8 Agroecological farming approaches that enhance resilience and mitigation to climate change in vulnerable farming systems

Mehreteab Tesfai, Alamu Oladeji Emmanuel, Joyce Bakuwa Njoloma, Udaya Sekhar Nagothu, and Ngumayo Joel

Introduction

Current farming systems rely heavily on the intensive use of external resources and inputs such as water, mineral fertilizers, and pesticides to increase agricultural production (Bernard and Lux, 2017). Such farming systems have caused severe degradation of land water resources, soil depletion, increased outbreaks of pests and diseases, biodiversity loss, decline of ecosystem services (ESSs), and high levels of greenhouse gas emissions (e.g., FAOSTAT, 2020). There is a widespread recognition and growing concern that agricultural approaches based on *high-external inputs and resource-intensive farming systems* cannot deliver sustainable food and agricultural production (e.g., FAO, 2018) and it is likely that 'planetary boundaries' will even be further exceeded by such systems (e.g., Struik and Kuyper, 2017). Hence, more sustainable and affordable production methods are needed to protect and optimize the Earth's natural resources, while increasing productivity, adaptation, and mitigation to climate change. At the same time, the assumption is that sustainable agroecological farming systems provide several economic, environmental, social, and health benefits, and are the main prerequisite for food and nutrition security (e.g., Nguyen, 2018).

In recent years, key actors including regional governments, international agencies, civil society, and non-governmental organizations have demonstrated their commitments *to a new paradigm shift based on agroecology (AE)*. Some of these initiatives include (i) the new research and innovation programme by the European Commission (EC) (2020, 2021) 'Horizon Europe – Cluster 6: "Food, Bioeconomy, Natural resources, Agriculture and Environment"' launched in 2021 that supports a number of sub-priority topics on agroecology, and (ii) the Research Institute of Organic Agriculture (FiBL) and the FiBL project 'SysCom' in Kenya, Bolivia, and India (https://systems-comparison.fibl.org/). In addition, assessment reports, e.g., by IPCC (2019), FAO (2019), HLPE (2019), and UN Decade of Action on Nutrition (2016–2025), have all emphasized AE's potential

DOI: 10.4324/9781003273172-8

contributions to climate change mitigation and adaptation, biodiversity preservation, and ESSs. Other international and regional institutions and agencies like the AGRA (2016) and IPES-Food (2016), and international peasants' movement (e.g., La Via Campesina: https://viacampesina.org/en/international-peasants-voice/) are promoting AE as a potential to climate-neutral and resilient farming systems (CNRFSs).

Definition and concepts of agroecology

There has been continuous debate about the definition of agroecology, as evident from the literature (e.g., FAO, 2018; Wezel and Silva, 2017), with no widely accepted, common definition of agroecology yet. There are no clear, consensual boundaries between what is agroecological and what is not (HLPE, 2019). However, there is a consensus that agroecology embraces three dimensions: a transdisciplinary science, a set of principles and practices, and a social movement that is interlinked and complementary (Figure 8.1).

Agroecology is a powerful strategy that reduces the trade-offs between productivity and sustainability of agriculture and food systems (*social, economic, and environmental*) while ensuring 'no one is left behind' (Niggli et al., 2021). It promotes the diversity of crops and livestock, fields, farms, and landscapes, which altogether are key to improving the sustainability of food and agricultural systems, food actors' empowerment, and environmental health (von Braun et al., 2021). The agroecology approach has the potential to contribute to several Sustainable Development Goals (SDGs) of the United Nations as listed in Table 8.1.

The main *objectives of the chapter* are to (i) describe the common AE practices/approaches implemented in *agroforestry-based farming systems* and discuss their implications to ecological and socio-economic dimensions of AE; and (ii) recommend optimal combinations of AE practices/approaches that enhance food security, resilience, and mitigation to climate change in the different agroecological settings.

