The role of agroforestry can be seen from its contribution to the economic, ecological, sociocultural functions of people, as well as the mitigation and adaptation of greenhouse gases through carbon sequestration. Land management through agroforestry, actually increases the absorption of CO in the air. According to studies, there is a possible decrease in primary forest in the world due to designation for other functions. Therefore, agroforestry is one of the safety valves for forest sustainability where people can take advantage of agricultural products to meet their basic needs and in handling climate change. Furthermore, based on a cluster determination study in accordance with the land area and composition, there are various types of monoculture, semi-monoculture and mixed farming crops grown from the coast to the mountains. These crops are used to analyze the cluster variables, with the villages on the small island of Maluku classified as good (the average score for the sustainability index was 89.2) and moderate (the average score for the sustainability index was 69.7), with none in the poor category.

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Chapter 2

Assessment of Biomass and Carbon Stock along Altitudes in Traditional Agroforestry System in Tehri District of Uttarakhand, India

Kundan K. Vikrant, Dhanpal S. Chauhan and Raza H. Rizvi

Abstract

Agroforestry represents an integration of agriculture and forestry to increase productivity and sustainability of farming systems and farm income. It has been recognized as carbon sinks due to the need of climate change mitigation. The objective of this study was to compare the carbon stock in living biomass between altitudes and agroforestry system in Tehri district, Uttarakhand. The system compared was: Agrihortisilviculture system (Trees, crops and fruits), Agrihorticulture system (Trees and Fruits) and Agrisilviculture system (Trees and crops.). 1350 sample plots were selected in three altitudes. Three altitudes were: Lower (286-1200 m), Middle (1200-2000 m) and Upper (2000-2800 m). Results indicated that carbon was influenced by the altitudes. Carbon stock in the lower altitude (286-1200 m) was higher compared to the middle and upper altitudes. Agrihortisilviculture system contained maximum carbon stock compare than other system. It is concluded that agroforestry systems are playing an important role in the biodiversity conservation, soil enrichment and carbon storage in Tehri district of Uttarakhand.

Keywords: Agroforestry system, Climate change, Altitudes, Carbon storage

1. Introduction

The third IPCC Assessment Report on climate change (IPCC 2000) contains an endorsement of the potential for agroforestry to contribute to increase in carbon stock in agriculture lands. Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. Trees in agroforestry farms improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increase N, help in extraction of nutrients from deep soil horizons, and promotion of more closed nutrients cycling. Agroforestry is an ideal option to increase productivity of wasteland, increase tree cover outside the forest and reduce human pressure on forests under different agro-ecological regions, and is thus a viable option to prevent and mitigate climate change effect [1]. Most, if not all, agroforestry systems have the potential to sequester carbon for a short period, say 6–8 yrs. [2]. With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric C could be captured and stored in plant biomass and in the soils [2]. An IPCC special report [3] (IPCC 2000) indicates that conversion of unproductive croplands and grasslands to agroforestry have the best potential to soak up atmospheric C. In agroforestry, soil restoration process involves recovery of organic based nutrients cycle through replenishment of soil organic matters, about half of which is C [4]. Removing atmospheric carbon (C) and its storage in the terrestrial biosphere is vital for compensating the emission of greenhouse gases. Agroforestry, a land- use system has an integral relationship with the farm community to supplement fuel, fodder, fruits, fibers and organic fertilizers on one hand and capture abundant amounts of carbon on the other. Agroforestry systems are believed to have good potential to sequester carbon [5] and thus immensely important in the era of climate change. Human activities change carbon stocks in terrestrial ecosystems through rapid land-use transformations [6]. At the moment, agroforestry has generated much enthusiasm as a result of the National Action Plan for Climate Change [7] which, under its Green India mission, has exclusively emphasized the agroforestry interventions. It is proposed that under agroforestry, 0.80 m ha of area would involve improved agroforestry practices on the existing lands under agroforestry and that 0.70 m ha would involve additional lands under agroforestry. There is now consensus that the agroforestry systems and practices hold viable potential to meet the present basic human needs, besides addressing several major agro-ecological, carbon sequestration and socioeconomic issues. Moreover, National Agroforestry Policy 2014 of India has also focused on encouraging fast growing tree species for carbon sequestration and environmental amelioration. The C sequestration potential of agroforestry systems is estimated to be between 12 and 228 Mg, with a median value of 95 Mg. Therefore, based on the earth's area that is suitable for the practice, 1.1–2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years [8]. Long rotation systems such as agroforestry, home gardens and boundary plantings can sequester sizeable quantities of C in plant biomass and in long-lasting wood products. Soil C sequestration constitutes another realistic option achievable in many agroforestry systems. The potential of agroforestry for CO_2 mitigation is well recognized. There are a number of short comings however, that need to be emphasized such as the change in vegetation under agroforestry systems, *etc*. [8] (Albrecht and Kandji 2003). Significance of agroforestry with regard to C sequestration and other CO_2 mitigating effects is being widely recognized, but there is still paucity of quantitative data on agroforestry systems with varying altitude in Himalayan region. This study was conducted to determine the carbon stock capacity of different agroforestry system in Indian Himalaya along altitudes.

2. Materials and methods

2.1 Study area

The present study was undertaken in Tehri l district of Uttarakhand state which lies in the Northern region of India. Of the total 8,479,562 human population of the state, 78% lives in rural areas. The agriculture land in the hills of Uttarakhand is scattered and fragmented and the per capita land holding of Uttarakhand farmers is 0.2 ha, and about 36% of rural families live below the poverty line and agriculture contributes around 37% to state gross domestic production [9]. The Tehri district lies between 30^0 03′ and 30^0 53' North latitude and 77^0 56′ and 79^0 04′ East longitude having geographical area of 3,642 km^2 [10]. Geographical area of the district is 3642 km^2, of which forest area is 3221.56 km^2 [11]. Tehri district lies in the hilly areas of the state and agriculture is the major occupation of its in habitants. Total population in the district is 616409, population density is 169 person/km^2 and the rate of increase in population is 2.37% per ten years [12]. The location map showing the details of the study area is presented in **Figure 1**. The land use pattern shows 2,236 km^2 areas under forest cover (including reserve forest, civil soyam forest, community land and community forest), 1142.42 km^2 under cultivation and the rest are wasteland, barren land, Pastureland and grooves and snow-covered mountains [13] with 58,569 ha area under cultivation, of which irrigated land in only 12.21% [11]. Average rainfall of this district is 1395 mm and means average temperature varies from1 14.8 ^{0}Cto 29.5^{0}c with average relative humidity of 60.5%. On the basis of different altitudes and agro-climatic zone [14], the district was divided into three zones *viz*. foot hill/subtropical zone is lower altitude (286–1200 m), middle altitude i.e. Sub temperate zone (1200–2000 m) and upper altitude *i.e* temperate zone (2000–2800 m) and above 2800 m area there are no habitation in the district therefore this area is not under study. Out of nine developmental blocks, six blocks representing three zones were selected for present study villages in Tehri district. The details of the villages studied are given in **Table 1**.

2.2 Description of Systems

Farmers practices mainly three agroforestry systems *viz*. agrisilvicultural system (trees and agriculture crops are growing in same pieceof land), agrihorticultural

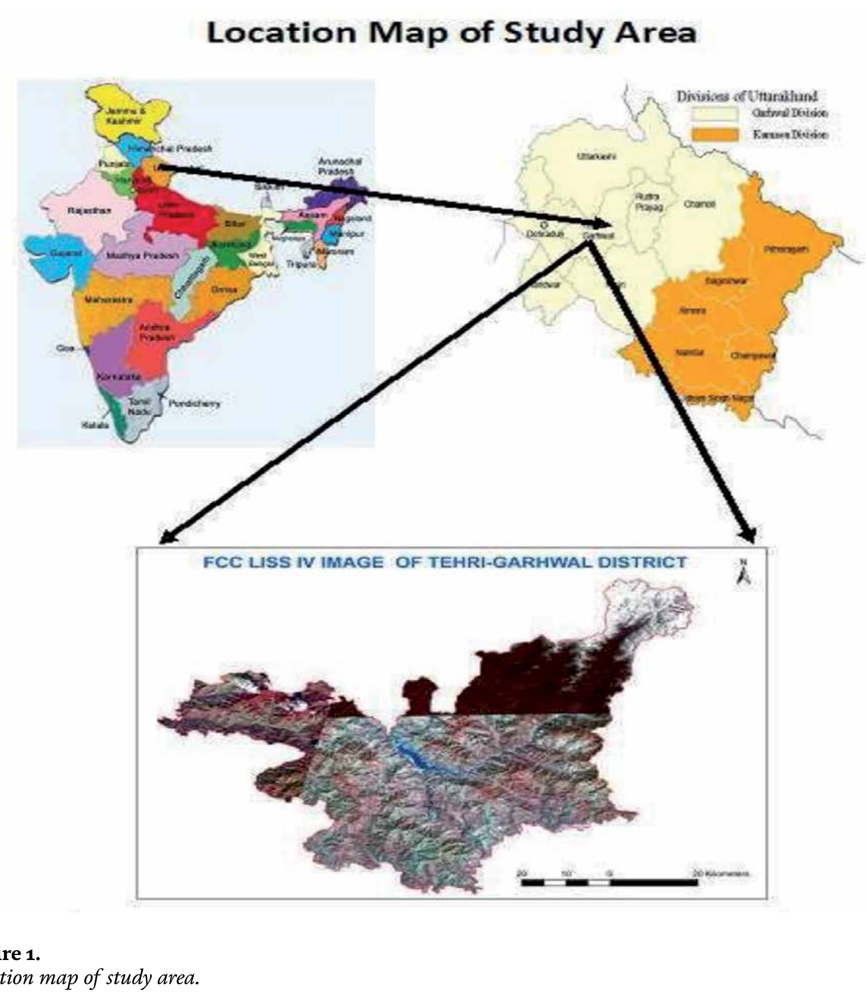

Figure 1.
Location map of study area.

Blocks	Altitudes (m)		
	Lower (286–1200 m)	Middle (1200–2000 m)	Upper (2000–2800 m)
Devprayag	Bagi, Grothikhanda, Palisen, Bachhendrikhal	Langur, Dungi	Juranaa
Kritinagar	Maikhandi, Jakhnand, Dhaulangi	Timal gaon, Dagar, Riskoti	No settlement area
Chamba	Kyari, Pali	Guldi, Purshal	Saud, Chopriyal gaon
Thauldhar	Dharwal, Jaspur	Indra, Sonara	No settlement area
Jakhnidhar	Raswari, Undoli	Manthal, Chah	No settlement area
Pratapnagar	Bausari	Kothaga, Kandakhal	Kualgarh, Banali

Table 1.
Study villages in Tehri district.

system (edible fruit trees and agriculture crops are growing in same Piece of land) and agrihortisilvicultural system (trees including edible fruit trees, forest trees and agricultural crops are growing in same Pieceof land) in the district. The characteristics of each system are as follows:

2.3 Agrisilviculture system (AS)

It is quite common throughout the district. This system is managed for the production of fuel, fodder, fibre and small timber trees with the agricultural corps. Agriculture crops such as wheat (*Triticum aestivum*), peas (*Pisum sativum*), potato (*Solanum tuberosum*), cauliflower (*Brassica oleracea*) and mustard (*Brassica compestris*) *etc*. during the winter season; and maize (*Zea mays*), tomato (*Lycopersicon esculentum*), pepper *(Pepper nigrum)* and french bean (*Phaseolus vulgaris*) *etc*. during the summer season are grown in monoculture or mixed cropping on the permanent terraces prepared across the hill slopes, while fodder, fuel and timber trees such as *Grewia oppostifolia, Celtis australis, Bauhinia variegata, B. purpuera, Albizia leeback etc.* are deliberately left or grown on the bunds of terraces.

2.4 Agrihorticulture system (AH)

This system is commonly practicedin those areas where fuel and fodder is easily available from other sources, and or size of the land holding is large. Agriculture crops mainly leafy and rhizomatous cropsare grown within space of horticulture trees such as *Mangifera indica* (Mango), *Citrus limon* (Nimbu), *Musa paradisica* (Kela), *Psidium guajava* (Amrud), *Mallus domestica* (Apple), *Prunus domestica* (Plum), *Prunus armeniaca* (Apricot), *Prunus persica* (Peach), *Prunus dulcis* (Almond) and *Pyrus communis* (Pear) *etc.*

2.5 Agrihortisilviculture system (AHS)

This system is managed for production of fruits, grains, fodder and fuelwood. Fruit trees are planted at regular space with in the fields, and fodder or small timber trees are left on the field bunds while the annuals are grown as intercrop. Species grown are same as that in the other two systems.

2.6 Plot selection & Forest Inventory

Ten sample plots of (100 m^2) size each were randomly laid out in each agroforestry system in each altitude. The shape of the plot is trapezoidal, with the short parallel to the contours at the top of the site. All three agroforestry system covered in each block on each altitude. The (100 m^2) size plot was used for tree (woody perennials) enumeration and 1x1m size plot was used for (annuals *i.e.* agricultural crop, grass and weeds). All trees falling in the plot (100 m^2) were enumerated. The DBH (diameter at breast height (i.e. 1.37 m) was measured with tree caliper and height with Haga altimeter.

2.7 Estimation of biomass

Bole volume was measured with bark using the following formula was given by (Presselar 1865) [15]:

$$V = f \times h \times g \tag{1}$$

V = Volume
f = form factor
h = height
g = basal area
Form factor was calculated using formula as given in Eq. (2) (Pressler 1865; Bitterlich 1984) [15, 16] was used for calculating the form factor.

$$f = 2\,h_1 / 3h \tag{2}$$

Where f = form factor
h_1 = is the height at which diameter is half of the diameter at breast height and
h = is the total height
Stem biomass was estimated by multiplying the stem volume with wood specific gravity [17] (IPCC 2006). The value of wood specific gravity of different agroforestry species in Garhwal Himalaya were used as reported by various authors (Kumar *et al.* 1989 [18]; Sheikh *et al.* 2011 [17]; Choudhry and Ghosh 1958 [19]; Rajput *et al.* 1985 [20]; Raturi *et al.* 2002 [21]; Purkashyatha 1982 [22] *etc.* was given in **Table 2**. For Branch biomass total number of branches irrespective of size were counted on each of the sample tree, then these branches were categorized on the basis of basal diameter into three groups viz. < 6 cm, 6-10 cm and > 10 cm. From each of sampled tree two branches from each group were randomly selected and were weighed for obtaining fresh weight. Sub samples of each component were oven dried to constant weight at 650 C. The following formula (Chidumaya 1990) [36] Eq. (3) was used to determine the dry weight of branches:

$$B_{dwi} = B_{fwi} / 1 + M_{cbdi} \tag{3}$$

Where B_{dwi} - oven dry weight of branch, B_{fwi} - fresh/green weight of branches, M_{cbdi} - moisture content of branch on dryweight basis. Leaves from the sampled branches were also removed, weighed and oven dried separately to a constant weight at 65°C to determine leaf biomass Eq. (4) (Chidumaya 1990, [36]).

Sl. No	Species	Specific gravity	Source
1	*Quercus leucotrichophora*	0.826	Raturi et al. (2002) [21]
2	*Grewia oppositifolia*	0.606	Purkayastha (1982) [22]
3	*Melia azedirach*	0.491	Raturi et al. (2002) [21]
4	*Celtis australis*	0.444	Rajput et al. (1985) [20]
5	*Toona ciliata*	0.424	Raturi et al. (2002) [21]
6	*Adina cardifolia*	0.583	Raturi et al. (2002) [21]
7	*Mangifera indica*	0.588	Chowdhury and Ghose (1958) [19]
8	*Citrus limon*	0.91	Ting and Blair (1965) [23]
10	*Pyrus communis*	0.676	Tumen (2014) [24]
11	*Ficus roxburghii*	0.443	Sheikh et al. (2011) [17]
12	*Prunus cerasoides*	0.69	Kumar (1989) [18]
13	*Anogeissus latifolia*	0.757	Purkayastha (1982) [22]
14	*Psidium guajava*	0.59	Sheikh et al. (2011) [17]
15	*Morus alba*	0.603	Purkayastha (1982) [22]
16	*Citrus sinensis*	0.916	Joseph and Abdullahi (2016) [25]
17	*Juglanse regia*	0.59	Wani et al. (2014) [26]
18	*Bahunia verigata*	0.55	Kanawajia et al. (2013) [27]
19	*Ficus palmate*	0.578	Sheikh et al. (2011) [17]
20	*Malus domestica*	0.67	Miles and Smith (2009) [28]
21	*Prunus armenica*	0.50	Miles and Smith (2009) [28]
22	*Prunus persica*	0.90	Babu et al. (2014) [29]
23	*Myrica esculenta*	0.737	Sheikh et al. (2011) [17]
24	*Pyrus pashia*	0.70	Kumar (1989) [18]
25	*Ficus auriculata*	0.443	Sheikh et al. (2011) [17]
26	*Punica granatum*	0.99	Felter and Lloyd (1898) [30]
27	*Carica papaya*	0.918	Afolabi, I. S. and Ofobrukweta, K (2011) [31]
28	*Bombax ceiba*	0.33	Troup (1921) [32]
29	*Rhododendron arboreum*	0.512	Rajput et al.(1985) [20]
30	*Pinus roxburghii*	0.491	Rajput et al.(1985) [20]
31	*Embilica officenalis*	0.614	Sheikh et al. (2011) [17]
32	*Psidium guajava*	0.59	Kanawjia et al. (2013) [28]
33	*Celtis australis*	0.444	Rajput et al. (1985) [20]
34	*Albizia leeback*	0.69	Mani and Parthasarathy (2007) [33]
35.	*Rhus Parviflora*	0.620	Chowdhury and Ghose (1958) [19]
36.	*Wood fructicosa*	0.55	Chaturvedi et al. (2012) [34]
37	*Musa Paradisica*	0.29	Omotosa and Ogunsile (2010) [35]
38	*Acacia catechu*	0.825	Purkayastha (1982) [22]

Table 2.
Specific gravity of agroforestry species.

$$L_{dwi} = L_{fwi} \,/\, 1 + M_{cbdi} \tag{4}$$

Where L_{dwi} - oven dry weight of Leaves, L_{fwi} - fresh/green weight of Leaves, M_{cbdi} - moisture content of leaves on dry weight basis.

Total above ground biomass was the sum of stem biomass, branch biomass and leaves biomass [37]. Below ground biomass of tree was calculated by multiplying the aboveground biomass by a factor of 0.25 for broad-leaved species and 0.20 for coniferous species [38]. The biomass carbon of tree was estimated from the sum of above ground biomass and below ground biomass of tree.

Crop biomass was estimated using 1 m X 1 m quadrates by a destructive method. During 2015–2016, when the crops were at their peak biomass in March to April for *Rabi* (winter) and August to September for *Kharif* (summer) seasons. All the agricultural crops, grasses and weeds plants occurring within the border of the quadrats were harvested at ground level and sorted out and collected samples were weighted. Fresh weight was converted into dry weight on the basis of plant samples kept in the oven for drying at 80 °C for 24 hours. The crop biomass was converted into carbon by multiplying with a factor of 0.45 [39]. In annual crops, below ground biomass was estimated by multiplying with reference root: shoot ratio for each crop species [40]. Total biomass carbon stock of agroforestry system was the sum of total biomass carbon of trees and total biomass carbon of crops. The biomass carbon was estimated from total biomass by multiplying biomass with a factor of 0.45 [39].

2.8 Statistical analysis

The data was analyzed applying two-way analysis of variance (ANOVA) Wherever the effects exhibited significance $P \leq 0.0\ 5$ probabilities, all analysis was performed using GEN STATISTICS 32 version [41] (VSN International 2017).