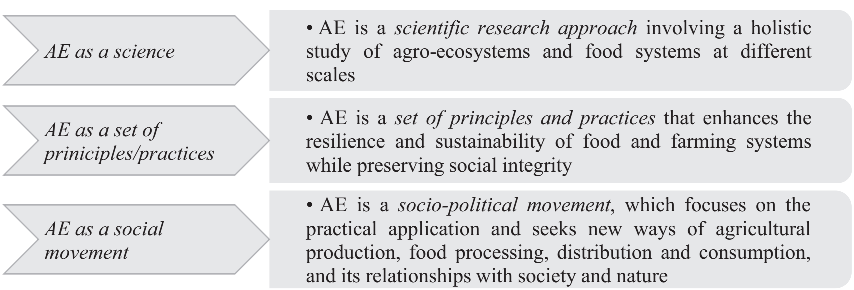

Figure 8.1 Three dimensions of agroecology.
Source: Authors' own compilation.

Table 8.1 Potential AE contributions to relevant SDGs and specific targets along with references

SDGs	*Targets**	*References (examples)*
SDG 1: *no poverty*	1.3, 1.4, 1.5	Niggli et al. (2021)
SDG 2: *zero hunger*	2.1, 2.2, 2.3, 2.4, 2.5	Deaconu et al. (2021)
SDG 3: *good health and well-being*	3.9	FAO (2018)
SDG 5: *gender equality*	5.1	von Braun et al. (2021)
SDG 6: *clean water and sanitation*	6.4	FAO (2018)
SDG 8: *decent work and economic growth*	8.3, 8.5	CNS-FAO (2021); ILO (2018)
SDG 10: *reduce inequalities*	10.2	FAO (2018)
SDG 12: *sustainable consumption and production*	12.1, 12.2, 12.3	FAO (2018)
SDG 13: *climate action*	13.1, 13.2, 13.3	Leippert et al. (2020)
SDG 15: *life on land*	15.1	Altieri and Nicholls (2018)
SDG 16: *peace, justice, and strong institutions*	16.7	FAO (2018)
SDG 17: *partnerships for development goals*	17.6, 17.9	FAO (2018)

Source: Authors' own compilation.

* Note that the specific targets and corresponding indicator descriptions can be found at https://unstats.un.org/sdgs/indicators/indicators-list/.

Elements of agroecology and their implications for practice

Table 8.2 provides the ten elements of the AE framework as defined by FAO (2019), and their implications for practice. According to the report, the ten AE elements encompass ecological characteristics of AE systems (*diversity, synergies, efficiency, resilience, and recycling*), social characteristics (*co-creation and sharing of knowledge*, *human and social values*, *culture and food traditions*), and the enabling political and economic environment (*responsible governance, circular and solidarity economy*). Most of these elements of AE relate well to the 13 principles of AE developed by HLPE (2019).

The above-mentioned ten elements of AE are interconnected and interdependent with one another. These elements of AE and their practices also fit well with the aims and goals of the regenerative agriculture (e.g., *produce more from less*: less land area, less input of chemicals, less use of water, less emission of greenhouse gases, less risk of soil degradation, and less use of energy-based inputs). However, a detailed discussion on regenerative agriculture is beyond the scope of this chapter.

Main barriers for agroecology adoption

The multiple benefits of AE have been demonstrated in specific contexts and gained prominence in scientific literature, and agricultural and political discourse. Despite this, AE has not been mainstreamed and not widely adopted in

Table 8.2 The ten elements of AE (FAO, 2019) and their implications when put in practice

AE elements	*Implications for practice*
• *Diversity*	Producing and consuming a *diverse range of cereals, pulses, fruits, vegetables, and animal-source* products contributes to improved nutritional outcomes, diversity in diets and markets
• *Synergies*	Combining annual and perennial crops, livestock and aquatic farming, trees, soils, water, and others enhances synergies in the context of climate change
• *Efficiency*	Producers are able to *use fewer external resources*, *reduce costs*, and *reduce environmental impacts* by enhancing bio-based measures, biological control, recycling biomass, nutrients, and water
• *Recycling*	AE practices support biological processes by imitating natural ecosystems that drive recycling of nutrients, biomass, and water to minimize waste and pollution
• *Resilience*	Diversified AE systems are more resilient and have *greater capacity to recover from* extreme weather events (e.g., *drought*, *floods*) and better resistance to *pest and disease attack*
• *Co-creation/sharing of knowledge*	Blending *indigenous knowledge, practical knowledge, and scientific knowledge* addresses challenges across food systems and resilience to climate change
• *Human and social values*	AE places a strong emphasis on human *dignity*, *equity*, *inclusion, and environmental justice* for all and thereby contributing to improved livelihoods
• *Culture and food traditions*	AE plays an important role in re-balancing *traditional and modern food habits* by promoting healthy food production and consumption, and by supporting food sovereignty (the right to adequate food)
• *Responsible governance*	*Transparent, accountable, and inclusive* governance mechanisms support producers to transform their farming systems following the AE practices
• *Circular and solidarity economy*	AE seeks to *reconnect producers and consumers*, prioritizes local markets, and supports economic development by creating short circular value chains that reduce food losses and wastes