3. Results and discussion

In the Himalayan region, a number of indigenous agroforestry systems have been known from Himachal Pradesh [42] (Atul and Khosla, 1990) and Uttarakhand [42] (Dadhwal *et al.,* 1989) out of which agrihortisilviculture system, agrisilviculture system and agrihorticulture system are very common and frequent. Dadhwal *et al.,* (1988) [42] and Toky *et al.,* (1989) [43] have recognized these three agroforestry systems with their multifarious benefits to the hill farmers. Existing agroforestry systems and its components in Tehri district has reported in Vikrant *et al*. 2015 [44]. In lower altitudes, the agroforestry system differed significantly in Above ground biomass, Below ground biomass (AGB), Total tree biomass (TTB), Total biomass (TB) and Total carbon (TC) ($P \leq 0.05$). In general, T0tal carbon were higher in agrihortisilviculture system (2.44 Mg ha^{-1}) followed by agrisilviculture system (1.60 Mg ha^{-1}) (**Table 3**). At middle altitudes, agroforestry system shows significantly difference in AGB, BGB TTB, TB and TC ($P > 0.05$). Total carbon storage were found maximum in agrihortisilviculture system (2.22 Mg ha^{-1}) followed by agrisilviculture system (1.53 Mg ha^{-1}) (**Table 4**). Agroforestry system differed significantly in AGB, BGB TTB, TB and TC ($P \leq 0.05$) at upper altitudes. Agrihorticulture system shows maximum (1.64 Mg ha^{-1}) carbon stock followed by agrisilviculture system (1.3 Mg ha^{-1}) (**Table 5**). Effect of interaction between altitudes and systems is depicted in **Table 6**. Crop biomass (CB)

Parameters	System			DF	Type III	Mean square	F	Pr > F
	AHS	AS	AH					
AGB	2.79	2.45	1.84	2	202.25	101.12	16.89	0.00
BGB	0.7	0.62	0.47	2	50.56	25.28	4.22	0.00
TTB	3.49	3.07	2.31	2	269.67	134.83	22.53	0.00
CB	1.95	0.37	0.28	2	5.04	2.52	29.97	0.00
TB	5.44	3.44	2.59	2	348.32	174.16	28.02	0.00
TC	2.44	1.60	1.16	2	15.41	7.7	8.24	0.00

Significance at the level of probability of 5% (P < 0.05).
AGB = Above ground biomass BGB = Below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 3.
Comparison among system for AGB, BGB, TTB, CB, TB and TC, in (Mg C ha^{-1}) along lower altitudes of Tehri district, Uttarakhand (n = 60).

Parameters	System			DF	Type III	Mean square	F	Pr > F
	AHS	AS	AH					
AGB	3.64	2.43	2.19	2	202.17	101.122	16.91	0.00
BGB	0.91	0.60	0.54	2	50.54	25.205	4.22	0.00
TTB	4.55	3.03	2.73	2	269.67	134.83	22.55	0.00
CB	0.39	0.37	0.56	2	5.049	2.524	9.97	0.00
TB	4.94	3.40	3.29	2	454.34	207.17	34.6	0.00
TC	2.22	1.53	1.48	2	204.45	93.22	15.57	0.00

Significance at the level of probability of 5% (P < 0.05).
AGB = above ground biomass BGB = below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 4.
Comparison among system for AGB, BGB, TTB, CB, TB and TC, in (Mg C ha^{-1}) along middle altitudes of Tehri district, Uttarakhand (n = 60).

Parameters	System			DF	Type III	Mean square	F	Pr > F
	AHS	AS	AH					
AGB	2.37	1.85	1.48	2	20.87	10.43	4.26	0
BGB	0.8	0.51	0.49	2	5.21	2.6	1.32	0
TTB	3.17	2.46	1.97	2	27.83	13.91	5.68	0
CB	0.46	0.42	0.42	2	0.03	0.01	0.13	0.87
TB	3.64	2.88	2.4	2	29.68	14.84	5.58	0
TBC	1.64	1.3	1.08	2	6.01	3.006	5.58	0

Significance at the level of probability of 5% (P < 0.05).
AGB = Above ground biomass BGB = Below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 5.
Comparison among system for AGB, BGB, TTB, CB, TB, and TC, in (Mg C ha^{-1}) along upper altitudes of Tehri district, Uttarakhand (n = 30).

are significant differences between altitudes and agroforestry sytem ($P \leq 0.05$), While CB showed nonsignificant difference with altitude andsystem.Biomass and carbon stock was found maximum in agrihortisilivculture system followed by agrisilivculture system and minimum in agrihorticulture system (**Tables 3–5**). It was observed that

Source	Stock	DF	Type III SS	Mean square	F	Pr > F
Altitude	AGB	2	136.54	68.27	19.35	0.00
	BGB	2	45.51	22.75	6.45	0.00
	TTB	2	182.066	91.033	25.817	0.000
	CB	2	0.451	0.226	2.696	0.069
	TB	2	198.887	99.443	27.047	0.000
	TC	2	40.275	20.137	27.047	0.000
System	AGB	2	88.26	44.13	12.51	0.00
	BGB	2	29.42	14.71	4.17	0.00
	TTB	2	117.697	58.848	16.689	0.000
	CB	2	0.451	0.226	2.696	0.069
	TB	2	165.417	82.708	22.495	0.000
	TC	2	33.497	16.788	22.495	0.000
System x Altitudes	AGB		12.66	3.16	0.89	0.00
	BGB		4.22	1.055	0.29	0.00
	TTB	4	16.887	4.222	1.197	0.312
	CB	4	2.321	0.580	6.934	0.000
	TB	4	25.577	6394	1.739	0.142
	TC	4	5.179	1.295	1.739	0.142

Significance at the level of probability of 5% ($P \leq 0.05$).
AGB = above ground biomass BGB = below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 6.
Analysis of variance for AGB, BGB TTB, CB, TB, and TC by altitudes, system and the interaction of both variables of Tehri district, Uttarakhand.

agrihortisilviculture system yields higher biomass carbon stock than other agroforestry systems across the altitudes may be due to adequate management of trees under agroforestry systems of the atmospheric carbon capture and stored in plant. It is indicated that as the biomass carbon was decreased with increasing altitudes across systems is m. The similar results are also reported by (Kaur *et al*. 2000 [45]; Maikhuri *et al.* 2000 [46]). Albert and Kandiji (2003) [8] reported that carbon variability in plant biomass can be high within complex systems and productivity depends on several factors including the age, structure and the management of the system. Among agroforestry systems, biomass carbon stock followed the order agrihortisilviculture>agrisilviculture> agrihorticulture. There was no significant difference between biomass carbon stock with altitudes and systems (**Table 2**). The main reasons for higher carbon density in tree based systems as exhibited by perennial components, is attributed to continuous accumulation of biomass in the woody component [47]. Moreover, from the agriculture fields and grasses almost all of the above ground biomass carbon stock is removed annually.

4. Carbon stock contribution by trees species in agroforestry across altitudes

Total thirty eight agroforestry trees species were observed in different agroforestry systems of the district. Out of thirty eight, *Grewia oppositifolia, Celtis australis*, *Melia azedirach*, *Quercus leucotrichophora*, *Ficus roxburghii*, *Myrica* *esculenta, Rhododendron arboretum, Citrus limon, Juglans regia* accumulated maximum biomass carbon stock in the district (**Figure 2**). **Figure 3** represents that among the dominant tree species *Quercus leucotrichophora* contributed maximum (15.11%) biomass carbon stock followed by *Ceitis australis* (6.94%), *Grewia oppositifolia* (6.45%) and rest of species contributes (49.34%). In the present study, *Quercus leucotrichophora* contributed maximum biomass then other tree species. Biomass in *Quercus leucotrichophora* was higher as reported by (Devi *et al*. 2013 [48]; Sharma *et al*. 2010 [49]) for lower Western Himalaya. *Grewia opposoitifoila* contributed maximum number of trees but biomass contribution was lower than *Quercus leucotrichophora,* may be due continous lopping of its branches for fuel and fodder during lean period by local people therefore stunting and bushy growth of *Grewia* was noticed in agroforestry field. Kumar *et al*. (2012) [50] reported that overexploitation of resources from traditional agroforestry trees reduce input biomass.

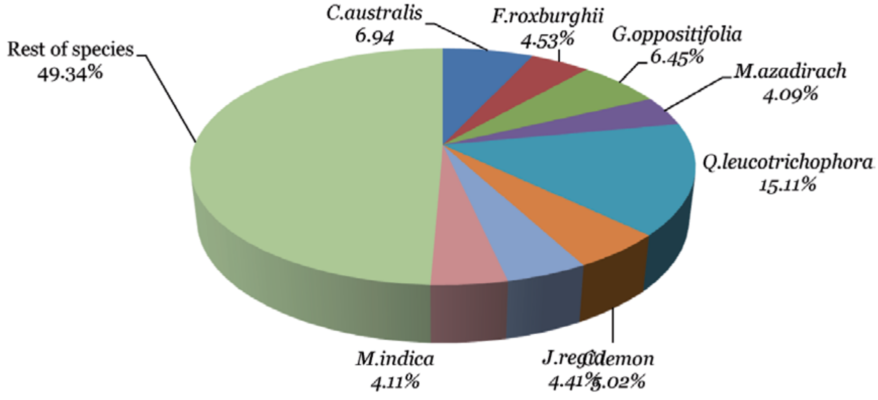

Figure 2.
Carbon stock contributed by trees species in agroforestry of Tehri district.

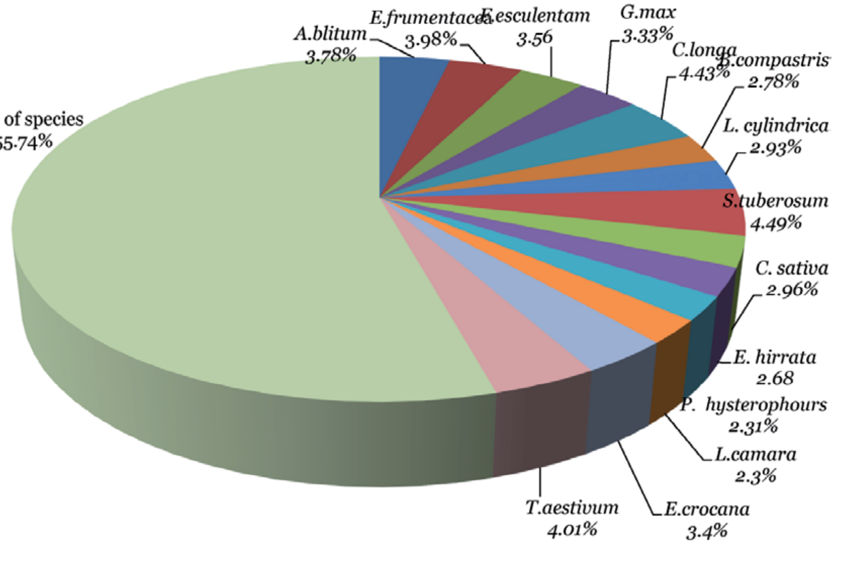

Figure 3.
Carbon stock contributed by crops species in agroforestry systems of Tehri district.

5. Carbon stock contribution by crop in agroforestry across altitudes

Forty crops species associated in agroforestry systems were observed in the district. Out of forty, maximum biomass carbon containing crop species are *Solanum tuberosum* (4.49%), *Curcuma longa* (4.43%), *Tetricum estivum* (4.01%),*Ehinochloa frumentacea* (3.98%), *Amarnathus blitum* (3.78%), *Fagopyrum esculenta* (3.56%), *Eleusine coracana* (3.4%)and *Glycine max* (3.33%) and rest of the species contributes (55.74%) biomass carbon stock (**Figure 3**). In the present study *Solanum tuberosum* contributed maximum biomass as compared to other crop species. It may be attributed that *Solanum tuberosum* had maximum leaf area and dry weight as compare to other crop species. Due to large leaf area, it is capable for absorption of maximum sunlight and has a maximum amount of CO_2 fixation [51, 52].

6. Conclusion

Agrihortisilviculture system had maximum biomass carbon stock at lower altitudes. Across the altitudes, farmers mostly adopted agrihortisilviculture system. Considering biomass and carbon stock, lower altitude (286–1200 m) subtropical zone have more potential for carbon sequestration in agroforestry. *Grewia oppositifoila, Quercus leucotrichophora* and *Celtis australis* were dominant agroforestry tree species which contributed more biomass carbon stock as compared to other species and are mostly adopted by the farmers in agroforestry. Therefore, these three species were considered suitable agroforestry tree species in the district. In agroforestry systems, particularly agrisilviculture and agrihortisilviculture land use systems are playing an important role in the carbon storage an Tehri district of Uttarakhand. Hence these systems need to be promoted further for economic and environmental security. Due to ban of green/live trees felling in the entire Indian Himalayan region, agroforestry systems can be a good source of earning significant carbon credit to thefarmers. Therefore understanding and implementation of carbon sequestration will help to maintain climate change mitigation from agroforestry.

Acknowledgements

First Author is thankful to Prof. N.P.Todaria, Head (Retired), Departmentof Forestry and NR, HNB Garhwal University, Srinagar Garhwal, Uttarakhand for guidance during the course of present work and UGC, New Delhi for providing Rajiv Gandhi National Fellowship(Grant No. RGNF-2012-2013-SC-BIH-30641). The authors are very thankful to the farmers of Tehri Garhwal for providing cooperation during field work.

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Chapter 3

Agroforestry as a Small Landholder's Tool for Climate Change Resilience and Mitigation in Zimbabwe

Tariro Kamuti

Abstract

Zimbabwe's agro-based economy is dominated by the country's majority population who live in rural areas and practice smallholder agriculture. While ameliorating the condition of the participant households, current practices of smallholder agriculture have caused challenges to the governance of land, water and forest resources. Massive deforestation has proceeded at an alarmingly high level, in a way that has threatened the long-term viability of smallholder agriculture and the sustainability of natural forest resources. So, smallholder agriculture has driven forest landscape changes that pose inherent environmental challenges including climate change. This chapter blends institutional and landscape approaches to explain how the integration of agroforestry, as a livelihood strategy, can be a tool for climate change resilience and mitigation in Zimbabwe. Drawing on documentary evidence, the chapter concludes that alternative institutional and livelihood initiatives anchored on agroforestry can transform smallholder agriculture and lead to climate change resilience and mitigation.

Keywords: Deforestation, smallholder farming, climate change, resilience, mitigation, agroforestry, reforestation, Zimbabwe

1. Introduction

Zimbabwe's agro-based economy is dominated by the country's majority population (about 70%) who live in rural areas and practice smallholder agriculture [1, 2]. While ameliorating the condition of the participant households as the mainstay of their livelihoods, there is the emergence of challenges in productivity with subsequent effects on production levels which stem from deteriorating environmental conditions. Practices of smallholder agriculture have in the long run caused challenges to the governance of land, water and forest resources. The decline in quality and quantity of these resources has led to the degradation of landscapes which in turn pose constraints on living conditions. These conditions leave people more vulnerable to external influences like climate change impacts as their capacities for climate change resilience and mitigation are compromised. The climate crisis is now more apparent given that climate change impacts are being experienced around the world more often than before, with Zimbabwe having its own experiences of climate change impacts, especially in the growing season. The growing season is critical because agriculture in Zimbabwe largely relies on rain whose variability is felt by poor households because of their limited capacities to adapt [1, 3–5]. One of the most apparent impacts of climate change is the occurrence of extreme weather conditions which directly affect people's physical living conditions while hitting hard on agricultural production systems through which people eke a living [2–4]. For example, around the Middle Zambezi Biosphere Reserve in Zimbabwe climate change has been felt through water shortages, the transformation of forests, loss of livestock and wildlife, and famine [6]. Analysis of weather patterns over a long time in Zimbabwe has shown that there has been an observable trend of increase in average temperatures, declining mean rainfall per year, shifts in the rain season, increase in the occurrence of droughts and mid-summer dry periods, and the rise in the incidence of severe tropical cyclones [4, 7–9]. Thus, drastic changes in the weather regime especially during the rainy season, affect the production levels which in turn affect livelihoods [1, 10]. Effects of climate change are contingent on each locality such that people from different areas may not necessarily experience the same conditions of climate change impacts [10, 11]. For example, a study in two districts in Zimbabwe showed that the majority of respondents in Makoni associated climate change with the delayed start of the rainy season, and increased frequency of flash floods, while most respondents from Wedza linked climate change to successive dry summers, high temperature ranges across all seasons, and afflictions attacking crops and livestock [11].

This chapter attempts to explain how the integration of agroforestry, as a livelihood strategy, can be a tool for climate change resilience and mitigation in Zimbabwe. Climate change is causing devastating effects at various temporal and spatial scales. Broadly, from the time preceding the industrial era from around 1850–1900 up to now, the average temperature has gone up substantially [12]. In the intervening period from 1850 to 1900 to 2006–2015, this average temperature has gone up by 1.53°C thereby causing global warming [12]. Global warming has the effect of increasing the occurrence, extent and period of high temperature-linked weather patterns on terrestrial ecosystems [12]. For example, droughts have also increased in occurrence and severity [12]. The average rise in temperature over a long period has caused changes in climatic regions including the increase in land under dry conditions thereby negatively affecting the flora and fauna [12]. Climate change can accelerate the deterioration of the land "through increases in rainfall intensity, flooding, drought frequency and severity, heat stress, dry spells, wind, sea-level rise and wave action" [13]. Land degradation has an impact on livelihoods as it limits what human beings can obtain from the natural environment thus increasing their chances of falling into poverty [14]. The goods and services from nature range from food, water, clean air, fuelwood, the ability to increase groundwater, to the capacity to act as a sink for carbon, which all further have socio-economic implications [14]. Zimbabwe loses approximately US$382 million per annum due to land degradation and this is equivalent to 6% of its Gross Domestic Product [14].

Climate change resilience here refers to the ability of communities to recover and rise above the effects or losses which they may have incurred due to climate change impacts. I will take climate change mitigation to mean the reduction in the impact of climate change on people's livelihoods and welfare. Interventions to deal with climate change are generally classified into three groups which are "hard solutions, such as engineered infrastructure like levees; soft solutions, including insurance and early warning systems; and nature-based solutions" [15]. Nature-based solutions are "interventions that use ecosystems as part of a broader, societal response to environmental change" [16]. One of the nature-based solutions which enhances climate change resilience and mitigation especially for vulnerable communities is an ecosystem-based adaptation (EbA). Ecosystem-based adaptation "is a people-centric concept that recognizes ecosystem integrity as critical for human resilience to climate change" [15]. These approaches are based on the recognition of the central role of biodiversity in connecting ecosystems to human needs. So various kinds of ecosystems help enhance the capacity of human beings to withstand the adverse conditions brought in by climate change. For example, "wetlands, forests and mangroves, represent a proven strategy for building resilience to climate change … (as) natural systems (that) can reduce the impact of floods and droughts, decrease hillside erosion and protect lives and property against storm surge and high waves" [15]. Agroforestry fits well under nature-based solutions.

Agroforestry here is taken in general to refer to, "the integration of trees and woody shrubs in crop and livestock production systems" [17]. Agroforestry assumes some multifaceted roles in that some trees and woody shrubs constitute part of the agricultural systems as food and cash crops, while their integration in agriculture at the same time will enable the harnessing of their ecosystem roles that are critical in enhancing climate change resilience and mitigation. Thus, the idea that agroforestry is a source of livelihood is not new. However, this chapter is just amplifying the voice that there is a need to ramp up efforts to use agroforestry not only as a source of livelihood but to be integrated into broad measures towards climate change resilience and mitigation. This is more applicable at the small landholder level where climate change impacts are most felt. Households can do agroforestry with limited resources to help themselves while contributing to the greater good of climate change resilience and mitigation through the cumulative positive effects of agroforestry within local communities. The hard and soft solutions are expensive for vulnerable communities to implement, so nature-based solutions to climate change resilience and mitigation become a viable option. Nonetheless, small landholders have to devise ways to cope with the new climatic conditions that are prevailing now. The adoption of agroforestry is thus a viable option.

The chapter proceeds by blending the institutional and landscape approach as a conceptual basis to analyze the developments in small landholder agriculture in Zimbabwe. This is motivated by the idea that farmers are at the interface of institutional processes that guide their ownership, access and use of natural resources that are found in different landscapes. This will be followed by a treatise of how small landholder agriculture is connected to environmental quality that determines the levels of climate change resilience and mitigation. Next, is the section on climate change resilience and mitigation in Zimbabwe. This will be followed by a detailed justification of agroforestry as a viable strategy to complement other climate change resilience and mitigation measures. Then the discussion will open to reflect on the suggestion of agroforestry as a tool to enhance climate change resilience and mitigation. Concluding remarks will summarize the content of the book chapter.

2. Blending institutional and landscape approaches

Vegetation is important in natural cycles such as water and carbon cycles which all have a bearing on weather in the short term and climate in the long run. Forest resources are a critical component of ecosystems which together with the land constitute landscapes. The issue of "landscape sustainability" has gained prominence from around 2013 when so much attention has been given to the long-term 'health' of various terrestrial ecosystems [18]. Agroforestry as a human-driven initiative fits in the forest resources on agricultural landscapes that help to resuscitate and strengthen ecosystems for a human benefit like climate change resilience and mitigation. Human wellbeing depends on these forest resources as well as the ecosystems and landscapes where they are rooted. Thus, human beings virtually rely on landscapes to obtain various ecosystem goods and services [19–21]. Landscapes approaches tend to be holistic in attending to the various dimensions of sustainability through "addressing multiple disciplines, knowledges, and needs that span science-society-policy interfaces and policy sectors and scales" [22]. Three distinct ways through landscape approaches are integrative have been noted. First, a landscape is taken as an interface between society and ecology where these two elements are given a fair chance to analyze their role in determining how the landscapes are constituted [23]. Second, landscape approaches are inclusive of all stakeholders at different levels of organization as their concerns and perceptions are considered for their buy-in and involvement [23]. Third, landscape approaches depend on a dynamic system of management that balances the needs of all the levels of organization to create landscapes that serve several functions [23].

Issues relating to ownership, access and use of natural resources bring in the human-nature dimension and its role in shaping the spatial and temporal outlook of landscapes. Thus, institutions are used to mediate human-nature relations, particularly in determining ownership, access and use of natural resources. Institutions are here regarded as the rules or regulations that are implemented on the access and utilization of natural resources at various levels of organization. The type and extent to which institutions are implemented to interface human-nature relations determine the condition of landscapes. For example, institutions are accepted to have an impact on how human beings utilize land which results in the transformation of landscapes [19, 20]. These components of a socio-ecological system are not mutually exclusive as it has been observed that there is a pitfall of analyzing them as disparate elements [19]. The argument is well put that "the spatial patterns in ecosystems that result from institutions are widely recognized and well analysed (e.g., changes or differences in deforestation patterns under different regulations) but the feedbacks from these patterns back to institutions (and especially, the creation and modification of institutions) are seldom explicitly analysed in studies of landscape ecology and land cover change and hence are poorly understood" [24]. This multifaceted situation needs to be looked at holistically to craft wholesome approaches that take care of the various dynamics that arise from how institutions set in motion by human beings influence ecosystems and the subsequent feedbacks.

Institutional arrangements are important in this chapter to understand that governance determines how natural resources are utilized to meet human demands. Natural resources also have limits through the quantity of goods and level of services which can they avail to support livelihoods depending on how they are managed. Institutions stand in between human beings and natural resources on various landscapes and the two-way interactions between them needs to be understood. Those interactions have a bearing on climate, thus inherently they can either cause or mitigate against climate change. The proposal to consider agroforestry as a tool for climate change resilience and mitigation can be understood in the context of how the relationships between human beings and natural resources are mediated by institutions across various landscapes. There is an assertion that "institutional, policy and governance responses to address land degradation are often reactive and fragmented, and fail to address the ultimate causes of degradation" [25]. This means that measures are put in place when land degradation has already happened, and these efforts are not well coordinated and ultimately not effective in attending to the factors that lead to the deterioration of landscapes. Overall, institutions do matter when considering the fight against climate change across various landscapes. However, there is a need to acknowledge the dynamics of power relations in nature-based solutions to tackling climate change which underpins this idea of institutions [16].

3. Smallholder agriculture and its impact on Forest resources in Zimbabwe

There is a history of policies that promoted white farmers to produce commercial crops such as tobacco by colonial governments in southern Africa whose countries fall within the areas dominated by miombo woodlands [26]. Thus, there has been a trend of damage to indigenous forests and their subsequent replacement with exotic timber and fruit trees as part of forestry, reforestation or agriculture in general. Deforestation is a major environmental challenge in Zimbabwe. People cut down trees mainly for household energy needs, construction purposes, clearing land for crop production, and overgrazing. Most recently trees have been felled to provide energy for treating flue-cured tobacco mostly in Mashonaland East, Mashonaland Central, and Mashonaland West Provinces of the country. Production of tobacco contributes to around 5% of deforestation in Africa, but unfortunately, there is a gap in considering the negative effects to the environment which come back to affect people's livelihoods [26]. Biodiversity loss is a crisis that is facing humankind today in conjunction with the climate crisis [27]. About a million species face the risk of being lost forever due to damage to ecosystems which will further worsen the current crises facing humanity [3, 28].

Globally, it was forecast that environmental change would be mainly pushed by the rise in population and its subsequent increased food needs [29]. Thus, population growth has caused a rise in demand for land under crop and livestock production subsequently putting pressure on land, water and forest resources to sustain livelihoods mainly in the rural areas. It has also been concluded that land degradation is a great challenge worldwide which is inherently associated with a decline in biodiversity pushed by an increase in area under arable and livestock production, poor agricultural and forestry management systems, shifting climatic regime, urban sprawl, urban and mining development [3]. In Zimbabwe, incessant and prolonged power outages from the country's electricity utility since the late 1990s have increased demand for firewood as an affordable alternative source of energy. Since then, the general transport of firewood (due to strong rural–urban linkages) and its trade from the rural areas have added to the toll of deforestation. The challenge of deforestation has been exacerbated by the lack of corresponding efforts in reforestation. So, even though vegetation is a renewable natural resource, the rate at which regeneration of trees and other components of the ecosystem that survive after the damage is lower than the rate of the loss is incurred [30]. Massive biodiversity loss follows. Indigenous forests also consist of woody tree species that are slow-growing which makes it difficult to restore forests to their climax levels within a generation. Historically, society has been able to contain short-term changes within a human generation climatic conditions but now climate change is enduring and happening at a faster rate than what they can do to cope [1, 31].

Crop and livestock production systems with less or without corresponding conservation in the rural areas have thus had a net effect of transforming landscapes in a way that contributes to environmental damage and subsequent degradation. This has compromised what the environment can give back to the people in terms of environmental goods and services which keeps driving productivity down to precarious levels that threaten livelihoods [3]. The effect of deforestation on landscapes is critical since the majority of the Zimbabwean population is rural-based and dependent on smallholder agriculture. This burden to the environment is also coupled with the colonial legacy of the displacement from fertile land and the concentration of the population into marginal land in what was called native reserves. These areas with marginal land have already been areas of low agricultural potential due to adverse agro-ecological conditions characterized by low annual rainfall and poor soils, thereby having a low carrying capacity [3].

Under these circumstances, the biogeographical conditions in such areas have been worsened leaving the majority of the people who largely depend on agriculture at a vulnerable position where their capacity to adapt to climate change impacts is curtailed [3, 9, 32]. For example, shifts in the micro-climate have been witnessed with low locally induced rainfall during the rainy season than what it used to be 20–30 years ago. The increase in the bare surface due to clearance of the ground cover has increased the levels of soil erosion due to runoff and wind leading to the development of gullies while rivers and water reservoirs have been silted resulting in less fresh water available for domestic consumption and agricultural production in turn. Wetlands that have provided key environmental goods and services have been destroyed to pave way for agriculture due to the rise in the demand for land. Overgrazing has been due to a lack of control of stocking levels to levels of the carrying capacity of the land. With thin topsoils, the water holding capacity of the soil has been reduced, which together with increased runoff when it rains, and low annual rainfall, have eventually reduced the groundwater recharge. The decline in the water table levels also means that there will be less underground water available for extraction during times of crises in the dry season. Reduced water supplies have a direct effect on agricultural production [3]. The decline in agricultural production subsequently reduces available household food, their earnings, and ultimately the quality of life [33]. Environmental goods and services are variable both spatially and temporally across landscapes depending on the state of human-nature relationships [21]. Causes of climate change are global (with developing countries contributing far less), its impact at the local level is critical in such conditions of general environmental degradation. Therefore, it is now imperative to prevent, decrease and scale back the deterioration of landscapes to secure food and water while enhancing climate change resilience and mitigation [3].

4. Climate change resilience and mitigation in Zimbabwe

Climate change is a global challenge which is not confined to a country's national boundaries. So, climate action can start to be analyzed from the global level going down until it reaches the local level. This is where global environmental governance comes into play as countries around the world come together to formulate solutions against climate change. In this respect, numerous attempts have been made to reach a global consensus to combat climate change. This has resulted in the formulation of multilateral agreements on various issues relating to nature which have a bearing on confronting challenges associated with climate change. These agreements constitute part of international institutions which governments can tap in to formulate their specific policies and programs. Zimbabwe is a signatory to or a member of several international agreements, conventions and protocols such as the Paris Agreement, Agenda 21, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Convention on Biological Diversity, United Nations Convention to Combat Desertification, United Nations Framework Convention on Climate Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Agenda for Sustainable Development (AfSD), and the Southern African Development Community (SADC) Protocol on Environmental Management for Sustainable Development. All these are global and regional institutional mechanisms by which the country has committed itself in unison with other nations to formulate its policies and regulations which are relevant to the efforts against climate change. All these efforts are underpinned by the need to take good care of the natural environment so that it can in turn provide humanity with natural goods and services that sustain lives. In the same vein, that is where one can contextualize the role and subsequent integration of institutions and landscapes through agroforestry as one of the tools that can be used to enhance smallholder farmers' resilience and mitigation against climate change.

At a national level, these internationally crafted institutions from the world and regional bodies provide an overall framework and specific targets that government policies, laws, plans and programs can formulate and aim to achieve. National governments are also organized in various ways in pursuit of their specific environmental sustainability goals. Zimbabwe has various ministries and agencies which deal with issues relating to land, agriculture, water, forestry, fisheries, energy and other sectors that are all integrated and coordinated in a way that recognizes the critical role of nature and thus help to fight against the effects of climate change. The various ministries relating to land, agriculture, environment and water, and the various agencies like the Environmental Management Agency, Forestry Commission, Agricultural Extension Services, for instance, all have specific mandates, but their coordination and integration help to take care of the country's international environmental obligations while striving to people's livelihoods and welfare. Agroforestry in this case fits into broad agricultural and environmental policies, while there are specific laws crafted to cater for these issues.

The Forestry Commission has been instrumental in spearheading reforestation programs in Zimbabwe. The parastatal has worked with other state agencies, non-governmental organizations, private companies and local communities through various kinds of cooperation and working relationships. Using their motto, "Trees are Life" they have run campaigns to promote the conservation of trees. The National Tree Planting Day, which is synonymous with this parastatal is part of this campaign. Within these efforts, there has been the promotion of the propagation and growing of fruit trees. However, within these efforts to conserve trees and reclaim degraded landscapes, agroforestry has not been comprehensively developed and adopted as a viable initiative in favor of climate change resilience and mitigation. The state needs to seriously consider supporting initiatives that integrate agroforestry in the broad environmental policy and nature conservation. Agroforestry then should not be narrowly defined through the growing of fruit trees but taken as a broad nature-based initiative that encompasses environmental and agricultural production systems that have spiral effects on other sectors of the economy. These productions systems are simply anchored on the integration of trees and woody shrubs. This is the reason why all stakeholders need to work in unison under this clarion call to reduce the impact of climate change which affect the country as part of the less developed world with severe impacts on the poor, vulnerable and marginalized majority.

5. Agroforestry as a nature-based intervention against climate change

Embracing nature-based interventions against climate change is a compelling option available to small landholders in Zimbabwe. With a greater percentage of the population already practising some form of agriculture, agroforestry can be easily integrated into the existing household livelihood strategies. In some cases, families are already into agroforestry but not within the extent to which they can reap greater benefits both directly in getting, for example, food or firewood and indirectly through ecosystem services which help to ease the impact of climate change. These interventions can be "sustainable agriculture, integrated water resources management and sustainable forest management" [34]. Agroforestry as an ecosystem-based solution against climate change fits well with these nature-based interventions as the strategy has elements of sustainability, agriculture, water and forest resources management rolled into one. Most of the livelihood strategies in the rural areas are anchored on direct dependence on nature and it will be in the interest of the people there to take care of their immediate environs for them to sustain their livelihoods. Urban development had drastically the landscapes wherever towns and cities are found. However, the proliferation of urban agriculture in Zimbabwe has become an acceptable practice within backyards or open spaces around the suburbs. Home gardens, as one method of agroforestry, are very appropriate in this scenario of urban agriculture that is already existing there. This could explain the prevalence of fruit trees around people's houses in the towns and cities of Zimbabwe.

The land produces and acts as a reservoir of greenhouse gases (GHGs) and functions in the interplay between energy, water and atmospheric gases between the ground and air above it [12]. Natural forests that have not been damage can store up to 510 billion tons of carbon dioxide and the world will not achieve its targets set by the Paris Agreement if forests continue to be damaged [27]. Key sectors such as agriculture, forestry and other land uses account for 76% of the overall GHGs produced in Zimbabwe [14]. In this respect, it has been found out that "land-based mitigation options rank among the most cost-effective opportunities to sequester carbon emissions. Economic evaluations of various climate change mitigation alternatives show that capturing carbon through restoring degraded lands (including degraded-forest) is a cost-effective option that offers multiple co-benefits" [35]. To mark World Wildlife Day by CITES on 3 March 2021, the theme was "Forests and Livelihoods: Sustaining People and Planet," to emphasize the critical part played by forests and their associated biodiversity in supporting human lives especially indigenous people and local communities (IPLCs) who manage 28% of global terrestrial ecosystems [28]. The role of IPLCs should be acknowledged and taken into consideration to frame everlasting solutions in the fight against climate change impacts through nature-based interventions [36–38]. A study of communities around the Middle Zambezi Biosphere Reserve has also shown that the people have rich local ecological knowledge which helps them in raising their resilience against the external conditions induced by climate change [6].

This shows that forests should not just be protected from further degradation, but they need to be reclaimed too since 73% of the Earth's land surface has been modified by human activities [27]. Thus, there is a need to engage in natural resources management systems that serve human needs in tandem with the sustainability of forests [28]. These efforts to restore biodiversity can succeed when the cultural systems are put at the center of methods that yield win-win solutions for natural ecosystems and climate change resilience and mitigation [37]. Just like any country that is committed to the AfSD, Zimbabwe has a chance to play its part through SDG 15 which deals with "life on land" and specifically to achieve target 15.3 that refers to Land Degradation Neutrality (LDN) [14]. Good management of the land helps in lowering the adverse effects of climate change while the conservation of forest resources is critical in fighting poverty [12, 14, 39].

To tackle climate change, one has to understand the intricate ways through which people engage in activities to sustain their lives interface with natural ecosystems as these are not mutually exclusive. In her research, Laura Vang Rasmussen, an Assistant Professor at the University of Copenhagen, Denmark puts it aptly that, "the problem at the moment is that forest conservation, agricultural development, and poverty reduction are viewed as distinct from each other. However, the three factors do influence each other. Strategies to increase agricultural productivity can harm forests. On the other hand, an increase in wooded areas makes it more difficult to produce enough food. So we hope that our research can contribute to highlighting the complex dynamics between agricultural productivity, deforestation, poverty and food security," [39]. I then add that for example, forests and their dynamic relationship with other ecosystem constituents play a critical role in dealing with climate change impacts. In the same vein, the practice of agroforestry is an attempt to restore natural ecosystems while increasing agricultural productivity that raises outputs for the benefit of human beings. This is borne out of the understanding that the livelihoods of vulnerable people are anchored on natural resources including forests [30].

The majority of the Zimbabwean population is rural where they largely practice a mixture of arable agriculture and livestock production on communal land that is based on common-pool resources. These agricultural production systems are mainly in the mode of family farming which is based on family labor working on small landholdings. The general set-up under communal land tenure in rural Zimbabwe is such that people occupy individual landholdings for settlement (housing and basic amenities) and arable agriculture with common areas under pastures (for example, forest landscapes) and sources of water like wetlands, springs, rivers or man-made features like dams, wells and boreholes. Earlier on, I have highlighted how some of the agricultural practices by smallholder farmers are leading to land degradation which has devastating effects on productivity and increasing the levels of vulnerability and high risk of climate change impacts. So, there is a need to look again at the structures and practices of smallholder agriculture in the country with the idea to leverage them with agroforestry as a complementary strategy. Agroforestry here will be a way to sustainable livelihoods through ecosystem goods and services while increasing capacity for climate change resilience and resilience. Adoption of agroforestry at the household level by the small landholders will cumulatively uplift the local communities' climate change resilience and mitigation. This should work well with family farming that integrates various traditional and cultural values and practices in supporting their livelihoods [36, 37]. As farmers increase the range of crops which they can grow as a technique to increase productivity, studies have shown that this technique is useful for smallholder farmers to cope with climate change impacts [1, 33]. It can be argued that this method can be extended to including agroforestry to increase the range of what smallholder farmers can grow on their land [33]. This can be accomplished through, for example, intercropping of crops and tree species that complement each other together with conservation agriculture which helps to regulate soil moisture content [38, 40].

6. Discussion of agroforestry as a small landholder tool

Issues that relate to the factors that influence people's involvement in forest management programs need to be studied to determine the appropriate interventions [30]. Rural-based households in Zimbabwe encounter many hurdles to come out with relevant and applicable ways to cope with climate change impacts [8]. These issues need to be addressed and the government should lead the initiatives of mobilizing resources and participation of other stakeholders to spearhead supportive programs that integrate agroforestry as a climate change resilience and mitigation strategy. This is because it has been noted that the government's capacity to implement effective programs to combat climate change is limited despite having the right institutional mechanisms in place [5]. For instance, a study in two districts of Makoni and Wedza within the eastern Manicaland Province showed that smallholder farmers were not well informed about climate change though they could be able to describe conditions that show the onset of the phenomenon [11].

This shows challenges in addressing climate change at the awareness phase starting from the household level, which means that there is a lot to do to reach the extent of implementation of relevant plans of action with the involvement of the smallholder farmers [3, 10]. Development programs can be effective in bringing positive change in people's lives if they enhance their climate change resilience and mitigation [10].

A study of the importance of agroforestry in efforts against climate change impacts involving smallholder farmers in Kenya has shown that the trees enhance resilience against either scarcity or deluge of water thereby raising the threshold to which they can be affected by these extremes [41]. Family farming practised by these small landholders is suitable in this case and that is why the practised is well recognized under the declaration of the UN Decade of Family Farming which spans the period 2019–2028 [37]. The study concludes that "in both drought and flood events agroforestry had an important role to play in reducing sensitivity, largely through improving environmental conditions (shade, soil erosion, windbreaker, microclimate regulation), and increasing adaptive capacity by providing critical tree products and financial benefits (fruit, food, firewood, construction materials, fodder, traditional medicines, money from sales of fruit products)" [42]. This shows the multifaceted and positive role of agroforestry in climate change resilience and mitigation and more importantly for the small landholders who are often vulnerable. For example, concerning challenges encountered when there is a shortage of water, there is need perhaps a need to plant trees that are drought tolerant together or invest in irrigation infrastructure so that there is a substantial shift from rain-fed agriculture [2].

This strengthens the idea of adopting ecosystem-based initiatives as part of the broad nature-based solutions recommendations in tackling climate change among low-income groups who at most occupy small landholdings. The basis of these approaches is underlined by the critical role played by biodiversity which needs to be integrated into the climate change solutions. In this way, "integrated biodiversity conservation and climate change adaptation approaches can be instrumental in making people, places and wildlife more resilient to climate change. Beneficial outcomes may include improved food and water security, protection against the impacts of extreme weather events, more-secure livelihoods, the safeguarding of critical ecosystems and habitats, and carbon sequestration" [43]. The benefits show a win-win situation by balancing the livelihood needs of people while the landscapes upon which they eke their living are also taken care of so that they are sustainable. Ecosystem-based adaptation has shown positive spinoffs in food and water security in the Philippines, Bangladesh, Mongolia, and Uganda [44].

7. Conclusion

This chapter has highlighted the need to use agroforestry as a small landholder's tool for climate change resilience and mitigation in Zimbabwe. The majority of the Zimbabwean population resides in rural areas and largely depend on arable and livestock farming. While climate change is a global phenomenon, it has variable effects at a local level. More climate change impact is being felt in low to middle-income countries where the majority of the people are poor and directly depend on natural resources for their livelihood. Increased pressure on forest landscapes due to various human activities without adequate natural resources management systems and practices, has resulted in the transformation of those landscapes to precarious levels of degradation. Land degradation reduces the capacity of natural ecosystems to sustain livelihoods while increasing the levels of vulnerability of small landholders to the vagaries of climate change.

It is also important to note that natural resource access and use depend on the various kinds of institutions that are put in place to regulate and control these processes. Governance of access and use of those natural resources stretches from the global, regional, national up to local levels where we find small landholders. This governance includes both formal and informal systems of regulations that deal with the use of natural resources for people to sustain their livelihoods. As such, climate change is a global phenomenon, which is not confined to national boundaries, thus it requires them to work together to find collective solutions. In this regard, global environmental governance has been strengthened to reach a consensus to tackle climate change. This has led to the signing of several international agreements, conventions and protocols which provide frameworks to guide country roles and development of their policies, plans and programs to increase climate change resilience and mitigation.