Source: Author's own elaboration adapted from FAO (2019).

different farming systems and agroecological zones (AEZs) worldwide. The main barriers to widespread adoption and upscaling of AE practices/approaches at field/farm/landscape levels include the following:

i *Lack of awareness and knowledge about AE*: Despite successful AE experiences in some regions of the world (CNS-FAO, 2021), there is a lack of awareness among key stakeholders (e.g., decision-makers) and the public on the potential of AE to tackle environmental, social, and economic challenges posed by climate change and its contributions to achieving multiple targets of the SDGs (see Table 8.1). Moreover, limited information is available on the extent to which AE can be applied to larger farms (Parmentier, 2014) and the economic and social impacts of AE for different groups in the farming communities (Bezner Kerr et al., 2019). There are differences in approaches and ideologies resulting in conflicts of interest between proponents and opponents of AE. For example, ideological differences exist among scientific communities and fertilizer companies (e.g., Yara International ASA) that promote increased external farm inputs (e.g., chemical fertilizers). Such conflicts need to be resolved by minimizing the trade-offs while maximizing synergies and complementarities of ecological and socio-economic dimensions of AE (Mockshell and Kamanda, 2018).

ii *Insufficient investments on AE research and extension systems*: Current research and extension systems do not sufficiently address the key AE principles/practices when compared to the investments on conventional agriculture (IAASTD, 2009). There is a lack of incentive in long-term research and limited funding available, e.g., to assess the yield gap between 'intensive farming systems' and 'AE systems' (CNS-FAO, 2021). The current agricultural research and extension systems predominantly focus on single disciplines, single technology, and single commodity, and use top-down extension models to transfer knowledge/technology.

iii *Additional labour costs*: Adoption of AE farming practices such as AC systems with agroforestry incurs additional labour cost (Schoonhiven and Runhaar, 2018). This is a challenge for smallholder farmers who cannot afford especially in the initial year of establishment. Therefore, farmers are not motivated to adopt unless the immediate net benefits or profits of AE farming are visible.

iv *Inadequate policy support, gender integration, multi-actor partnerships*: Lack of policy and institutional enabling environments deters widespread implementation of AE (Anderson et al., 2020). Gender integration in AE projects plays a crucial role in adopting AE practices, for instance, in the African context (Bezner Kerr et al., 2019). However, much has not been done at the policy or practice level to strengthen gender integration in promoting agroecology. There is a lack of coordination/collaboration among stakeholders in implementing AE projects (Ayala-Orozco et al., 2018), probably due to the absence of relevant platforms/networks/partnerships.

v *Lack of evidence on the interactive effects across AE practices*: Despite the extensive literature on AE farming systems in the form of scientific and popular publications, there is a lack of evidence on the *optimal combinations of integrated AE practices and their impacts* in different agroecological regions, farming context and scales.

There is no 'one-size-fits-all' solution to AE farming system challenges (Schader et al., 2014) but to use a combination of solutions. Combining sustainable intensification (SI) approaches with AE approach/practices is the way forward to address the multiple challenges faced by smallholders. The key principles of SI (Box 8.1) are in line with the principles of AE elements. Both SI and AE have a common objective, i.e., to achieve food and nutrition security (FNS) while reducing

Box 8.1 Components of sustainable intensification

i *Increasing production, income, nutrition, or other returns* on the same amount of, or less land and water by efficient and prudent use of inputs and productive use of knowledge and capacity to adapt, innovate, and scale up.

ii *Minimizing greenhouse gas emissions by* increasing natural capital and the flow of environmental services, and reducing impact on forests through alternative energy sources.

iii *Strengthening resilience and reducing environmental impacts by* adopting innovative technologies and processes while minimizing inputs that have adverse impacts on people and environment.