Zimbabwe has put in place various kinds of institutional arrangements for its people to take care of the natural environment including forests, water and land. While these institutions look good on paper, there are a lot of challenges that need to be addressed in terms of the implementation of programs that help conserve the natural environment. It has been seen that various kinds of unsustainable activities lead to the degradation of the natural environment particularly in the rural areas where the majority population lives and directly depend on natural resources. This includes the cutting down of trees for various purposes including the increase in land and arable agriculture and livestock production. So, land degradation is associated with loss of biodiversity which is a critical component of natural ecosystems. Land degradation results in the loss of ecosystem goods and services, which compromise food production and water supply. Most importantly, land degradation is linked to climate change.

The chapter has justified why nature-based solutions are viable options for the smallholder farmers in the rural areas in the face of climate change. These solutions include ecosystem-based adaptation which are anchored on restoration of biodiversity. Agroforestry is an ecosystem adaptation intervention that is feasible for small landholders to adopt in Zimbabwe because of the multifaceted roles of trees and shrubs that are integrated into livelihood strategies. The implementation of such a strategy has its shortcomings that need to be worked around too. Favorable conditions for the adoption of agroforestry as a tool to enhance climate change resilience and mitigation make it a suitable approach under the constraints that face vulnerable the rural population.

Acknowledgements

Many thanks to the editor and anonymous reviewers.

Conflict of interest

There is no conflict of interest by the author.

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Chapter 4

Agroforestry Trees for Fodder Production in Limpopo Province, South Africa

Kingsley Kwabena Ayisi, Paulina Bopape-Mabapa and David Brown

Abstract

Climate change and land degradation, resulting from human-induced pressures on ecosystems are threatening crop productivity, food and feed supply, and food security in the Limpopo Province of South Africa, especially within the socio-economically marginalised communities. A combination of survey and field experimentations were conducted from 2016 to 2018 to assess potential climate-smart farming practices that can assist farmers to adapt to local climate change and variability in the province. Results from the survey revealed that agroforestry system with woody perennial speices which encourages minimum soil disturbance, increase soil cover and increase agrobiodiversity is being promoted in the province as one of the effective avenues to achieve sustainability in farming systems in the midst of global climate change. *Moringa oleifera* and *Acacia karroo* (now *Vachellia karroo*) were identified as potential agroforestry tree species to address feed gaps during dry winter months, based on their good nutritional value, drought hardiness and effective carbon capture for climate change mitigation.

Keywords: *Moringa oleifera*, *Vachellia karroo*, climate change, feed, smallholder farmers, food security

1. Introduction

Climate change and soil degradation are real challenges which are currently stressing the already threatened habitats and ecosystem functioning in Africa, with consequent impacts on agricultural productivity and food security [1, 2]. The fast pace of climate change is frightening as this will have a far-reaching impact on agro-ecosystems and their productivity. Human-induced pressures on ecosystems are placing many inhabitants on the African continent at risk, especially within the marginalised communities who rely heavily on the natural environment for sustenance and livelihood [2]. Climate predictions for South Africa indicate that the country has been getting hotter at least 1.5 times more than the global average of 0.65 °C over the past five decades with an increasing number of warmer days and decreasing cooler days [3, 4]. Furthermore, the average annual rainfall of South Africa is 450 mm which is far below the world's average of 860 mm per annum. The country is also characterised by a comparatively higher evaporation rate [3, 5] placing severe stress on soil moisture retention. A yield improvement of more than

20 percent over current investments in agricultural research and development is required, if South Africa is to adapt to the adverse consequences of global climate change [6]. Incidences of water stress and soil fertility degradation during growth results in reduced crop growth, yield losses, low quality products and high level of yield variability.

Agriculture and food security are expected to be highly impacted from the increasing heat and water stresses, land degradation and resource depletion [1] which will likely overburden rural economies in South Africa [7]. In a semi-arid environment such as the Limpopo Province of South Africa, where smallholder agriculture is usually rainfed, the reported impacts of these climatic stresses are already evident on rangeland degradation and livestock production [8]. Livestock production is an important agricultural activity in the rural areas of the province, with the natural pastures (rangelands) and crop residues serving as the main sources of feed, especially during winter dry months. However, the supply of good quality and quantity feed from the rangelands and crop residue cannot be sustainably maintained during the winter and early spring months mainly because of low and erratic rainfall in preceding summer season [9]. The adoption of feed supply systems that are more productive, efficient in resource use, resilient to climate risks and have less variability and greater stability in their outputs in the Limpopo Provinceis required if productivity in crop and livestock farming system is to be maintained.

The national Department of Agriculture, Land Reforms and Rural Development has embarked on LandCare Programmes as an effective avenue to achieve sustainability in the smallholder farming system in South Africa. LandCare is a community based and government-supported approach to the sustainable management and use of agricultural natural resources with the overall goal of sustainable productivity, food security, job creation and better quality of life for all. The programme is implemented through five focus areas, namely: VeldCare (Rangeland), SoilCare, WaterCare, JuniorCare and Conservation agriculture (CA). Conservation agriculture, which promotes permanent or semi-permanent organic soil cover, zero or minimum tillage, and agro-biodiversity in association (intercropping or agroforestry) or sequentially (crop rotation) [10] is one of the practical and affordable location-specific adaptation strategies to address global climate change.

Regarding cropland diversification, agroforestry is being promoted as a feasible strategy that can be adopted by resource-poor farmers to cope with climate change [11]. To optimise the benefits of agroforestry interventions, an approach where CA practices are combined with the establishment of woody perennial species in agroforestry system could significantly improve the productivity of farmers amid climate change in the Limpopo Province. A key aim of the agroforestry system is to enhance positive interactions between its component species leading to the achievement of a more ecologically diverse and socially productive output from the land than is possible through conventional agriculture.

Reported advantages of agroforestry system in conservation agriculture include the restoration of soil health which is pivotal for increasing agricultural productivity, improved supply of fodder for livestock and enhance economic benefits [12, 13]. The recent understanding of global climate change and its consequent impacts on food security and humanity has given credence to Agroforestry as an important climate-smart practice for farmers. The system has a strong ability to sequester carbon and mitigate climate change while increasing the socio-economic and environmental sustainability of smallholder farming system. Furthermore, agroforestry can contribute to the achievement of several listed Sustainable Development Goals (SDGs) and achieve national developmental imperatives.

Additional benefits of agroforestry are improved livelihoods through enhanced crop and livestock health and nutrition, increased economic growth and strengthened environmental resilience and ecosystem sustainability. The diversification of farm enterprise through agroforestry minimises the risk of complete loss of income, in extreme weathers especially from annual crops which are more vulnerable to such harsh conditions relative to the woody perennial component species. Through long-term carbon sequestration, soil enrichment and biodiversity conservation can be enhanced. The prolific root growth of tree species in agroforestry systems builds spongier soils to increase soil's capacity to soak up heavy rainfall and hold the water for dry periods.

Despite the reported benefits of agroforestry systems, the adoption of the techniques among farmers in the Limpopo Province has been suboptimal. Factors that influence the adoption of agroforestry is reported to vary between studies, and as such, further enquiry into adoption process under local scenario is critical to understanding the effectiveness of the system within a community [14]. Currently, locally generated information on agroforestry practices under conservation agriculture in the Limpopo Province is limiting. A survey study conducted by Ayisi, Belete [15] however, indicated that most farmers in the province have a keen interest in adopting agroforestry as a landuse option. The incorporation of fruit trees and fodder species were identified as some of the preferred species by farmers for agroforestry.

To scale out the adoption of agroforestry in the farming system in the Limpopo Province and to address fodder flow constraints among farmers, detailed information on growth, yield, quality of potential fodder species and their overall impacts in conservation agricultural systems in the province is required. *Moringa oleifera* and *Acacia karoo* (*now Vachellia karroo)* are identified as potential tree species that can be cultivated for fodder in the province, with moringa being the most preferred. Moringa is a fast-growing tree species which can reach up to 6–7 m within a year under low rainfall of at least 400 mm per annum [16]. It is also known forits resistance to drought and diseases and also establishing well under harsh growing conditions where most trees cannot withstand [17]. *Moringa oleifera* can be cultivated in all five districts of the Limpopo Province under diverse climatic conditions [18]. In comparison with two dominant indigenous tree species, Mopane (*Colophospermum mopane*) and Marula (*Sclerocarya birrea*), moringa was reported to be superior in photosynthetic rate and stomatal conductance under drought conditions, indicating its potential for climate change mitigation [18].

Vachellia karroo (*formerly Acacia karroo*) is a leguminous indigenous species that easily grow under a wide range of habitats. As a result, it can become an aggressive invader on farmlands and grazing areas. Several areas of the Limpopo Province have already been severely invaded by the species. The carrying capacity of grazing areas and grassland productivity can also be reduced significantly from invasion mainly due to tree-grass competition for soil moisture [19].

Despite its invading characteristics and thorniness, *Vachellia karroo* leaves, pods and seeds are valuable feed supplements during the dry season [20] as they are at times collected by farmers to feed their livestock. Livestock farmers in the Limpopo Province are thus, already knowledgeable about the value of *Vachellia karroo* as a livestock feed supplement but detailed information about its impact on their livestock productivity and quality, particularly goats is limiting. Identifying effective ways of using *Vachellia karroo* will greatly improve smallholder livestock productivity in the province whilst addressing the environmental impact caused by its invading characteristics.

The current approach to controlling the invasion of *Acacia species* in the province is by mechanical and chemical means, controlled fires and the use of goats to browse on the species. Clearing of *Vachellia karroo* on rangelands has been reported to increase of grass productivity [21]. Any additional approach which can utilise the pruned biomass from the *Vachellia karroo*after mechanical control for livestock feeding will be beneficial. Furthermore, if a reduced amount of *Vachellia karroo* is left on defined areas of the rangelands, the increased quantity and quality of the grass in combination with the invader *Vachellia karroo* legume will constitute a workable tree-livestock pasture system to address feed gap for the livestock farming communities in the Limpopo Province.

This study was initiated to promote agroforestry systems among smallholder farmers in the Limpopo Province of South Africa, following two key objectives: First, to understand the reason behind the lack of adoption of agroforestry by farmers as a landuse option to adapt to climate challenges despite the numerous government's interventions. Secondly, to report on results from local on-station and on-farm experiments about the potential of *Moringa oleifera* and *Vachellia karroo (formerly Acacia karroo)* as agroforestry fodder tree species in combination with conservation agriculture practices to address feed gaps in the province.

2. Materials and methods

2.1 Study location

The study was conducted in the Limpopo Province of South Africa. The Limpopo Province is currently divided into five administrative districts, namely Vhembe, Capricorn, Waterberg, Sekhukhune and Mopani with 29 Local Municipalities across the districts (**Figure 1**). Though, the province has a wide range of annual rainfall, ranging from <300 mm to >1000 mm, most parts are relatively dry receiving an annual rainfall of around 400 to 500 mm. Part of the study with field experimentations was conducted at the University of Limpopo experimental farm (Known as Syferkuil) and Itemeleng Bamakhutjwa Farmers' Cooperative (Ofcolaco) during 2014–2015.

2.2 Climate

The Limpopo Province is characterised by hot summer temperatures and cooler winter months with annual rainfall around 500 mm. The spring season starts in September whereas winter commences in June. The monthly temperature and rainfall recorded during the period of experimentation at the two locations are presented in **Figure 2**.

The project objectives were achieved through on a combination of several activities including meetings with relevant stakeholders and farmers, workshop deliberations, review of pertinent government documents and field experimentation. With the assistance of the provincial department of agriculture, farmers engaged in conservation agriculture across the different districts and local municipalities of the province were selected for the study. Farmers from all the five districts participated in the study, thus presenting diversity in the agroecological conditions (rainfall, temperature and soil) under which they are farming.

The approach used to achieve the two project objectives are presented as follows:

a. Resistance to the adoption of agroforestry

Information about the study sites is presented in **Table 1**. The survey was conducted from November 2016 to May 2017 using a quantitative structured

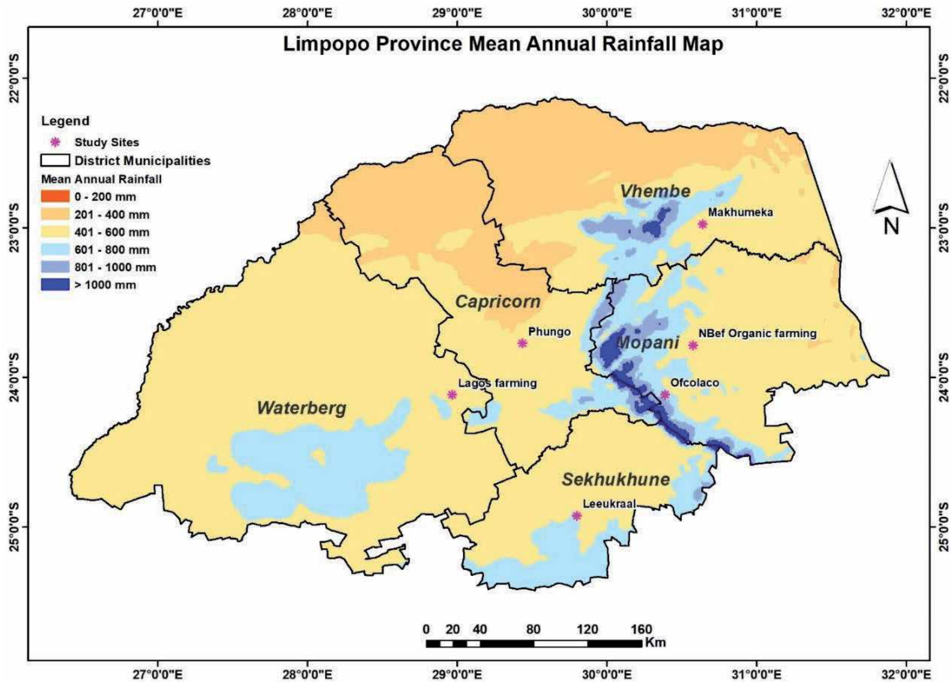
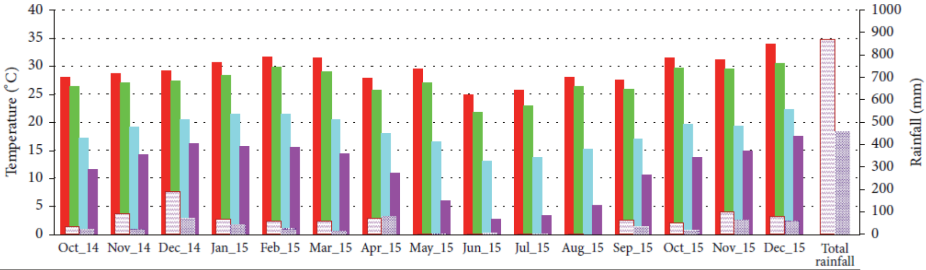


Figure 1.
The administrative districts of Limpopo Province showing annual rainfall and study sites.



	Oct_14	Nov_14	Dec_14	Jan_15	Feb_15	Mar_15	Apr_15	May_15	Jun_15	Jul_15	Aug_15	Sep_15	Oct_15	Nov_15	Dec_15	Total rainfall
Max temp: Ofcolaco	28.05	28.72	29.22	30.58	31.7	31.54	27.78	29.57	24.93	25.7	28.02	27.56	31.44	31.11	34.01	
Max temp: Syferkuil	26.35	27.04	27.44	28.37	29.88	29	25.68	26.97	21.75	22.85	26.38	25.93	29.6	29.55	30.57	
Min temp: Ofcolaco	17.12	19.16	20.43	21.37	21.49	20.44	17.97	16.5	13.07	13.67	15.2	17.06	19.67	19.3	22.26	
Min temp: Syferkuil	11.5	14.23	16.22	15.65	15.56	14.32	10.86	5.91	2.75	3.38	5.16	10.53	13.65	14.82	17.51	
Rain: Ofcolaco	34.04	93.47	191.77	66.02	60.19	60.45	69.59	0.25	0.51	0.25	1.27	62.21	50.54	100.59	79.76	870.91
Rain: Syferkuil	21.08	23.37	70.12	43.68	24.13	14.98	81.28	0.25	4.57	1.52	0	32.26	17.28	64.26	60.19	458.97

Figure 2.
Weather data recorded during the 2014 and 2015 field trials at Syferkuil and Ofcolaco.

questionnaire to gather all relevant information from the categories of farmers listed in **Table 1**. Focus group discussions and field observations were also conducted to validate the data obtained from the farmers. The questionnaire included open-ended questions which were valuable in allowing farmers to freely express their opinions about the adoption of agroforestry in their conservation agricultural practices. The farmers selected had previously been trained in climate-smart and conservation agricultural technologies.

b. Field trials for tree fodder assessment

Following the analysis of farmers' perception on the adoption of agroforestry as a valuable landuse option for climate change mitigation, the reliable supply of

Farm	District Municipality	Local Municipality	Current Farming Activity	Farming system	No. of farmers	Coordinates
Trichardsdaal: Ofcolaco	Mopane	Maruleng	Maize, Vegetables, Drybean, Mangoes and litchis Pigeon pea, Cattle and goats	Irrigated and dryland	38	S 24 06 45.68 E 30 23 15.85
NBef Organic farming	Mopane	Ba-Phalaborwa	Moringa, and Vegetables, tree lucerne	Irrigated Organic farming	12	S 23 47 00.2 E 30 34 28.7
Phungo Livestock Farm, Palmietfontein	*Capricorn*	Polokwane	Sheep and goats raised on rangeland with grass and Acacia shrub.	Dryland	4	S 23 46 14.24 E 29 26 05.13
Lagos farming cooperative	Waterberg	Mogalakwena	Goat production raised on rangelands and moringa.	Irrigated and dryland	2	S 24 06 50.68 E 28 57 56.82
Leeukraal farm in Nebo	Sekhukhune	Makhudumathaga	Dryland maize and sorghum production, cattle and goats raised on rangeland	Dryland	48	S 24 55 22.15 E 29 48 00.05
Makhumeka Irrigation scheme	Vhembe	Thulamela	Conventional vegetable, maize and mango production.	Irrigated	25	S 22 58 23.2 E 30 38 20.3

Table 1.
Information on survey study conducted in Limpopo Province.

livestock feed from agroforestry tree species to address feed shortages emerged as one of the key focus areas that farmers are determined to pursue. To facilitate the incorporation of agroforestry fodder in the farming activities in the Limpopo Province, a review of the limited field studies on *Moringa oleifera* and *Vachellia karroo* that have been conducted in the province and their potential as a feed source for livestock farmers is reported here.

2.3 *Moringa oleifera* trial

2.3.1 Study site

The moringa trial was established as a randomised complete block design (RCBD) at two locations in the Limpopo Province, namely the University of Limpopo experimental farm at Syferkuil and farmers' field at Ofcolaco, Trichardsdaal Mopani District 2014 to 2016 to assess the effect of planting density and cutting interval on aboveground biomass production and nutritional quality of *Moringa oleifera* under different climatic conditions. The densities examined were four levels, namely, 435,000, 300,000, 200,000, and 100,000 plants ha^{-1} under four replications. Planting was carried out on 07 to 15 December 2014 at the two locations.

Irrigation was applied for four hours twice a week using a sprinkler irrigation system until the sixth week to encourage good tree establishment, afterwhich the study was allowed to run under rainfed conditions. Weather data were collected throughout the trial from Syferkuil and at a weather station located less than 10 km from the experimental area at Ofcolaco. During the course of the study, the experimental units were well maintained by removing weeds manually with hand hoes. Insect pest and plant disease incidences were not observed during the study. To reflect the financial constraints experienced by the local smallholder farmers, no fertiliser was applied in this study. The initial physical and chemical properties of the soils under test were determined at a depth of 0–30 and 30–60 cm using an auger to identify their nutrient status.

Aboveground biomass was harvested manually with pruning shears from a 2.5 m^2 area when 90% of the plants within an experimental unit reached a height of at least 50 cm, measured from ground height of 10 cm above the ground surface. The height of plants was measured from five plants selected randomly from an experimental unit prior to harvesting the biomass. The measurements were made between ground level and the tip of the uppermost leaf of the plant. Biomass harvesting from main plant and regrowth occurred in all four seasons, Summer, Autumn, Winter and Spring designated as H1, H2, H3 and H4.

Moringa leaf samples, dried at room temperature (24∘C) for 72 hours, and then further oven-dried for 48 hours at 65∘C until the samples had reached constant dry weight were ground to pass through a 2 mm sieve. Ten grams of a fine fraction was used to determine their chemical composition. Crude protein was determined using the Kjeldahl method [22]. Other minerals such as P, K, Ca, Mg, Mn, and Zn were determined using atomic absorption [23].

Data were analysed using the standard analysis of variance procedure with the Statistix version 10.0 to determine the effect of planting density and harvest frequency on measured variables. Where significant *F*-values from the treatment effect were found, means were separated by the least significant difference (LSD) at a probability level of 0.05. Linear correlation and regression analyses were performed using Microsoft Excel to determine the relationship between cutting frequency and biomass yield.

2.4 *Vachellia karroo* trial

2.4.1 Study site

The study was conducted at the University of Limpopo experimental farm at Syferkuil in 2015 to access the impact inclusion of *Vachellia karroo* in the diet of indigenous Pedi goats on palatability indices, feed intake, digestibility, body weight change, carcass characteristics and histological parameters. Fresh leaves of *Vachellia karroo* were hand-harvested at the University of Limpopo Experimental farm using pruning shears in summer (November 2014 to January 2015). The leaves were air-dried under the shade to minimise nutrient loses to ultraviolet rays [24]. The leaves were separated from the branches by shaking them off gently after drying, leaving the thorns behind. The leaf meal was stored until feeding time. *Setaria verticillata* (a bristle grass) hay was obtained from a local farmer and included in the study. The dried leaves of both *Vachellia* and *Setaria* were milled using a hammer mill (13 mm screen) to reduce diet selection by the animals when fed.

2.5 Results, discussion and analysis of fodder agroforestry practices

2.5.1 Farmers perception on agroforestry adoption

Following the analysis of responses from 129 farmers engaged in conservation agricultural programmes in the Limpopo Province of South Africa, the following could be deduced about the cultural practices and attitudes that contribute to resistance to the adoption of agroforestry development alternatives:

Limited land area per household which cannot accommodate trees. Majority of smallholder dryland farmers in the Limpopo Province operate on parcels of land ranging from 1 to 3 hectares. Despite their willingness to grow trees, there is a general feeling among the farmers that trees occupy large space which could limit the production of the main crops of interest. Land constraint to adoption of agroforestry practices has been reported by Kabwe, Bigsby [14].

Lack of land ownership for long term investment in the woody perennial species. Control of land in rural communities in South Africa is by the Traditional Leaders. Farmers are usually given a temporary permit to produce crops on allocated parcels of land which are valid for 1 to 3 years. The lack of long-term security of land ownership is a major constraint to farmers that are engaged in conservation agriculture. This constraint has been reported by other authors [11]. The authors recommended that long-term, secure tenure and access to significant land is a key prerequisite if smallholder farmers in rural communities are to adopt and reap the benefits from agroforestry.

Extension service for CAwT is sub-optimal in most rural communities of the Limpopo Province. This is partly attributable to the fact that conservation agriculture is a relatively new concept in the province and hence the agricultural extension personnel are not well equipped in this area to effectively render the desired service to farmers. Capacitating the extension service in CAwT will invariably increase awareness and contribute to the uptake of agroforestry systems by farmers. In a study in other parts of Africa, it was observed that a group of female farmers and youth showed significant uptake in agroforestry and an increased in agroforestry planting across fields in villages receiving extension services was evident.

Inadequate water in drier areas for successful cultivation and management of beneficial woody perennial species was mentioned as a constraint. Water is the major resource limiting crop production in the Limpopo Province. To address this, a good understanding of the sources and patterns of tree water uptake is crucial to better understand how trees influence the local water balance and the productivity of an agroforestry system. This knowledge will also be a useful guide in the selection of component plant species for agroforestry systems.

Over-aged women in farming who though have deep knowledge about tress but are constrained by the physical strength required for farming. This problem is being addressed by the government through specific programmes targeting the youth.

Lack of improved germplasm to support agroforestry. Good cultivars of herbaceous crops such as grain crops as well as breeds of livestock exist for farmers to use in agroforestry systems. However, the availability of improved varieties and seedlings for the woody perennials in the system is largely lacking and this needs to be addressed. Farmers engaged in conservation agriculture receive good support from the provincial department of agriculture and land reforms in terms of seeds and other production inputs such as fertilisers and agrochemicals.

Farmers do not have access to credit facilities to satisfy the financial requirements of intensive agriculture including agroforestry. Farmers requested assistance from the provincial government in this regard.

The *interference of tree species with land preparation equipment* and *excessive shading* by large trees on herbaceous annual component crops which may reduce yields of the latter were mentioned by the farmers. This specific situation could be improved by the choice of the tree component, careful pruning and using the harvested biomass for livestock feed or mulch to improve soil organic matter, fertility and moisture-holding capacity.

Farmers indicated that there is a *lack of control over movements of livestock, mainly cattle* in their communities and the roaming animals will likely damage tree seedlings before they are well established. Furthermore, if palatable tree species are planted on their farmland, this will attract both domestic and wild animals leading to the destruction of their fragile fences. Protecting tree species against roaming livestock and wildlife during the juvenile stages until they are well established is an important consideration in the implementation of agroforestry by conservation agriculture farmers. However, the high demand for fencing to protect young tree and shrub seedlings from roaming ruminants is costly for farmers and hence the assistance the government is required.

Few of the farmers mentioned that dense stand of trees on their farmlands could attract snakes and pose a threat to the farmers and their children who occasionally assist them in the farm operations.

Despite the challenges outlined above, over 70% of the farmers interviewed expressed their desire to incorporating agroforestry in their conservation agricultural farming operations. The inclusion of fruit trees for income and fodder species to address feed shortages in dry winter and early spring months were the preferred technologies mentioned by the majority of the farmers.

2.6 Results from field experimentation

2.6.1 Moringa oleifera *trial*

A summary result from moringa planting density and fodder field trials conducted at the two locations in the province, Syferkuil and Ofcolaco revealed that dry matter production of moringa varied with location, planting density and biomass sampling stage. On average, more biomass was produced at Ofcolaco relative to Syferkuil (**Figure 3**). Biomass production generally increased with increasing density across the two locations at all sampling stages, with higher rates of increase occurring at the 481 sampling date at Syferkuil and the 56 and 366 DAP at Ofcolaco.

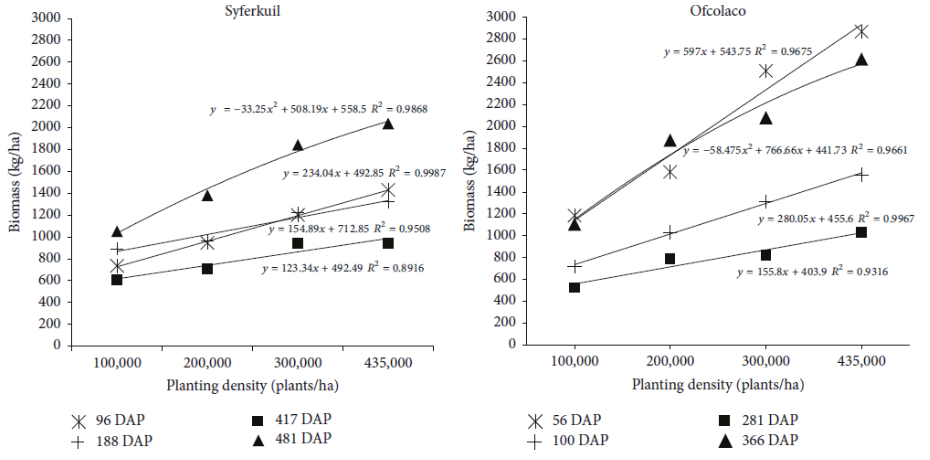


Figure 3.
Moringa biomass production as influenced by planting density and sampling stage at Syferkuil and Ofcolaco. (Extracted from Mabapa et al., 2018). H1 (Autumn), H2 (Winter), H3 (Summer), H4 (Spring).

Lower biomass was harvested at 481 and 281 DAP at Syferkuil and Ofcolaco compared to the other sampling dates. These periods coincided with the winter months where moringa dropped significant amounts of leaves, (*Extracted from Mabapa, Ayisi* [18]).

2.6.2 Seasonal influence on moringa biomass

Low temperature and drought such as experienced in winter and early spring periods of the Limpopo Province reduced moringa biomass production (**Table 2**) and nutritional composition (**Figure 4**). The mineral ion that was severely impacted was iron. To optimise the use of moringa as a nutrient source during winter and early spring when feed supply is severely constrained, the biomass can be harvested more intensely in summer and autumn months and stored for the winter period. Moringa should also be mixed with grass as feed inclusion to increase the volume of feed available to the livestock.

2.6.3 Nutritional value of moringa

The crude protein content of moringa leaves ranged from 27.96 to 33.74% at Syferkuil and from 16.32 to 30.3% at Ofcolaco. (**Table 2**). At Syferkuil, plant density and cutting interval did not influence crude protein (%), Ca, Mg, K, P, and Zn content. However, a decrease in iron content and an increase in manganese content were observed during the third harvest across all planting densities (**Table 2**). At Ofcolaco, cutting interval had a negative influence on the nutritional quality of moringa leaves mainly at harvests 3 and 4. The chemical properties affected by sampling interval were crude protein, K, P, Fe, Mn, and Zn content. At harvests 1 and 2, the chemical compositions were generally higher than later, although at harvests 3 and 4 these fell markedly (**Table 2**).

2.7 Vachellia karroo trial

The nutritional composition of *Vachellia karroo* leaves and *Setaria verticillata* grass hay is presented in **Table 3**.

Syferkuil	**96 DAP**	**177 DAP**	**417 DAP**	**481 DAP**	**$LSD_{(0.05)}$**
CP (%)	32.92	27.96	32.93	33.74	*ns*
Ca (%)	1.60	1.76	1.48	1.76	*ns*
Mg (%)	0.67	0.63	0.65	0.82	*ns*
K (%)	1.60	1.73	2.04	1.64	*ns*
P (%)	0.29	0.32	0.34	0.39	*ns*
Fe (mg/kg)	207.0	166.0	152.0	323.0	*74.45*
Mn (mg/kg)	65.00	61.00	86.00	61.70	*13.29*
Zn (mg/kg)	26.00	24.50	28.70	21.80	*ns*
Ofcolaco	56 DAP	100 DAP	281 DAP	366 DAP	*$LSD_{(0.05)}$*
CP (%)	24.20	30.3	17.02	16.32	3.49
Ca (%)	1.82	1.92	2.22	2.00	ns
Mg (%)	0.66	0.66	0.88	0.76	ns
K (%)	2.35	2.55	0.63	0.70	0.19
P (%)	0.47	0.58	0.18	0.17	0.02
Fe (mg/kg)	138.0	182.0	176.0	75.0	35.12
Mn (mg/kg)	95.70	82.60	100.1	98.10	2.89
Zn (mg/kg)	28.10	28.00	19.9	11.10	1.96

Table 2.
Nutritional value of Moringa oleifera leaves at 435000 plants ha^{-1} as influenced by sampling date at Syferkuil and Ofcolaco.

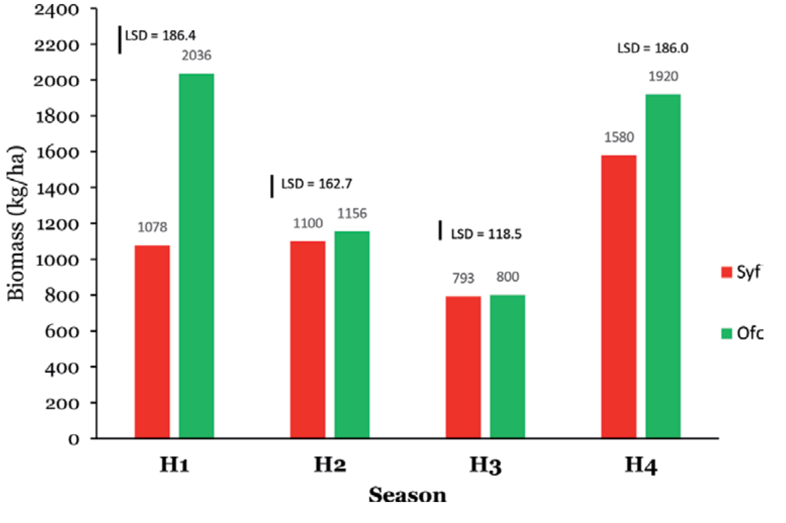


Figure 4.
Seasonal biomass production of moringa at Syferkuil and Ofcolaco across densities. H1 (Autumn), H2 (Winter), H3 (Summer), H4 (Spring).

V. karroo leaves have crude high protein contents, ranging from 10.65 to 14.65% (mean of 12.7%). The crude protein contents of *V. karroo* could support maintenance requirements and some production levels in ruminants, particularly, goats. Thus, *V. karroo* leaves have the potential of being a protein feed for ruminants, especially during the long dry season. The results of the palatability indices indicated

Nutrient (% DM)	*Acacia karroo* leaves	*Setaria verticillata* hay
Dry matter	97.1 ± 2.01	96.2 ± 0.40
Organic matter	92.1 ± 0.21	91.4 ± 0.12
Crude protein	12.7 ± 2.02	7.9 ± 1.12
Fat	2.4 ± 0.10	0.8 ± 0.01
Ash	7.9 ± 0.40	8.6 ± 0.31
Acid detergent fibre	32.5 ± 3.02	50.7 ± 4.01
Neutral detergent fibre	38.0 ± 4.01	77.9 ± 3.02
Condensed tannins#	2.0 ± 0.01	ND
Total Phenolics##	1.95 ± 0.001	ND

#: Condensed tannins as percentage DM leucocyanidin equivalent ##: Expressed as tannic acid equivalent (%); ND: Not detected

Table 3.
The nutritional composition of Vachellia karroo *leaves and* Setaria verticillate *grass hay.*

that diets with higher *V. karroo* inclusion levels had higher intakes and relative palatability rankings by goats, regardless of the higher condensed tannin and phenolic levels. Inclusion of *V. karroo* leaf meals improved nutrient digestibility and growth rate of goats. *V. karroo* leaf meal inclusion did not adversely affect goat meat tenderness, juiciness, flavour, taste, aroma and overall acceptability. Reduction in internal parasites and methane gas emission were also recorded in goats fed with tanniniferous *V. karroo*.

3. Concluding remarks

Climate change has become a threat to smallholder crop and livestock productivity in many rural areas of South Africa. To address this challenge, coordinated efforts in the implementation of workable technologies needs to be pursued. However, agricultural practices and technologies communicated to farmers in previous years by diverse stakeholders have not produced the desired results. In some situation, the information received has reduced farmers' awareness about the fact that their physical well-being depends, to a large degree on the way the natural resources are managed.

From the information gathered from the farmers, it is deduced that the general lack of knowledge about the benefits of woody perennial species in an agro-ecosystems does not encourage the adoption of agroforestry. Several farmers view the presence of trees on farmlands as an interfering, rather than a beneficial component. Additionally, in some rural communities, where members are aware of the benefit of certain tree foliage in livestock feed, farmers could not comprehend how the management operations should extend to the tree species.

For successful scaling out of this farming practice in the Limpopo Province, thorough training of participating farmers and all the relevant stakeholders will be required. Relevant research into management practices required for successful agroforestry interventions is also critical to the successful adoption of agroforestry in the province.

Planting *Moringa oleifera* at a relatively high density increased biomass production. A planting density of 435,000 plants ha^{-1} resulted in higher biomass accumulation at all sampling intervals. Moringa can thus, be planted by farmers at higher densities on their fields in an agroforestry system. Moringa can be harvested at a height of 50 cm above ground level, which facilitates mechanical harvesting, and while the stem is still pliable. The relatively high protein content of moringa leaves makes it an attractive fodder crop for farmers who are eagerly seeking a solution to address winter and early spring feed gaps. The crude protein content of moringa far exceeded that of *V. karroo* and that of *Setaria verticillata* up to 20 and 25 percentage respectively. *V. karroo* will thus be able to supply livestock farmers with satisfactory amounts of crude protein, to sustain productivity. The moringa tree is also rich in other nutrients, making it a potentially valuable source of feed supplement for livestock in the Limpopo Province. Furthermore, both *M. oleifera* and *V. karroo* have proven to be valuable species that can survive harsh growing conditions where most of the dominant natural quality natural quality grasses such as *Panicum maximum*, *Themada triandra* and *Urochloa mosambicensis* fail in winter months.

V. karroo leaves have the potential of being a protein feed for ruminants and its inclusion in the diet increased intake by goats regardless of the higher condensed tannin and phenolic levels. Leaf meals with *Vachellia karroo* improved nutrient digestibility and growth rate of goats and did not adversely affect goat meat tenderness, juiciness, flavour, taste, aroma and overall acceptability. Additional benefit recorded was a reduction in internal parasites and methane gas emission when goats were fed tanniniferous *V. karroo.*

With careful planning, research and education, specific agroforestry systems could be established in the different agro-ecological zones of the Limpopo Province to satisfy local livelihood and adaptation needs.

Acknowledgements

The authors express their gratitude to the Department of Science and Innovation, The National Research Foundation and the VLIR-IUC programme for their financial support for the conduct of the study. The contribution made by the Limpopo Department of Agriculture and Rural Development is also acknowledged.

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Chapter 5

Potential and Opportunities of Agroforestry Practices in Combating Land Degradation

Jag Mohan Singh Tomar, Akram Ahmed, Jahangeer A. Bhat, Rajesh Kaushal, Gopal Shukla and Raj Kumar

Abstract

Agroforestry an established practice for centuries is the deliberate combination of perennials with food crops and/or livestock either simultaneously or sequentially. Agroforestry systems are bio-diverse and are associated in numerous ways for combating desertification and mitigating climate change. Agroforestry practice is a possible way of reducing deforestation and forest degradation and can alleviate resource-use pressure on natural conservation areas. Among many other reasons responsible for climate change, our traditional approaches towards forest management have failed thereby giving way to a drastic climate change, which slowly but has indeed harbingered the cataclysmic future that awaits us if we do not act now. This paper thus acquaints the readers with the role of agroforestry in mitigating the soil erosion, rehabilitation of degraded lands, improving water conservation and replenishment of soil fertility. Besides, the role of agroforestry in improving the soil health and overall ecosystem has also been discussed. This paper furthermore, attempts to recognize the role that agroforestry can play in mitigating the repercussions of climate change apart from improving natural resource sustainability and future food security issues.

Keywords: Agroforestry, carbon, climate change mitigation, ecosystem services

1. Introduction

Population explosion worldwide is putting huge pressure on natural resources, which is creating our planet a precarious place to live. It is expected that by the end of the 21st century the world population will reach 8 billion and food required to feed the entire population will be about 120 M tons. It is estimated that by the year 2050 food demand will increase by 60% globally and 100% for the developing countries. Therefore, there is a pressing need to conserve natural resources like soil, water, and vegetation for future demands to accommodate the ever-increasing population growth. Climate change is threatening our very existence and is accepted as a vital issue in the 21st century. Increased emissions of greenhouse gasses due to anthropogenic factors are responsible for average increase in earth temperature and global climate change. Agroforestry has immense potential in mitigating climate change concerns by lessening global warming since vegetation assimilates the CO_2 gas in the process of photosynthesis which is one of the main contributors to greenhouse gases.

Agroforestry is a farming system that integrates crops and or livestock with trees and shrubs [1]. Agroforestry provides many benefits that includes favorable microclimate, reduction in erosion, enhanced biodiversity, increased water quality, more infiltration leading to effective groundwater recharge, enhanced and elongated dry flow, improvement in habitat, soil fertility, etc. Agroforestry is promising for a sustainable solution in response to soil conservation, land degradation, and also can bridge the gaps between climate change and mitigation strategies. Agroforestry has the immense capacity to provide sustainable agricultural benefits and approximately 1.2 billion people of the world is practicing agroforestry one way or the other way [2]. It has high potential to balance between the demands and requirements of population growth and natural degradation. The present review investigated the potential and opportunities of agroforestry in combating soil and water degradation and the role of agroforestry in climate change mitigation.

2. Mitigation of soil erosion through agroforestry

Topsoil on earth is the most productive, as essential macronutrients (N, P, K, Ca, Mg and S) and micronutrients (B, Cl, Fe, Cu, Zn, etc.) for plants are mostly found in topmost layers of the soil. These essential nutrients are required for completing the life cycle of plants. Soil erosion is a process in which topsoil is displaced from its location by different agents mainly water and wind. Globally, about 24 billion tonnes of fertile soil is lost annually through water erosion [3]. The soil pool loses 1100 Mt. C into the atmosphere as a result of soil erosion and another 300–800 Mt. C annually to the ocean through erosion-induced transportation [4].