Source: Pretty et al. (2011)

negative impacts on the environment (Bernard et al., 2017). They can generate healthy soils, crops, and animals, which is a core element of regenerative agriculture (Newton et al., 2020). One basic divergence between the two is SI focuses on increasing the food production side of the food systems. At the same time, AE addresses the whole food systems along their value chains and relationships with society and nature (Lampkin et al., 2015). In this chapter, we will focus on the convergence of SI and AE by promoting the essential elements of AE (Table 8.2) and their implications to practice, science, and policy.

The chapter has been divided into four main sections. The first section introduces AE definition and concepts, principles and practices, the potential for sustainable developments, gaps and barriers for adoption and upscaling. This is followed by case study descriptions of farmer-led AC with *Gliricidia* agroforestry demonstration trials in Zambia and the methodological approaches used. Then, a detailed analysis of the research results is presented and discussed including fundamental AE principles, practices, and policy. Towards the end, optimal combinations of the AE practices that enhance food security, resilience, and mitigation to climate change are recommended.

Case study and methods used

This chapter presents some findings from a multi-disciplinary alley cropping (AC)-*Gliricidia* agroforestry project[1] in Zambia, as a case study. Alley cropping (also sometimes referred to as 'Hedgerow intercropping') is defined as the practice of planting rows of trees and/or shrubs to create alleys with companion crops in between. The AC with *Gliricidia* agroforestry system combines maize and legumes (groundnuts and soybeans), where smallholder farmers have implemented a set of AE principles/practices since 2019. The study's primary objectives were to (i) monitor the soil nutrients, in particular nitrogen and organic carbon inputs and outputs, under agroforestry systems (e.g., *Gliricidia sepium*) at different levels of intensification and measure crop yields and (ii) assess the impact of agroforestry-based interventions on the nutrients of selected crops to address whether agroforestry practices result in healthier and nutrient-rich food crops.

The study was conducted in maize growing districts of eastern Zambia in five selected *Chiefdoms* (an area/region governed by a chief). The *Chiefdoms* covering the study are *Mkanda* (Chipangali district), *Zumwanda* (Lundazi district), *Mwasemphangwe and Chikomeni* (Lumezi district), and *Magodi* (Chasefu district), as shown in Figure 8.2 and Table 8.3.

The main farming system in the study areas is maize-based monocropping with low-input and low-output smallholder agriculture (Table 8.3). Farmers (including women) lack access to good quality seeds and adaptive knowledge about climate-resilient crops, crop residues, and soil management practices, among others. Hence, gender integration becomes a challenge in the overall context of smallholder agriculture. Crop diversification with legumes and/or agroforestry in particular AC systems will provide multiple benefits to smallholder farmers who are vulnerable to climate change. Alley cropping (of maize-legumes that includes groundnuts and soybeans) with agroforestry trees such as *Gliricidia sepium* was recently introduced in the study areas.

In the case study areas, soil fertility is declining over time due to several factors, among others burning of crop residues, leading to low organic matter levels of the soils. Soil health/soil quality, defined as '*the continued capacity of soils to function*

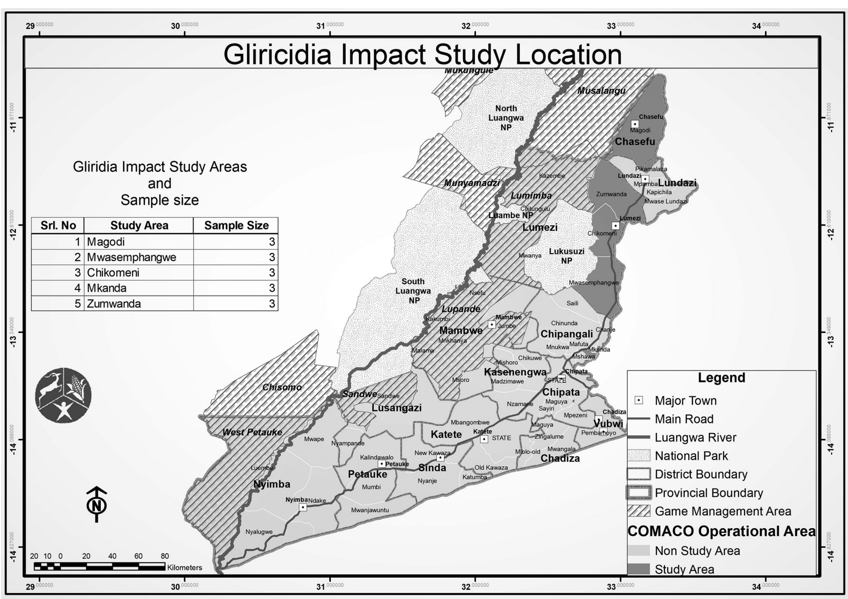

Figure 8.2 Map of the case study sites in the eastern Zambia.