It is expected that rainfall pattern will vary greatly due to global climate change and the effect of climate change will increase soil erosion. In India, the annual rainfall amount along with the frequency of high-intensity storm events will increase by 2030 compared to the baseline i.e. 1970 which will accelerate erosion and runoff. Nearing et al. [5] reported that an increase of soil erosion and rainfall amount is of the order of 1.70. Lee et al. [6] reported 2°C increase in annual temperature which will increase wind erosion by 15–18%. Therefore, without some improved practices like agroforestry, wind erosion is expected to accelerate in arid and semiarid regions. Windbreaks, alley cropping, and riparian buffers are especially designed to reduce wind erosion [7]. Thus, agroforestry will give more flexibility in socioeconomic and environmental service perspective in changing climatic situations. Vegetation with its canopy cover reduces the kinetic energy of the rainfall. The energy left with the falling raindrops depends on the height of canopy cover from the ground surface. It is reported that 4-meter canopy height decreases the kinetic energy by 80% [8]. Plant litter absorbs the rest of the energy of the falling rainfall which reduces the soil erosion to a certain level. The plant litter reduces the runoff by improving the infiltration and water holding capacity of the soils. The decomposition of plant litter, root decay, and exudation from the rhizosphere increases the organic matter content in soil and enhances the soil structure which is less prone to erosion.

Protecting the topsoil from erosion is of high priority for ensuring sustainable food production and food security. Agroforestry systems are widely accepted and agreed around the globe due to its influence on soil erosion control. Studies reported in the past concluded that developing countries have well-adopted agroforestry systems for controlling soil erosion from the steep slopes [9–14]. Alley cropping reduces soil loss to a great extent mainly due to its dense canopy cover which reduces the kinetic energy of falling rain. Alley cropping system is very effective in absorbing almost the entire energy of rain as the trees used in this system are mostly of short stature or shrubby. The shrubs form a barrier to runoff and take more time to infiltrate into the soil and thus less runoff. Soil loss is proportional to the square root of runoff volume, the less the volume of the runoff, the less is the transportation power of the runoff [15].

In Nigeria in an alley cropping system consisting of maize with Leucaena hedge results in soil loss only 76 kg ha^{-1} in comparison to No-till condition without Leucaena where soil loss was 10737 kg ha^{-1} [16]. In an experiment in north-western Himalaya at Dehradun, India (rainfall 1740 mm), the effectiveness of different barrier hedges, trees, and grasses on runoff and soil loss at 4% slope was studied (**Table 1**). Grasses were very effective in reducing soil loss despite with higher runoff (**Table 1**). Tree alleys are also effective in reducing the soil loss and runoff. Soil deposited in front of Leucaena based agroforestry system and Eucalyptus based system is represented in **Figure 1**, which represents that average deposition ranged from 15.77–28.5 t ha^{-1} in front of Leuceana hedges [17]. In Rwanda and Burundi

Treatment	Runoff (%)	Soil loss (t ha^{-1} yr.$^{-1}$)
Corn on contour	40	21
Leucaena hedges	21.3	12.1
Panicum (0.75 m wide)	36.7	7.0
Eulaliopsis (0.75 m wide)	42.7	10.0
Veteveria (0.75 m wide)	39.6	8.1
Leucaena trees (6–8 years)	20.4	8.4
Eucalyptus trees (6–8 years)	16.3	5.8

Table 1.
Effect of different barrier hedges, trees, and grasses on runoff and soil loss.

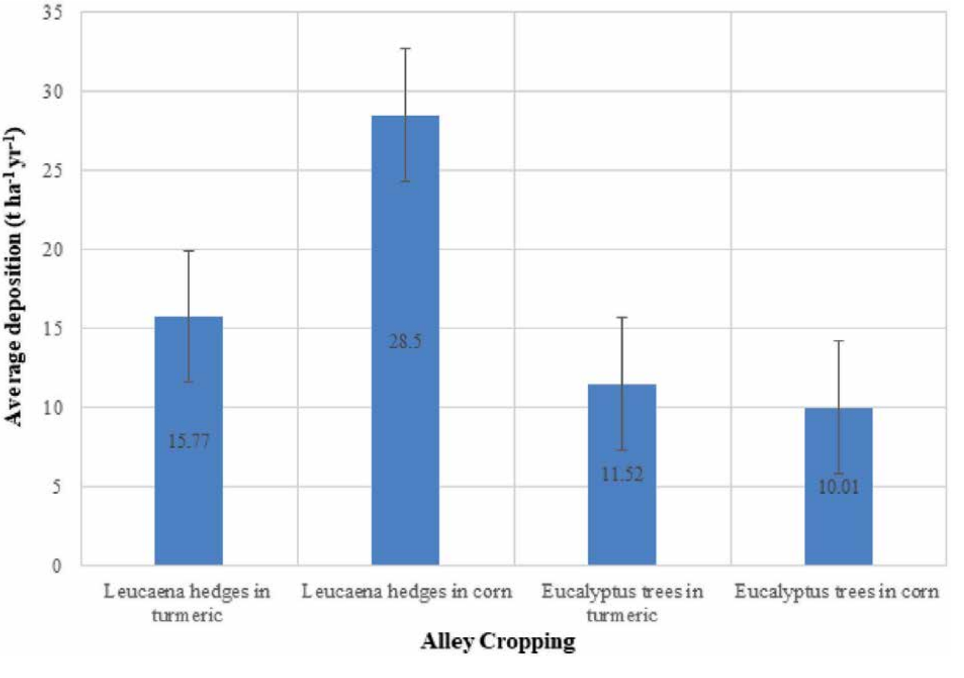

Figure 1.
Average soil deposition for different alley cropping system.

in ferrallitic soils (Ultisol) with rainfall, erosivity ranges from 250 to 700 on 20 to 60% slopes, soil loss ranges from 300 to 700 t ha^{-1} $yr.^{-1}$ in the form of sheet and rill erosion. However, surprisingly the runoff rate was only 10 to 30% of the rainfall. In these circumstances, agroforestry practices have been found suitable in reducing soil loss and produced enough biomass to mulch the surface as well as to increase soil fertility.

Numerous studies on soil loss and runoff for different agroforestry models have been carried out in Shivalik Himalayas in India. The soil loss and runoff of the agroforestry models i.e. Eucalyptus + bhabar grass, *Acacia catechu* + napier grass, Leucaena + napier grass, Teak + leucaena+ bhabar grass, Eucalyptus + leucaena + turmeric, poplar + leucaena + bhabar, Sesamum + rape seed are compared with cultivated fallow. The maximum and minimum soil loss and runoff were found in the case of Sesamum + rape seed and Eucalyptus + bhabar grass of 2.69 t ha^{-1}, 20.50% and 0.07 t ha^{-1} 0.05% respectively. For cultivated fallow land, the soil loss and runoff was 5.65 t ha^{-1} and 23% which was much more than the agroforestry models. The N loss was found minimum in Eucalyptus + bhabar grass model (0.46 kg ha^{-1}) and maximum in Sesamum + rape seed (42.50 kg ha^{-1}) whereas K loss was minimum in *Acacia catechu* + napier grass (0.52 kg ha^{-1}) and maximum in Sesamum + rape seed (3 kg ha^{-1}) respectively. In cultivated fallow land, the N and K loss was 51.30 kg ha^{-1} and 5.00 kg ha^{-1}respectively [18]. A study to understand the effectiveness of different pasture management techniques in reducing soil loss, runoff and nutrient loss (N & K) was conducted in Bundelkhand region of Central India. Runoff, soil loss and nutrient loss from pasture systems such as natural grassland, improved pasture, sown pasture and 3-tier silvopasture have been compared with respect to bare land. Results showed that among the pasture systems runoff, soil and nutrient loss was found maximum from the natural grassland i.e., 11.6%, 2.50 t ha^{-1}, 3.75 kg ha^{-1} $yr.^{-1}$ and 4.00 kg ha^{-1} $yr.^{-1}$ respectively and minimum soil and nutrient loss was found for 3-tier silvopasture system i.e., 1.27 t ha^{-1}, 1.27 kg ha^{-1} $yr.^{-1}$ and 2.10 kg ha^{-1} $yr.^{-1}$ respectively whereas runoff i.e., 9% was minimum for sown pasture.

Windbreaks/shelterbelts are very effective in arid and semi-arid regions specifically for wind erosion-prone areas. They comprised of single/multi rows/belt of trees which are planted in orientation perpendicular to the direction of wind. The belts of trees are very effective in ameliorating the microclimate and improving growth and yield of associated annual crops. Shelterbelt comprising of castor on the windward and shorter tree in leeward direction increased the yield of lady's finger and cowpea by 41% and 21% respectively than the control [19]. From different studies, it has been reported that shelterbelts reduce soil erosion by 50% [20].

Home gardens are also very effective in reducing soil erosion. Study conducted in Kerala (India) revealed that cardamom, pepper and mixed home gardens with coconut trees remarkably reduces the soil loss to 0.65, 3.55 and 1.45 t ha^{-1} respectively in comparison to soil loss 130 t ha^{-1} from land after removing forest canopy [21]. In an experiment in Nilgiris in India, runoff and soil loss was measured for 5 years (1959 to 1963) on 16% sloping land under five different vegetation cover viz., blue gum, black-wattle plantation, slola, broom, and indigenous grass. The runoff and soil loss data showed that blue gum cover produced the highest (1.08%) and grassland produced almost nil (0.018%) runoff.

3. Rehabilitation of degraded lands through agroforestry

Land degradation means the gradual deterioration of land quality in terms of agricultural productivity. An assessment by United Nations Development Programme (UNDP) showed that globally 40% of the land area comes under dryland out of which 29.7%, 44.3%, and rest falls in arid, semiarid, and dry sub-humid region respectively. The Food and Agricultural Organization (FAO) estimated that 43% of rangelands and 20% of cropping lands are degraded while Sub-Saharan Africa has the highest rate of land degradation. About 46% of land in Africa is affected by land degradation which suggests productivity loss of 20% over the last 40 years. About 68% of the land in Australia is under degradation while as in Asia about 25% of the land is vulnerable to degradation and will likely increase due to climate change issues. About 19.65 $Mkm^2$of the land worldwide is degraded out of which 10.94 Mkm^2 was caused by water. Many studies pertaining to agroforestry have been carried out in to tackle land degradation.

Increase in vegetation coverage is the fundamental approach to control land degradation. UNCCD (2004) revealed that forests and tree cover have potential combat land degradation and desertification by stabilizing soils, reducing water and wind erosion and maintaining nutrient cycling in soils. Different agroforestry systems have been designed after years of research for different categories of degraded lands. These agroforestry systems not only provide higher productivity but are also capable of conserving the resources efficiently. Silvipasture systems have been found to be very successful on degraded lands. Eucalyptus trees in combination with *Eulaliopsis binnata* harnessed almost all the runoff and trapped all soil inside the field except in 1988 when rainfall was extremely high than other years (**Table 2**). In the reclamation of the salt-affected area some of the tree species such as *Acacia farenesiana*, *Tamarix articulate*, *Propsopis juliflora*, *Pithecellobium dulce* and *Parkinsonia aculeate* were found to very effective [22]. In the reclamation of alkali soil, *Prosopis juliflora* (2 mx 2 m) + *Leptochloa fusca* was found most effective alone with the production of 161 t biomass and 56 t ha^{-1} grass in six years [22]. However, in alkaline soils at Dhipura (Madhya Pradesh, India), it was found *P. juliflora* not only increased the OC content but also enhanced the essential mineral content to great extent after 9 years. *Propopis chilensis* (Mesquite) tree was found to be effective in reducing pH, EC, and exchangeable Na level and increasing infiltration characteristics, OC, total N, available P, exchangeable Ca, Mg and K levels [23, 24]. Eucalyptus tree as reported with high transpiration rates was found very effective in reclaiming waterlogged areas [24].

Natural causes like forest fire, avalanches, landslides, flooding, and anthropogenic activities such as deforestation, overgrazing, construction works, unscientific farming in hills resulted in excess soil erosion and land degradation [25, 26]. A 4 ha landslide-prone area at Nalotanala on Dehradun-Mussoorie road in India, agroforestry plantation of *Ipomoea carnea*, *Vitex negundo* and napier with *Erythrino suberosa*, *Dalbergia sissoo* and *Acacia catechu* successfully stabilized the area after 10 years of practice. [27]. Acharya and Kafle [28] reported that due to continuous soil erosion

Parameters	Years				
	1985	1986	1987	1988	1989
Air dry grass yield (t ha^{-1})	1.2	8.6	1.5	5.1	4.1
Mean Eucalyptus height (m)	1.5	4.7	6.7	8.4	10.5
Mean Eucalyptus DBH (cm)	1.2	4.3	5.5	6.6	7.4
Runoff (mm)	—	—	—	10.01	—
Soil loss (t ha^{-1})	—	—	—	0.17	—
Monsoon rainfall (mm)	686	905	313	1586	934

Table 2.
Different parameters related to Eucalyptus and Bhabar agroforestry system.

in up-hills in Nepal, the bed levels of *Terai* river were increasing 35–45 cm annually [29]. Govt. of Nepal has leased the degraded forest lands and the tax-free lands to families below the poverty level for the reclamation of the degraded lands [30].

4. Soil moisture conservation and water quality improvement by agroforestry practices

Trees in the agroforestry system can increase the crop yield by conserving soil moisture through mulching. Soil moisture availability is higher under trees than open areas and the agroforestry system increases the infiltration characteristics of the soil and thus, it traps more water and increases the soil water content. In the arid region, Kumar et al. [31] observed the effect of soil water availability on *Hordeum vulgare* (barley) yield is compared for various agroforestry models with *Prosopis cineraria*, *Tecomella undulate*, *Acacia albida* and *Azadirachta indica*. It was found that *P. cineraria*, *T. undulate*, *A. albida* and *A. indica* increased crop yield by 86%, 48.8%, 57.9%, and 16.8% over the control. It is well proved that the agroforestry system improves the quality of the groundwater compare to the cropping system most of the applied nutrients are leached out which pollutes the groundwater [32]. Deep-rooted trees used in agroforestry consume the excess nutrients applied in the crop field. Therefore, acts as a filter and releases water with fewer nutrients and reduces groundwater pollution.

Seobi et al. [33] studied the effect of agroforestry and grass-legume buffers on soil hydraulic retention and soil physical properties for Putnam soil (fine, smectitic, mesic Vertic) in corn (*Zea mays*)–soybean (*Glycine max*) field in northeastern Missouri in USA from 1991 to 1997. Agroforestry buffers used for the experiment were 4.5 m wide and 36.5 m apart. The trees and grasses used in agroforestry buffers were redtop (*Agrostis gigantean*), brome (*Bromus spp*.), and birdsfoot trefoil (*Lotus corniculatus*) with pin oak (*Quercus palustris*, swamp white oak (*Q. bicolor*), and bur oak (*Q. macrocarpa*). Soil samples were collected from buffers and crop fields using core samplers up to 40 cm with a 10 cm interval. Pressure starting from 0 to −33 kPa was applied to soil samples and corresponding water content was noted. Results showed the grass and agroforestry buffers can store 0.9 cm and 1.1 cm more water for top 30 cm soil in comparison to the row crop. The reason for the increased soil water content in the agroforestry and grass buffer system may be attributed to the enhanced porosity. Thus, it increases the infiltration characteristics of the soil and reduces runoff.

The land is being cleared in arid and semi-arid regions of Australia to meet agricultural development by clearing the native forests. However, gradual salinization is being a problem of those lands due to rising groundwater level. In a study in two different experiment sites in Western Australia, the reclamation of those lands is carried out by using pinus (*Pinus radiate* & *P. pinaster*) - pasture and eucalyptus (*E. sargentii*, *E. wandoo, E. camaldulensis and E. calophylla*) -pasture agroforestry measures. Site 1 has an area of 76 ha out of which agroforestry covers 47 hectares whereas site 2 has an area of 30.25 ha out of which 17.24 ha covered with agroforestry. The long-term annual rainfall and pan evaporation for site 1 were recorded as 717 mm and 1800 mm respectively whereas for site 2, annual rainfall and pan evaporation was 713 mm and 1613 mm respectively. Results showed that groundwater level in site 1 was decreased by 1 m relative to the groundwater level in pasture land whereas in site 2 decreases in groundwater level were 2 m over the period 1979–1989. The salinity level is also found decreased by 9% and 6% for site 1 and site 2 respectively in comparison to the initial stage [34]. It is expected that due to less water availability caused by climate change will affect 2.7 to 4 billion people worldwide by 2050 [35]. Climate change will affect the water quality in terms of sediment, nutrients, dissolved organic carbon, pathogens, pesticides, and salt content in water [36]. In this scenario of changing climate, agroforestry practices will act as a remedy and will enhance the micro-climate, reduce runoff and evaporation, and also increase the soil moisture content and groundwater level and thus agroforestry practice will increase the water availability and food security guarantee.

5. Agroforestry promising for soil fertility replenishment

The role of the agroforestry system in enhancing and maintaining soil fertility and productivity and sustainability has been well documented [37]. Even those trees which do not fix N, enhance soil physical properties which helps in crop growth. Maintenance and enhancement of soil fertility levels are necessary for regional and global food security purposes. Several studies are reported and proved that from agroforestry system nutrient loss is less as compared to the agriculture farming. Grewal et al. [38] have reported that leucaena-napier grass allowed less nutrient loss compared to the traditional agricultural system. There was net gain of 38 kg N, 10 kg P, and 20 kg K as compared to the net loss of 15 kg N, 2 kg P and 14 kg K ha^{-1} in the traditional agricultural system. In a study with *Acacia nilotica* + *Saccharum munja* and *Acacia nilotica* + *Eulaliopsis binate* the soil organic carbon was found 0.91% and 0.99% after 5 years [39]. Tomar et al. [40] reported the effect of green manuring with different agroforestry tree species on dry matter yielding and production as well as post-harvest fertility of low land rice (*Oryza sativa*) in India. The green leaves of the tree species viz., *Erythrina indica*, *Acacia auriculiformis*, *Alnus nepalensis*, *Parkia roxburghii* and *Cassia siamea* at 10 t ha^{-1} were applied in rice fields during the rainy season of 2008 to 2010. The dry matter and paddy yield from those fields were compared with the fields which were treated with recommended $N\text{-}P_2O_5\text{-}K_2O$ (80:60:40 kg ha^{-1}) and control (no fertilizer and manure). The soil of the field was sandy clay loam, acidic, low in P content (6.95 kg ha^{-1}), medium in N (277 kg ha^{-1}), high in K (258 kg ha^{-1}), and OC (2.56%) respectively. In 1st and 2nd year of study, the grain and straw yield was higher in NPK plot (**Table 3**). However, in 3rd-year grain and straw yield was higher in green-leaf manure plots. *Erythrina* tree leaf manure was found superior among the other tree leaf manures. Application of green leaf manure increased the available soil NPK increased more compared to recommended $N\text{-}P_2O_5\text{-}K_2O$ dose and control. Therefore, based on the above observation, it could be said that plant residues can have long term implications in maintaining soil fertility without decreasing the crop yield. In arid and semi-arid regions, *Prosopis cineraria* in low intensity about 120 trees ha^{-1} increases the N level of soil. It is also used as a source of animal feed, fuel, timber and intercropping with millet and legumes increase the grain yield [41].