Table 8.3 Summary of the general characteristics of the study sites in eastern Zambia

Features of study sites	
Agro-climatic conditions	Tropical Savanna
Elevation (above sea level)	1,140–1,143 meter
Precipitation (range)	923–1,023 mm/yr
Air temperature (range)	18–27°C
Soil types (dominant)	Red-brownish clayey to loamy soils
Farming systems	Maize-based monocropping under rainfed
Major crops	Maize, groundnut, beans, cotton, sunflower, tobacco
On-farm tree (dominant)	*Gliricidia sepium*
Livestock	Chicken, cattle, goats, pigs
Ecological constraints	Low soil fertility, erratic rainfall/dry spells, crop residues burning
Socio-economic constraints	Small land sizes, poverty, food/nutrition insecurity, high population pressure, lack of access to quality seeds
Opportunities explored	Farm diversification with maize, legumes, and alley cropping

Source: Authors' own compilation.

properly and provide the required ecosystem services and goods', is essential for improving crop yield and crop nutritional quality. The crop nutritional quality largely depends on the composition and concentration of nutrients available in the soil. Maintaining healthy soil ensures nutritious, tasty, and safe foods, and enhances resilience and mitigation to climate change which are essential for achieving the SDGs such as SDG 2 (*zero hunger*) and SDG 13 (*climate action*). Hence, there is a need to understand whether crops produced under AC with agroforestry-based systems are more nutritious than those produced in conventional systems.

A set of AE practices that include *AC of maize, groundnuts, soybean with Gliricidia, conservation agriculture, composting/leaf manuring, residue mulching* were implemented in selected on-farm demonstration trials (*n* = 15) in the eastern province of Zambia through a farmer-led approach. Farmer-to-farmer extension services backed these demo trials through farmer field days for broader adoption of *Gliricidia* and knowledge sharing. Farmer-to-farmer knowledge exchange on AE farming practices was also carried out through multimedia platforms such as weekly radio broadcasts to the farming community in the case study areas.

Data collection and analysis

The AC system with *Gliricidia* agroforestry project in Zambia involved seven treatment (T) plots, i.e., intercropping of *Gliricidia* with maize (T1), soybean (T4), groundnuts (T5) and sole cropping of maize with mineral fertilizer (T2), sole soybean (T6), sole groundnut (T7) and sole maize with no mineral fertilizer (T3) used as a control. Soil samples (*n* = 178) were collected from three random positions in each treatment plot of the 15 on-farm demo trials. The soils were recovered from the topsoil and subsoil layer using a soil auger and were analysed for selected soil chemical and physical properties such as soil bulk density that was used in the computation of estimating carbon stocks in the soils.

Crop samples of maize, soybean, and groundnuts (n = 88) were collected using the standard sampling protocol developed for the project. The crop samples were cleaned, subsampled, and milled to a 0.5 mm particle size. The milled samples were evaluated for the nutritional contents (fat, ash, protein, starch, crude fibre, sugar, amylose, and total carbohydrate) and antinutritional contents (phytate and tannin) using standard laboratory methods of analysis of the Association of Analytical Chemist International (AOAC). The data generated were analysed for descriptive statistics and analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 9.4. The F-test was used for statistical significance. The treatment means were compared using the least significant difference (LSD) tests at $P < 0.05$.

Results and discussion

In the following subsections, the effects of AC systems with *Gliricidia* agroforestry interventions on soil health, crop yield, crop nutrient quality, and climate change adaptation and mitigation are presented and discussed.

Soil health assessment

The status of soil health was assessed through a set of measurable physical, chemical, and biological indicators. These include soil organic carbon (SOC) and/or organic matter (OM), soil nutrients (in particular nitrogen), soil pH (acidity), and soil structure related to bulk density of soils, used as a reflection of overall soil health indicators.

Over the two growing seasons (2019/2020 and 2020/2021), the SOC contents of the sampled soils (n = 182) varied in the range of 0.32% (0.60% organic matter, OM) to 1.10% (2.0% OM), which is very low to low despite some positive increase observed since the incorporation of *Gliricidia* leaf manure (Figure 8.3) into the treated soils (T1, T4, T5). The soils in the study sites would benefit from additions of organic fertilizers obtained from *Gliricidia* leaf manure and nitrogen-fixing legumes. However, retention and accumulation of OM and SOC storage in the soil require considerable time. Thus, repeated application of diverse organic sources (such as leaf biomass and crop residues) will stimulate microbial community growth and sequestration of carbon in the soils (Moebius-Clune et al., 2016).

The mean carbon stock per treatment ranged from 17.6 to 25.6 C t/ha (Figure 8.4) and similar results have been reported in different farming systems. For example, agri-silviculture agroforestry systems could store about 27 C t/ha and rainfed crop production systems in semi-arid areas about 16 C t/ha. The highest carbon stock was measured in T3 (sole Maize + no Mineral fertilization). The possible explanation for this could be that retention and accumulation of OM/OC storage in the soil requires a considerable time. Repeated application of diverse

Figure 8.3 Woman farmer incorporating *Gliricidia* tree leaves into the soils.

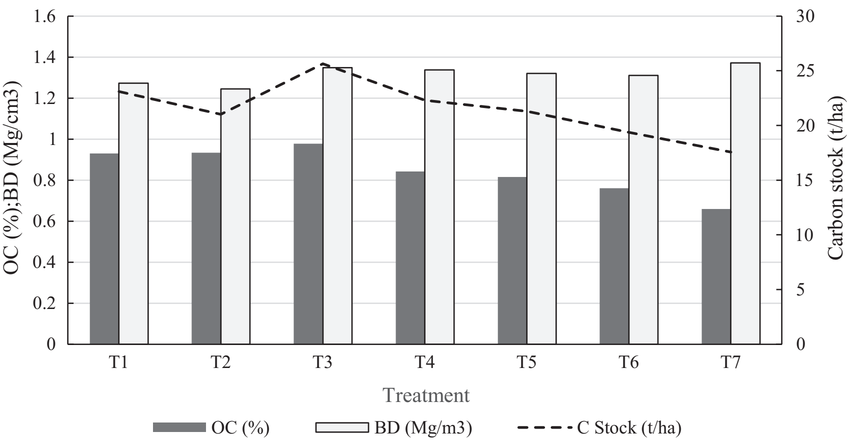

Figure 8.4 Mean organic carbon, BD, and carbon stock estimates from the seven treatment plots: T1: *Gliricidia* + Maize intercrop, T2: sole Maize + Mineral fertilization, T3: sole Maize + no Mineral fertilization, T4: *Gliricidia* + Soybean, T5: *Gliricidia* + Groundnuts, T6: sole Soybean, and T7: sole Groundnuts.

Source: Authors' own analysis.

organic sources (such as green manures and crop residues) in the long term will stimulate both microbial community growth and the stabilization (sequestration) of carbon in aggregates (Moebius-Clune et al., 2016). The magnitude of changes in soil OM depends on the quantity and quality of prunings, pedo-climatic conditions, and the system management as a whole (Makumba et al., 2007). There is

Table 8.4 Average grain yields of maize, groundnut, and soybean by treatment (*n* = 15 demo plots)

Treatment	*Maize (kg/ha)*		*Soybean (kg/ha)*		*Groundnut (kg/ha)*	
	2019/2020	*2020/2021*	*2019/2020*	*2020/2021*	*2019/2020*	*2020/2021*
T1	819.3	4520	–	–	–	–
T2	820.3	5954	–	–	–	–
T3	540.1	1227	–	–	–	–
T4	–	–	329	910	–	–
T5	–	–	–	–	393.2	708
T6	–	–	328.7	825	–	–
T7	–	–	–	–	372.4	737

T1: *Gliricidia* + Maize intercrop, T2: sole Maize + Mineral fertilization, T3: sole Maize + no Mineral fertilization, T4: *Gliricidia* + Soybean, T5: *Gliricidia* + Groundnuts, T6: sole Soybean, and T7: sole Groundnuts.
Source: Authors' own analysis.

a great potential to mitigate climate change through AC systems with *Gliricidia* agroforestry interventions in the study areas. Selling carbon credits may provide another source of income for farmers, but policies need to be in place for encouraging carbon markets to benefit smallholders practising AE.