In an alley cropping system red alder (*Alnus rubra*) in maize experiment at Oregon in the USA, it was found that 32–58% of total N in maize was transferred from N fixed by red alder and more transfer obtained when the distance between red alder and maize is less [42]. Avasthe et al. [43] reported that large cardamom (*Amomum subulatum* Roxb.) based agroforestry practice was found effective in conserving soil, water, and nutrients in the fragile mountain ecosystem of Sikkim Himalayas in India in comparison to a mixed forest and traditional maize-soybean-mustard cropping sequence. In this agroforestry system, cardamom is grown under the shade tree *Alnus nepalensis* which fixes atmospheric N. OC, available N, K except P was found higher in the soil in cardamom based on agroforestry system compared to maize-soybean-mustard cropping sequence. On the other hand, soil loss and nutrient loss in the soil also found less in large cardamom based

Treatments	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Organic carbon (%)		N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	2008	2009	2010	2008	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Erythrina	4.48	4.83	5.67	6.55	7.12	7.77	2.98	3.15	320.1	323.3	12.18	13.06	292.7	294
Alnus	3.50	4.10	4.67	5.66	6.11	6.45	2.95	3.06	295.3	309.7	9.42	11.72	296.0	295
Parkia	4.13	4.40	5.24	6.20	6.85	7.16	2.90	3.00	288.7	314.1	10.67	12.85	271.4	282
Acacia	3.92	4.66	5.30	5.83	6.90	7.49	3.05	3.18	299.3	307.5	11.20	12.31	274.8	278
Cassia	3.99	4.55	5.58	5.83	6.69	7.46	2.90	3.12	318.8	322.5	12.37	13.20	280.2	298
N-P_2O_5-K_2O	4.82	5.08	5.13	6.88	7.34	7.05	2.90	2.91	281.0	297.0	8.56	10.25	273.9	277
Control	2.80	3.13	3.35	4.18	4.75	5.04	2.80	2.80	269.4	270.7	7.39	7.20	253.8	265

Table 3.
Paddy grain and straw yield and post fertility status of the soil due to the application of tree leaves and N-P2O5-K2O fertilizer in compared to control.

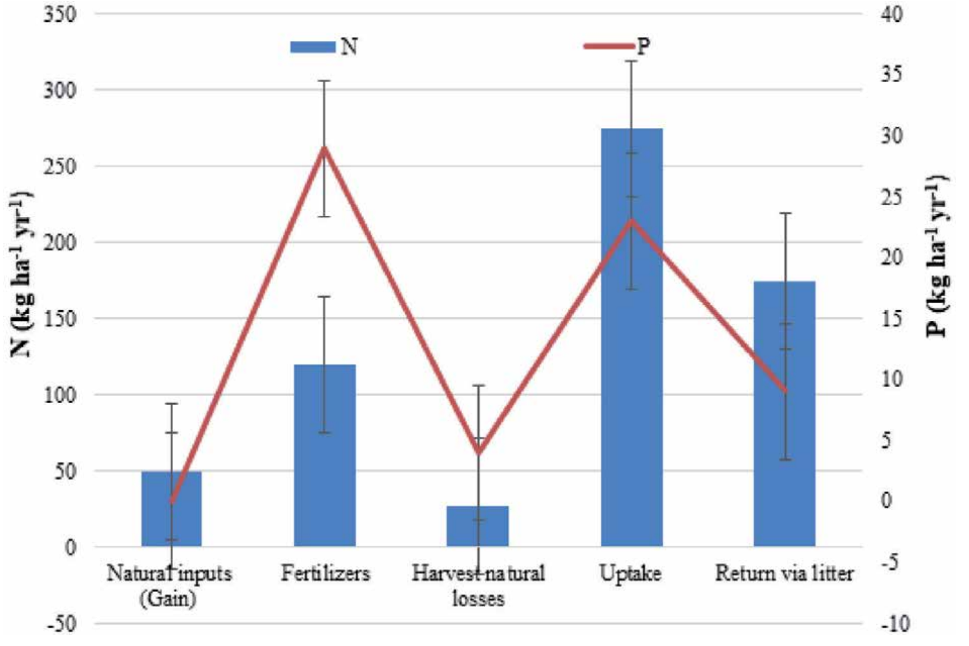

Figure 2.
Nutrient cycling in Coffee-Erythrina-Inga agroforestry.

agroforestry system than maize-soybean-mustard cropping sequence. In a study N and P gain, loss, uptake and return via litter in coffee-Erythrina-Inga agroforestry system was estimated [44] as shown in **Figure 2**.

In semi-arid region of India for neem-based agroforestry system, the annual litterfall was estimated as 6059 kg ha^{-1} from 400 neem trees which returned 98, 2.25, 3.2, and 131 kg ha^{-1} of available nitrogen, phosphorous, potassium, and calcium to soil [45]. Kang et al. [46] reported the comparative efficiency of pruning of *Gliricidia sepium* and *Leucaena leucocephala* in increasing the nutrient level in the soil. They found that *Leucaena* pruned compost is more efficient in increasing the nutrient level of soil compared to *Gliricidia*. Singh et al. [47] reported that the agroforestry system is more effective in increasing soil fertility than crop-based system. Patel et al. [48] reported that *Sesbania rostrata* fixed 307 kg N ha^{-1} whereas *S. cannabina* fixed only 209 kg N ha^{-1} in a shifting cultivation discarded area. In the north-eastern region of India, *Bambusa nutans* trees found effective in binding the soil nutrient in abandoned *Jhum* cultivated land [49, 50]. In arid region in Rajasthan in India, the soil microbial biomass C, N and P were found more in the agroforestry system than in soil with no tree [51].

6. Interference of agroforestry in soil health management

The agroforestry system increases the soil infiltration capacity. In an experiment, it was reported that the infiltration capacity of soils which were mostly clay to silt clay in texture and acidic in nature were in the order of Eucalyptus, Bhabar, Eucalyptus + Bhabar, and agricultural plot. The infiltration rate was about 3 times in Eucalyptus + Bhabar than the agricultural plot [52]. The effects of five agroforestry systems on soil physical properties have been investigated in the ICAR complex for the north-east region in India. The name of the agroforestry systems are Khasi mandarin (*Citrus reticulate* Blanco.) + annual agricultural crops;

Assam lemon (*Citrus lemon* L.) + annual agricultural crops; Arboretum (Mixed multipurpose tree species) + annual agricultural crops; Silvi-hortipastoral [alder (*Alnus nepalensis*) + pineapple (*Ananus sqennnsa* L.) + fodder and multistoried AFS [alder +tea (*Camellia sinensis*) + black pepper + annual agricultural crops]. The soil physical properties such as bulk density (BD), mean weight diameter (MWD) and apparent saturated hydraulic conductivity (AHC) were compared with the soil from the adjoining area of natural forest soils of same age. The mean bulk density of soil from natural forest was least (0.94 Mgm^{-3}) and highest for Khasi mandarin and Assam lemon (1.19 Mgm^{-3}). The bulk density was less for natural forest and other agroforestry systems due to heavy litter fall and decay of dead roots resulting in high organic carbon content [8]. Soil aggregates were represented with MWD which was observed highest for natural forest i.e., 3.13 and lowest in case of Assam lemon i.e., 1.39. The value of MWD is in the order as natural forest>multistoried AFS > Silvi-hortipastoral>Arboretum>Khasi mandarin>Assam lemon. The value of MWD was highest for natural forest due to more availability of organic matter content which helps in forming the aggregates. The reason for being a low value of MWD for Arboretum, Khasi mandarin and Assam lemon may be attributed to the frequent use of agricultural implements that disintegrate the soil structure. In all agroforestry systems, hydraulic conductivity was inversely related to soil depth. AHC signifies the rate of water movement through the soil profile. AHC was found rapid in natural forest (1.84 x 10^{-4} m/s) and least in case of Khasi mandarin system (0.38x 10^{-4} m/s). AHC varied for different agroforestry systems as Natural forest>multistoried AFS > Silvi-hortipastoral>Arboretum>Assam lemon> Khasi mandarin. This study concludes among the agroforestry system, multistoried AFS and Silvi-hortipastoral improves more soil moisture conservation capability, soil structure, and pore size distribution [53].

An increase in porosity was reported by Udawatta et al. [54] in the Midwest Region of the United States in maize-soybean field in conjunction with using agroforestry buffers. In grass and agroforestry buffer strips pore path was observed three and five times higher than in soil of maize-soybean field which may be a reason for increased infiltration rate. Pandey et al. [55] reported that the sand particles declined by 10% and 9%; clay particle increased by 14% and 10% under mid-canopy and canopy edge respectively compared to under canopy gap position. Silt particles quantity was not influenced by canopy position. Soil organic carbon, total N, total P were more under mid-canopy and canopy edge compared to the canopy gap. Seobi et al. [33] observed improved soil physical properties in agroforestry and grass buffer system in comparison to the row crop system.

7. Agroforestry in climate change mitigation potential

Agroforestry system acts as an atmospheric carbon sink and in carbon sequestration process, carbon is captured from the atmosphere and stored as carbon sink such as by oceans, vegetation and soils through certain biological and physical processes. Agroforestry system traps more atmospheric carbon compared to crop plants or pastureland [56, 57]. The capacity of agroforestry systems to sequester carbon depends on different factors such as tree species, age of tree, tree density, climate, geographical location, and management practices. In general, tropical humid climate sequestrates more carbon than arid, semi-arid, temperate region. On an average soil organic carbon pool in the soils of arid climate and cold region below 1 m depth is 30 and 800 tons ha^{-1} respectively. The total worldwide land area under agroforestry system is 1023 Mha which has potential to sequester carbon approximately 1.9 Pg over 50 years [58]. By improving the present management practices involved in agroforestry system, additional 17000 Mg year^{-1} carbon can be sequestrated by 2040 [59]. In another estimate, the area under agroforestry in world is 8.2% of total reported geographical area (305.6 m ha) and contributes 19.3% of total C stock under different land uses (2755.5 m t C) [60–62]. If worldwide present area of unproductive cropland and grassland of 630 Mha is converted to agroforestry which can harness additional 586000 Mg year^{-1} carbon by 2040. Riparian buffer, alley cropping and silvipasture system can sequester 4.7, 60.9, and 474 Tg C year^{-1}, respectively. Additional protection of farmland and cropland with windbreak can sequester additional 8.79 Tg C year^{-1}. Therefore, the agroforestry system in USA has a potential to sequester C as 548.4 Tg year^{-1}. By this way, agroforestry system in USA can trap 34% of greenhouse gas in the form of CO_2 [63]. In India, degraded land amounts over 100 Mha where only bushes and grasses grow only in monsoon season [64]. These lands are low in soil carbon and have ample scope to increase the soil carbon by planting proper tree species and grasses with proper management practices. In India, potential of agroforestry system in storing C is estimated 2400 m tons. It is estimated that the total area under agroforestry in India is 8.2% which contributes 19.3% of total carbon under different land uses [20]. Newaj et al. [65] found that *Albizia procera* under agro-silviculture system sequestered C more than in a pure tree. In this system, 2 crop rotations i.e. black gram-mustard and green gram-wheat were used. Three pruning treatments (70% canopy pruning, 50% pruning, and un-pruned) have been applied. After 3 years, it was found that sequestered carbon amounts 27.97, 22.96, and 21.33 t ha^{-1} in the un-pruned tree, 70% and 50% canopy pruning in agro-silvicultural system. In a homegarden with bamboo farming system in Assam India, the aboveground average carbon sequestration estimated as 1.32 Mg ha^{-1} yr.$^{-1}$ [66], while the presence of organic C was 30% and 114% greater in home gardens in comparison to the coconut plantations and rice fields [67]. Howlett et al. [68] found in a silvipastoral system in northeast spain a greater level of organic C in birch (*Betula pendula*) in comparison to pine (*Pinus radiata*). The reason is attributed to the fact that the subsoil environment created by pine is less conducive for plant growth and decomposition is reduced and the organic C built over time is less. In a study at Bahia, Brazil aboveground and below ground C sequestration had been studied under cacao (*Theobroma cacao* L.) based agroforestry system (AFS). In this cacao-based AFS, cacao was planted with woody species for shade such as *Erythrina spp.* and *Gliricidia spp.* or under these in natural forests. Cacao cultivated under natural forest trees is known as cabruca. The huge amount of belowground C accumulation is due to a large amount of leaf litter, decomposition roots of both cacao and woody trees. It is estimated that total amount of C stored in cacao based AFS in Bahia below 1 m depth was 302 Mg ha^{-1}. It has been reported that shade trees (55 trees ha^{-1}) in cabruca system stores 44% more carbon than the Erythrina trees (35 trees ha^{-1}) though the mean C stored by cacao + Erythrina and cabruca system was similar with a mean of 39.27 Mg ha^{-1} [69].

8. Ecosystem services from agroforestry systems

According to the 2005 Millennium Ecosystem Assessment, human beings are relished by supporting, regulating, provisioning, and cultural services from the ecosystem. They have become the most widely used framework to study the relations between ecosystems (including natural and human-modified ecosystems) and people [70]. Agroforestry has been demonstrated to combine production with multiple ecosystem services and goods [71] it provides multiple ecosystem services, combining the provision of agricultural, livestock and forestry products with regulating services, cultural services and supporting services. In this context, there is a general need to gain more insight into the overall, total functioning of an agroforestry system i.e., a broad picture of the simultaneous and multiple services provided by such a system.

Agroforestry is a viable land-use option that, in addition to the socio-economic benefits, offers several ecosystem services in the face of different environmental and social challenges [37, 72]. Agroforestry promotes multiple ecosystem services like improvement in soil quality, water conservation by slowing down surface run-off, reducing sediment transportation, soil biodiversity, enhances carbon sequestration, and increases diverse food and cover for wildlife habitat [73, 74]. However, being these services much interlinked so are difficult to measure autonomously but agroforestry has the potential to promote economic, environmental, social vitality, and land stewardship [73]. Sileshi et al. [75] while working in eastern and southern Africa reported that when agroforestry properly designed and strategically located, and the practices of agroforestry can contribute to ecosystem services by mitigating land degradation, climate change, and desertification while adding structural and functional diversity to the agricultural landscapes in the Miombo eco-region. Trees on farms can prevent environmental degradation and provides healthy system for human welfare [76]. However, agriculture has changed enormously in the second half of the last century, driven by agricultural policy and technological progress. Trees that characterized many agroecosystems across the globe have been lost to a large extent [77, 78]. Although, promoting the concept of ecosystem services, to better understand the diverse ecosystem services provided by agroforestry is very important to know. In Ethiopia, agroforestry was credited as a sustainable farming practice that uses and conserves biodiversity and limits agricultural expansion into natural forests [79]. However, this farm-based conservation of biodiversity was only recently advocated by the Convention on Biological Diversity [80–82]. If managed properly, agroforestry holds promise for ecosystem services and environmental benefits. The practices of agroforestry can be considered an adaptive strategy in areas with increasing climate variability and can serve as viable carbon sinks as they trap and store carbon.

9. Conclusion

Agroforestry provides goods and services from trees and reinstates degraded lands. The agroforestry system has the potential for making habitats for edge species conservation of remnant intrinsic species and their gene pools. In the wake of food scarcities and predictable climate change, the practices of agroforestry are gaining attention from the researchers and policymakers as a lucrative approach to develop food security, while at the same time backing to climate change adaptation and mitigation. However, to achieve the target of sustainability, we need to practice agroforestry with improved water management and innovative practices. Climate change will intensify constraints by creating weather more inconstant and will influence the yield by a further decrease in average yields worldwide. Changing food habits with an increase in population and water and land scarcity are also long-term trends that threaten our shared vision of a more prosperous future in which well-fed people everywhere can achieve their full potential without damaging their environment. Agroforestry can improve the resilience of agricultural production to current climate variability as long-term climate through the use of trees for intensification and diversification and buffering of farming systems.

Funding

This work was carried out without any funding.

Conflict of interest

No potential conflict of interest was reported by the author(s).

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Chapter 6

Farm-Forestry, Smallholder Farms and Policy Support – The Way Ahead

Vinod Chandra Pande

Abstract

Farm forestry, interchangeably used for the term agroforestry, encompasses growing trees and/or shrubs on farms, mainly to support agricultural production and supplement farm income on smallholder farms. This, as a bonus, also provides for ecosystem services *viz.*, protection of soil and water resources, biodiversity enhancement, carbon sequestration, and improvement in landscape values to the farm holding. In Indian context, this encompasses raising trees mainly on bunds or field boundaries on small holdings or sometimes intercropped in an agroforestry type configuration, if holding size is bigger. The techno-economic viability of this system has been extensively assessed and wide adoption, therefore, warrants a conducive policy support at local and community level. Governments have framed enabling policies towards this goal; however, desired outcome is still awaited. This study attempts to map out the present development and suggest the measures required at local and community level to make the government policies more fruitful. Policies framed at macro level need recalibration to suit local and community specific requirements in the changing climatic conditions for wider adoption and sustenance.

Keywords: farm forestry, smallholder farms, climate change, policy implication, adoption

1. Introduction

Agro-forestry, encompasses growing trees and/or shrubs on farms, mainly to support agricultural production and supplement farm income on smallholder farms, where agricultural production is the major livelihood support and yet most vulnerable to climate change [1–5]. The smallholder farms occupy world's farmland ranging from 62% in Africa to 85% in Asia [6] and, therefore, invulnerability support to these farms makes sense and promotion of agroforestry holds promise. In fact, diversification to agroforestry from monocropping has occupied prominence as monocropping annihilates nutrients from the earth and leaves soil week and incapable to support healthy plant growth. This enhances dependency on chemical fertilizers to support plant and crop growth. These problems are to a great extent addressed, apart from others, by shifting from mono cropping system to tree based system [7]. Crop diversification to agroforestry is, in fact, necessitated by socio-economic and environmental problems arising from mono-cropping.

The decision is largely governed by dynamic and sustainability factors such as soil health, soil degradation, environmental benefits and nutrient loss prevention [8–12]. Conservation of natural resources such as water and soil on smallholder farms is, among others, also a significant reason for introducing agroforestry considering the water footprint of crops [10]. This is crucial in a climate change scenario as the smallholder farms mostly bear the brunt of this phenomena. In fact, agroforestry has been recognized as an efficient tool to address the issues of climate change by IPCC [13]. The importance of smallholder agroforestry should, in fact, be reinforced with increased attention and resources to climate change adaptation and mitigation, possibly linked to climatic variables such as rainfall and CO_2 levels, to protect forests while simultaneously expanding tree growing on farms [14–16]. Agroforestry land use, in fact, enhances the provision of ecosystem services such as carbon sequestration [17], watershed protection and biodiversity. These positive externalities could be spatial, for example watershed protection for downstream users, or temporal, such as soil health and land rehabilitation.

Despite importance of agroforestry and the support it has received world over, much remains to be done to promote it in developing countries, for example, for enhanced fuelwood in countries like Ethiopia and Bangladesh. Large areas need to be planted with trees alongside crop for improved catchment protection in the agricultural landscape of India. There is, in fact, a need for shifting to a potential agroforestry cropping system from mono cropping system. The change suggested should also essentially address the income, employment and viability concerns of local stakeholders, particularly smallholder farms, for larger adoption. These farms have limited capacity to adapt to climate change due to various constraints such as low education levels, low income, limited land areas, and poor access to technical assistance, market and credits, and often chronic dependence on external support [18, 19]. The decision to shift is largely governed by dynamic and interactive factors such as agronomic and environmental characteristics, economic and policy considerations, skills and personal attributes of farm managers, and social concerns [20, 21].

2. Farm-forestry and climate

Agriculture is vulnerable to the vagaries of climate change, and smallholder farmers are most susceptible to its impact. It is projected that cereal yields may change by −5 to +2.5 per cent across different regions (**Table 1**).

Agricultural practices helpful in mitigation of climate change, such as agroforestry production system is one such hope, particularly in tropical climate. Climate variability is well buffered by agroforestry because of permanent tree cover and varied ecological niches, that is, the presence of different crops, *e.g.* shade-tolerant and light-demanding. The diversified temporal and spatial management options make agroforestry resilient. Permanent tree cover protects and improves the soil, while increasing soil carbon stocks (**Table 2**). Diversification of commodities allows for adjustment to market needs. The non-harvested components of agroforestry production play an important role to protect soil and local environment. In fact, carbon sequestration by trees contributes to climate change mitigation. The efficient integration of natural resource capture and use in agroforestry contributes to high greenhouse gas mitigation [9]. Overall, the sustainability attributes of agroforestry make a strong case for climate change adaptation. Because of their root and woody biomass, in the agro-ecosystems, along with the food, fiber, energy and vegetative soil cover, the agroforestry production systems are sustainable in the changing climate conditions.

Region	Percentage change	
	2020	2050
Sub-Saharan Africa		
Sahel and southern Africa	−2.5 to 0	−5 to +5
Central and East Africa	0 to +2.5	−5 to +2.5
Latin America and the Caribbean		
Tropics and subtropics	−2.5 to 0	−5 to −2.5
Temperate	0 to +2.5	0 to +2.5
Near East/North Africa	−2.5 to +2.5	−5 to +2.5
South Asia	−2.5 to 0	0 to −5
East Asia	−2.5 to +2.5	−2.5 to +2.5
Canada and the United States	−5 to +2.5	−10 to 0

Source: Parry et al, *1999 [22].*

Table 1.
Potential change in cereal production across regions.

Agroforestry system	Carbon storage potential
Agri-horticulture	12.28 tC/ha
Agri-silviculture	13.37 tC/ha
Silvipasture	31.71 tC/ha
Silvopastoralism	6.55 Mg/ha/yr

Source: Toppo and Raj, 2018 [23].