The bulk density (BD) of the soils ranged between 1.26 g/cm^3 and 1.36 g/cm^3, which is within the range of 1.0–1.7 g/cm^3 for typical agricultural soils (Brady and Weil, 2002). The soil bulk density serves as an indicator of compaction, root growth, and water movement in the soils, and it is a good indicator for soil health.

Crop yield assessment

Table 8.4 presents average grain yields (kg/ha) of maize, groundnut, and soybean by treatments. *Gliricidia*-maize intercrop (T1) and maize with 100% mineral fertilizer (T2) did not differ significantly ($P > 0.05$). In the 2020/2021 season, the yields (maize variety *MZ521*) are within the potential national yield range: 4,-500–6,000 kg/ha. The maize yield from the control plots (T3) rendered much lower compared with T1 and T2. There was an increase in yields in the second season for the groundnuts and soybeans with no significant differences between treatments. In all treated crops, the grain yields increased by more than two to three folds in 2020/2021. The yield increase can be attributed to good field management practices, including *Gliricidia* leaf biomass incorporation, conservation agriculture practices, and crop diversification.

Crop nutrient assessment

Table 8.5 shows the nutritional properties (NPs) and antinutritional properties (ANPs) of maize samples by treatment. The treatment showed a significant impact ($P < 0.05$) on all NPs and ANPs except for ash (inorganic matter) which was not significant at $P > 0.05$. The non-significant difference with ash content of the

Table 8.5 Nutritional and antinutritional properties of maize by treatment (*n* = 37)

Properties	*T1* (Gliricidia + *Maize intercrop)*		*T2 (sole Maize + Mineral fertilizer)*		*T3 (sole Maize + no Mineral fertilizer)*		Pr > F (T)	Pr > F (F × T)
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*		
MC, %	6.64 b	0.93	6.31 b	0.67	7.09 a	0.88	<0.0001	<0.0001
Ash, %	1.31 a	0.09	1.30 a	0.07	1.27 a	0.08	0.0927	0.0048
Fat, %	4.72 b	1.02	5.66 a	1.12	5.16 b	1.27	<0.0001	<0.0001
Protein, %	6.28 b	0.98	7.14 a	1.22	5.93 c	0.93	<0.0001	<0.0001
CF, %	4.00 b	1.28	4.06 b	1.26	4.41 a	1.49	<0.0001	<0.0001
Sugar, %	2.76 ab	0.8	2.63 b	0.72	3.01 a	0.79	0.0079	0.0130
Starch, %	71.89 b	1.05	72.42 a	1.12	72.55 a	1.19	<0.0001	<0.0001
Amylose, %	28.35 b	1.51	28.80 ab	2.48	29.55 a	2.6	0.0434	0.1604
CHO, %	77.05 a	2.65	75.53 c	1.96	76.14 b	2.19	<0.0001	<0.0001
Phytic acid, %	2.27 ab	1.97	1.98 b	1.71	2.52 a	2.18	0.0034	<0.0001
Tannin, mg/g	3.10 c	0.72	3.42 b	0.95	3.62 a	0.6	<0.0001	<0.0001

MC = moisture content; CF = crude fibre; CHO = total carbohydrate; SD: standard deviation, *F*: F statistic, *T*: test statistic. Mean values with different letters in the same row are significantly different at $P < 0.05$. *Pr > F*: this is the *P*-value associated with the *F* statistic of a given effect and test statistic.
Source: Authors' own analysis from field data.

maize samples agrees with the study by Ogunyemi et al. (2018), who also reported no significant difference in the ash content of maize samples subjected to different treatments (NPK and biochar fertilized). The mean values for ash, fat, and protein contents obtained for the *Gliricidia*-Maize intercrop (T1) without mineral fertilizer are higher than the results reported by Ogunyemi et al. (2018) for maize using biochar fertilizer. It implies that *Gliricidia* has a better effect on nutritional properties than mineral fertilizer (NPK) and biochar. Also, *Gliricidia*-Maize intercrop (T1) without mineral fertilizer significantly reduced the tannin and phytic contents of maize samples compared with the control (T3).