Table 2.
Carbon storage potential of some agroforestry systems.

The climate change priorities of agroforestry models encompass trees to ameliorate the impact of climatic variability and extreme weather events on agricultural productivity and the farm resource base. It contemplates diversification of farming enterprises by producing products and services that are independent of traditional agricultural markets, produce fewer emissions and are less susceptible to climatic variability and carbon dioxide sequestration in living biomass, soils and woody products as a means of offsetting agricultural emissions and providing marketing and partnership opportunities. In addition, there are ecosystem services viz., producing carbon-neutral green energy (bio-fuels) and carbon-storing/low energy building material (wood), expanding and linking natural habitats to support biodiversity adaptation and reducing the impacts of extreme weather events on agricultural production.

This approach, however, largely emphasizes the local climate mitigation/adaptation, as the value of planting trees for climate change has been driven by notions of carbon sequestration and trading. This overlooks the immediate value of trees on farms and the role they might play in helping farmers remain viable. Further, the climate change, particularly the temperature increase suggests that selection of tree species in agroforestry may be crucial in the mitigation of climate change. What worked in the past, including the local indigenous species, may not be right for the future. Therefore, identification of suitable species for region specific applicability is paramount to wider dissemination of agroforestry production system.

3. Farm-forestry and smallholder farms

In order to cope with extreme climate variation, many smallholder farmers are already implementing practices that maintain complex agrobiodiversity and a higher capacity of their production units to resist such risks [24, 25]. Yet the poor tree cover in agricultural land, world over, suggests poor adoption despite economic viability and environmental benefits of agroforestry systems [26]. Several issues plague the much-desired adoption level at farmers' end. The low adoption of agroforestry, despite huge potential, is explained, among others, by the lack of regulations and guidelines related to harvesting, transportation and marketing of agroforestry produce [27]. The smallholder farms, in particular, suffer from low quality infrastructure *viz.*, access to markets, financial assistance, disaster relief, technical assistance or government support [19] due to remote location in developing countries.

The long rotation of trees hinders their adoption on farms as forest policies in countries like India inhibit harvesting, transport and marketing of certain trees species declared as prohibited species. This discourages farmers in taking tree enterprise in their farms. The purpose of such policy is well intentioned but lacks in desired encouragement to stakeholders in large scale adoption of farm forestry.

Property rights, particularly land tenure, has been suggested to greatly affect adoption of agroforestry on smallholder farms. While longer gestation of tree enterprise along with the annual crop enhances profitability and environmental sustainability of farming, it warrants right to land to encourage farmer to invest in agroforestry, apart from other factors.

There are no supports for agroforestry-based land use practices, similar to those in crop production and inputs such as fertilizer, credit for smallholder farms, which discourages them going for tree-based crop production on their small holdings. In fact, the policy support for fertilizer encourages more fertilizer use rather than going for agroforestry which builds nutrients in the soil over a period of time.

The poor extension system in updating farmers' knowledge regarding sustainable tree-based land management also discourages farmers in larger adoption of agroforestry on their farms in developing countries. Farmers' traditional practice of growing trees on field boundaries does not support the farm profitability and environmental sustainability. Innovative and new ways of managing trees on farms (*e.g.* intercrop systems for soil health) are not yet known to the vast majority of farmers. The combination of suitable tree species with the cropping systems practiced by them needs scientific/technical backup not only about choice of tree species but also the desired silvicultural practices.

Although farm-forestry projects fail for a number of different reasons, one common factor is the inadequate attention given to socioeconomics in the development of systems and projects [28]. The socio-economic studies of agroforestry systems have revealed the vulnerability of farm profit in medium to longer term to output prices. With gestation period of more than a couple of years, the smallholder farmers are not convinced enough to adopt them. Because of higher initial establishment costs, the net capital inflow in the initial years, in agroforestry, is not favorable even for tree species of short duration. This is also true for agri-horticultural plantation where fruit bearing occurs some years later [29]. The right combination of crop and tree species is, therefore, crucial to win the faith of stakeholders.

4. Policy reforms promoting agroforestry/farm-forestry

The policy reforms directly targeting the expansion of agroforestry have experienced good success world over (**Table 3**). The re-interpretation and

Country	Programme	Ministry	Activities
Rwanda	Rwanda agroforestry and action plan 2018–2027	Ministry of Environment	Roadmap for promoting leadership and synergies in agroforestry
India	The India National Agroforestry Policy 2014	Ministry of Agriculture and Farmers Welfare	Providing a platform for converging the various tree planting programs outside of forest areas
Ethiopia	Ethiopian National Watershed and Agroforestry Multi-stakeholder Platform	Ministry of Agriculture and Livestock	Facilitates stakeholder linkages within and among national, regional, and international agroforestry and watershed networks
Niger	Reinterpretation and implementation of the Forest Code	Ministry of Environment	Strengthening on-farm tree access, reduced punitive punishment for tree cutting, discussion on acess rights
Ghana	National Agroforestry Policy 1986	Ministry of Food and Agriculture	Supporting research (adaptive trials and demonstration), training and extension education
Nepal	National Agroforestry Policy 2019	Ministry of Agriculture and Livestock Development	Site specific appropriate agroforestry systems and species, availability of planting material, credit and insurance for agroforestry plantation
Brazil	The National Program for Strengthening Family Farming 2003	Ministry of Agrarian Development	Refining financing mechanisms, enhancing training of extension agents
EU	Rural Development Policy 2007–2013	Agriculture and Rural Development Ministry of member states	Capital investments, grants to businesses and training for improvement of agriculture, forest and forestry products
USA	Agroforestry Strategic Framework 2019–2024	U S Department of Agriculture	Supporting research, tools and information for adoption of agroforestry

Source: Bernard et al*, 2019; Chavan et al., 2010; USDA, 2019; Smith, 2010 [13, 30–33].*

Table 3.
Agroforestry policy and reforms.

implementation of the Forest Code in Niger leading to expansion in farmer managed natural regeneration to over 5 million hectares of land [34] is good example. Similarly, granting communities the long-term rights to forest land in return for environmental stewardship of the land (HKM programme), in Indonesia, created a village forest concept (HutanDesa) providing villages rights to benefits of carbon or other environmental services [35]. In response to deforestation, increase in agricultural land area and to motivate farmers for planting trees, the Government of Kenya, in 2009 enacted new Farm Forestry rules requiring farmers to cover 10% of all farms with trees. Guatemala simplified the Forest Act, 1966 regarding procedures for timber harvesting in agroforestry systems resulting in diversification of land use by farmers in their farms as another source of income [36]. Several other countries developed or modified the agroforestry policies. Brazil refreshed agroforestry policy of 1997. The United States Department of Agriculture (USDA) developed an Agroforestry Strategic Framework 2011–2016 [37]. France passed an agroforestry policy, in 2010, to establish agroforestry as a legal agricultural land use qualifying for European Commission agricultural subsidies in the framework of the common agricultural policy (CAP). This helped farmers receive investment support for the establishment of the agroforestry systems on agricultural lands [38]. Asian countries like China (Grain for Green) and India (Greening India) have also embarked on ambitious programs to increase tree cover outside of forests, including some attention to smallholder agroforestry by providing necessary support such as providing market and/or establishing floor price for agroforestry product.

Development programs, such as National Adaptation Programs of Action (NAPAs) and Nationally Appropriate Mitigation Actions (NAMAs), as a result of increased attention to climate change, have helped advance agroforestry in some countries. Agroforestry has been recommended to make agricultural production and income more resilient to climate change and variability, transformations in the management of natural resources (*e.g.* land, water, soil nutrients, and genetic resources), resulting in higher efficiency in the use of these resources and inputs for production. Agroforestry, for climate-smart agriculture, is now considered as one of the strategies along with institutional and policy options to promote the transition to climate-smart agriculture at the smallholder farms [39]. The Comprehensive African Agricultural Development Programme (CAADP) endorsed an agriculture climate change adaptation and mitigation framework highlighting agroforestry in 2010. The United Nations Framework Convention on Climate Change (UNFCCC), similarly, recognized agroforestry as a key climate mitigation method within agriculture [40]. The African ministers of agriculture, in the same manner, endorsed wide scaling up of agroforestry to address climate change adaptation and mitigation objectives in agriculture in 2009.

The recognition of agroforestry in development programs and the reforms enacted highlight the good intention of the planners and policy makers world over. There are several case studies corroborating the resultant impact of the reforms and strengthening the belief on agroforestry production system, yet the evidences fall short of universal replicability due to poor adoption by and large. The climatic and bio-physical constraints, apart from socio-economic constrains, still hinder the desired spread of the successful models across the globe. The region-specific approach to address the issues need further studies to understand the constraints,

Barrier	Mean[1]	SD
Does not seem profitable	2.46	1.5
Lack of information on agroforestry	2.44	1.44
Not familiar with technology	2.3	1.56
No market for agroforestry products	2.29	1.51
Lack of seedlings	2.29	1.47
Lack of technical assistance	2.28	1.48
Lack of demonstration sites	2.25	1.52
Trees use much water	2.22	1.41
Insufficient land	2.04	1.32

[1]*Scale: 1 = most important barrier, 2 = important barrier, 3 = less important barrier, 4 = least important barrier, 5 = not a barrier.*
Source: Faulkner et al*, 2014 [41].*

Table 4.
Barriers to adoption of agroforestry technologies.

yet some broad consensus on general issues, based on the literature, have been extensively highlighted for limited farmers such as smallholders (**Table 4**).

5. Policy reforms implications

Policy reforms in agroforestry has played an important role in promoting agroforestry in different regions/countries differently. The policy reforms have helped promote agroforestry, at macro level, in facilitating adoption and expansion, yet there remains some concern related to, among others, tree germplasm multiplication and dissemination, long term private property rights over land and trees, recognition of agroforestry as an attractive investment area within agricultural institutions and programme. Some of these are outside the domain of agroforestry reforms, yet these are crucial for success of agroforestry reforms.

High quality seedlings production and supply across the farms which need quality trees is crucial. There is good involvement by governments in many instances. In some countries, governments have directly involved in providing seed and seedlings for tree planting efforts in non-agricultural areas to provide watershed protection services. The Ethiopian government, for example, has played an active role in all facets of upscaling tree planting including the establishment of government nurseries and sales at subsidized rates. The Kenyan government has, similarly, supported agroforestry tree seed and seedling supply to meet the newly enacted regulation that all farms must have 10% tree cover. Timber and fruit seedlings are being produced and sold by private sector nurseries, yet seed and seedling systems for tree systems are still not well privatized. The efforts still lack the up-scaling required to provide quality seed and seedlings to different agro-climatic regions. The efforts for local production and supply chain development is warranted with larger role at community and private level. Incentivization and technical back up of such units meeting requirements of region-specific demand of tree species needs a mass movement.

The likelihood of farmers' ability to adopt and reap benefits from agroforestry enhances with long-term tenure security to land [42] due to longer time periods required in testing, adapting and eventually adopting the agroforestry technologies and practices. Trees require lengthy periods to mature, and, therefore, the goods and services produced can affect the incentives for adoption, distribution of benefits, and the impacts leading to poor incentivization of the agroforestry production programme [43]. Absence of land secure rights have poorly impacted even the development of Payment for Ecosystem Services schemes [44], a self-sustaining model to promote agroforestry. Therefore, there is much to be done on this in several regions. While insufficient long-term rights to land have demotivated long term investment on land including agroforestry, this has also manifest itself as conflict between state and smallholder land users within *de jure* forest land such as in the Philippines and Indonesia.

Agroforestry is getting recognition in agricultural strategies, but often merely in a list of options for addressing sustainability. The capacity for agroforestry to generate income is hardly ever recognized in policy documents and, therefore, the associated policy support for its profitability at farms, particularly, smallholder is not quite evident. The micro studies conducted on agroforestry profitability provide ample evidence in favor of market linkage in general and price in particular. The long gestation period of tree harvest postpones the positive net returns flow because of higher initial costs of tree establishment. Smallholder farmers are quite susceptible to initial cash inflow and outflow in sustaining the production enterprise.

The price fluctuations, lack of assured market and poor accessibility to credit apart from other inputs adversely affect the profitability, cash flow and, in turn, perception about agroforestry production.

6. The way ahead

Agroforestry systems promoted through various policy interventions provide benefits such as wood products, fruits, fodder, and improved soil fertility which benefit farmers directly. Where farmers perceive private benefits the demand for agroforestry knowledge and germplasm is expected to be higher. In addition, there is more promotion of agroforestry for other benefits as well, such as for environmental services that accrue to broader society. Despite greater policy recognition of the importance of agroforestry, a number of constraints hinder wider adoption of agroforestry among smallholder farmers in developing countries, both at formulation and implementation levels.

Insufficient attention is paid to the needs of farmers regarding agroforestry trees as regards tree germplasm is concerned. Smallholder farms operate in tight budget constraints and therefore, tree species fetching good market price with shorter duration in combination of the local food crops is crucial to attract and sustain agroforestry enterprise. Of late, some efforts have been redirected exclusively to address this, yet much remains to be done. Similarly, agroforestry is getting attention in the climate change scenario, and this is much needed even in case of smallholder farmers, where more focus is required on tree species which serve the other objectives of small farmers. In particular, the tree species must also help increase their food security, increase or diversify their sources of income generation, take advantage of local or traditional knowledge, be based on local inputs, and have low implementation and labor costs. The agroforestry practices must be suiting to small holdings in combination with the traditional crops grown and meeting the profitability criteria to the extent possible.

While smallholder farmers may be motivated and supported with appropriate incentives to sustain the profitability of agroforestry on their marginal lands, the incentive systems for farmers to produce societal level benefits need to be established and clarified [45]. Payment for Ecosystem services (PES) have been extensively adopted in many regions but appropriate and sustainable models for a wider application is required for which extensive studies should be encouraged in different socio-economic set up. Government involvement in PES market is necessary in the context of smallholders particularly in developing countries. Involvement of corporate sector through Corporate Social Responsubility (CSR) fund is one possibility to promote tree species in agricultural landscape such as multinational company Unilever's investment in the upscaling of Allanblackia, a tree species producing oil with properties that are attractive for a range of food products [46]. The possibilities of a value chain development may be explored with focus on local tree species of a particular region by interlinking the interests of the private sector with appropriate forward and backward linkages with group of smallholder farmers. The initial success of Coca-cola, Pepsi, and Del Monte in food market chain in some African states may be upscaled in similar other areas by promoting enabling market and credit policies supportive of these partnerships between private company and smallholder farmers.

One of the ways to help smallholder farmers strengthen their farm-based livelihoods, in the face of the increasing stresses posed by climate variability, is to focus on helping them use farm management practices based on agro-biodiversity and ecosystem services that provide adaptation benefits. However, the existing policies undermining the maintenance and/or adoption of ecosystem-based approach that promote the simplification of agro-ecosystems, while increasing the use of agrochemicals and fossil fuel should be revisited. Agroforestry practices that help improve farming systems' profitability including increased resiliency to climate change should be promoted to support and protect the vulnerable group of smallholder farms.

Efforts are needed to support extension services to ensure smallholder farmers' access to best available information on adaptation strategies to enable them to make informed decisions in agroforestry production systems [47]. The agricultural extension programs, farmer field schools, agricultural technical programs that are going on in different parts of the world should be strengthened by the local, regional and/or the national governments especially for smallholder farmers under financial stress including climate change impact. The lackluster support to extension programs in many countries [48] need rigorous support in present time more than ever [49]. The farmer field schools and effective extension programs strengthen linkages and information exchange between technical institutions and smallholder farmers [47, 50]. Higher synergies among the efforts of NGOs, governments, scientists, private sector and the groups of farmers would go a long way in filling the extension services gaps and help promote suitable agroforestry practices [51].

7. Case studies

7.1 Family Farming Development Programme, Niger

The programme, implemented over several years in Niger, supported the resilient family enterprise and promotion of agro-sylvo-pastoral production [52]. This included natural regeneration of agricultural land with *Faidherbia albida*, watershed development, dune stabilization with *Acacia senegal*, restoration of pastoral land and establishment of hedge rows.

The interventions resulted in tangible and intangible benefits such as increased yields, volumes of produce marketed and resilience of agricultural system to drought and improved adaptation to climate change through positive environmental externalities viz., carbon sequestration and reduced carbon emission.

7.2 Sustainable agriculture, Indonesia

The farmers group 'Suka Maju' in Golo Ngawan village in the East Manggarai district on the island of Flores, Indonesia adapted sustainable agriculture with the support from local NGO Ayo. The interventions included land conservation and agroforestry to increase land productivity [53].

People initiated planting trees from the pea family and cash crops viz., cocoa, bananas, mahogany, cloves and *Gmelina arborea* and food crops on the terraced land. Following a patter, the inner side of the land was planted with cash crops and food crops. Calliandra, mahogany and *Gmelina arborea* were planted on the outer side of the land with 3 x 4 metres planting space between each tree. This resulted in increased the productivity of the land, through agroforestry, without requiring money and materials from outside the local area. Further, agroforestry prevented landslides and erosion, thereby, increasing the amount of water absorbed by the soil in the rainy season. Apart from sustaining income and food security, the agroforestry system improved the environment. The success of the system lead to its wider adoption in more areas in the region.

7.3 Grain for Green programme, China

The programme was introduced in 1999 in China, with the objective of improving grassland and forestry on slopes and included, among others, reforesting uplands to reduce erosion, downstream flooding and rural poverty. The was envisaged to be implemented by providing grain, saplings and/or subsidies, over a period to encourage up to 30 million rural households. To support this strategy, the forest law was revised to recognize the importance of compensation in return for environmental services.

The compensation and subsidy support ensured farmers' participation in spectacular development of agroforestry technologies mainly through fruit tree intercropping. Between 1999 and 2010, programme covered more than 15 million ha in 20 provinces [54].

8. Conclusion

Smallholder farms hold prominence world over, especially in Asia and Africa. Socio-economic constraints, apart from climatic stress, enhances their vulnerability making the livelihood difficult. Introduction of tree species provides cushion to production loss risks along with environmental benefits in climate change scenario. Many of the agroforestry practices are well known and have been proven to help smallholder farmers adapt to climate change, but current financial, political and technical constraints limit a more widespread adoption of these practices among smallholder farmers. The advantages of agroforestry, notwithstanding, the challenges and obstacles it faces adversely affects the desired adoption. Despite the fact that trees become profitable as they produce positive net present values over time, the breakeven point for agroforestry systems takes longer time. Similarly, markets for tree products are both less efficient and less developed than for crop and livestock commodities and value chains related to agroforestry systems receive little support.

While agricultural policies offer incentives for agriculture that promote certain agricultural models, such as monoculture systems, and tax exemptions are usually aimed at industrial agricultural production, agroforestry production enterprise, by and large, gets second hand status. Agricultural price supports or favorable credit terms, which are granted for certain agricultural activities but hardly ever for trees, are also discouraging agroforestry adoption.

Further, the conventional agroforestry methods and insufficient knowledge of sustainable production models, including germplasm, restrict the inclination of policy-makers in agroforestry development. The resources dedicated for research, dissemination, market information and propagation of quality germplasm, crucial for wide adoption of agroforestry practices fall short of the desired expectations. The existing land tenure practices also results in confusion about land delineation and rights, discouraging people from adopting and continuing agroforestry practices. In many developing countries, lack of long-term rights to land inhibits long-term investments including agroforestry. Further, forest regulations preclude tree growing on farms by restricting the harvesting, cutting or selling of tree products.

In absence of coordination between sectors, *viz.*, agriculture, forestry, livestock, rural development, environment, energy, health, water and commerce, agroforestry promotion suffers from policy conflicts and omissions, creating gaps or adverse incentives that work against its development. The various conflicting objectives within and between the different departments adversely affects agroforestry. It is high time a synergistic coordination is evolved between farmers, government, non-government and corporate entities at local community level with market inter-linkages to sustain the interests of farmers as well as private enterprises. Providing tax incentives to private/corporate entity and easing harvest, transport and price policy at farmers level holds promise.

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Edited by Gopal Shukla, Sumit Chakravarty, Pankaj Panwar and Jahangeer A. Bhat

The book is a collection of chapters that deal with agroforestry systems on small farms. It compiles a variety of suitable agroforestry systems that can both sequester carbon and mitigate climate change while also providing socio-economic benefits. The book also discusses the ways in which small landholders can use agroforestry to combat land degradation.

Published in London, UK

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ISBN 978-1-83962-731-6