Table 8.6 presents treatment effects on the soybean samples' NPs and ANPs. Both treatments had a significant ($P < 0.05$) effect on fat, amylose, total carbohydrate (CHO), energy, and ANPs. The result agrees with the studies by Etiosa et al. (2017) and Alamu et al. (2019), who reported similar values for soya bean seeds. A higher mean value was observed for protein, starch, amylose, crude fibre, and CHO contents when *Gliricidia* + soybean intercrop (T4) was used. There were lower mean values for ANPs in T4 but comparable ash contents and significantly lower fat contents ($P < 0.05$). The observation is similar to what Alamu et al. (2019) reported, where they observed low values of ANPs for the soybean samples taken from integrated soil management practices plots. The amylose and CHO contents were significantly increased while tannin and phytic acid contents were reduced in T4. Some soybean samples from T4 showed higher ash, protein, and carbohydrate contents but lower phytic acid and tannin contents than farmer plots from T6 (sole soybean).

Table 8.6 Nutritional and antinutritional properties of soybean by treatment (*n* = 26)

Parameters	*T4 (Gliricidia + Soybean)*		*T6 (sole Soybean)*		Pr > F(T)	Pr > F (F × T)
	Mean	*SD*	*Mean*	*SD*		
MC, %	8.08 a	1.08	8.10 a	1.08	0.9763	0.0002
Ash, %	5.55 a	0.83	5.81 a	0.61	0.1080	0.0127
Fat, %	18.65 b	3.59	20.98 a	5.07	<0.0001	<0.0001
Protein, %	37.73 a	3.20	36.98 a	4.04	0.1065	<0.0001
Sugar, %	5.45 a	0.75	5.62 a	0.69	0.0786	0.0126
Starch, %	22.86 a	0.94	22.95 a	0.96	0.9306	0.0006
Amylose, %	1.76 a	0.51	1.64 b	0.30	0.0970	0.0049
CF, %	2.11 a	0.32	2.04 a	0.37	0.4271	0.7015
CHO, %	27.88 a	6.06	26.09 b	6.15	0.0134	<0.0001
Phytic acid, %	6.47 b	1.14	7.09 a	1.19	0.0758	0.1953
Tannin, mg/g	3.88 b	0.92	5.02 a	1.70	0.0006	0.0192

Source: Authors' own analysis from field data.

Table 8.7 Nutritional and antinutritional properties of groundnut by treatment (*n* = 25)

Properties	*T5* (Gliricidia + *Groundnuts)*		*T7 (sole Groundnuts)*		Pr > F (F)	Pr > F (F × T)
	Mean	*SD*	*Mean*	*SD*		
MC, %	5.69 a	0.84	5.65 a	0.52	0.4305	<0.0001
Ash, %	2.57 a	0.15	2.60 a	0.16	0.0925	<0.0001
Fat, %	47.23 a	6.72	44.97 b	6.46	<0.0001	<0.0001
Protein, %	19.01 a	2.28	17.94 b	2.21	<0.0001	<0.0001
Sugar, %	4.05 b	0.61	4.15 a	0.66	<0.0001	<0.0001
Starch, %	23.77 b	1.08	24.08 a	0.92	0.0011	<0.0001
Amylose, %	1.66 a	0.50	1.68 a	0.59	0.4802	<0.0001
CF, %	3.29 b	0.83	3.44 a	0.92	<0.0001	<0.0001
CHO, %	22.22 b	7.27	25.42 a	7.23	<0.0001	<0.0001
Phytic acid, %	4.38 a	0.84	4.35 a	0.75	0.8221	<0.0001
Tannin, mg/g	6.44 a	1.90	6.09 b	2.02	0.0490	0.0008

Source: Authors' own analysis from field data.

Table 8.7 shows the mean values and treatment effects on NPs and ANPs of groundnut. The result for nutritional properties of groundnut reported agrees with previously published studies on the proximate composition of groundnut samples (Asibuo et al., 2008; Atasie et al., 2009). Both treatments (T5 and T7) exhibited a significant effect ($P < 0.05$) on fat, protein, sugar, starch, crude fibre (CF), total carbohydrate (CHO), total energy, and tannin content of groundnut, but a non-significant effect on ash, amylose, and phytic acid at $P > 0.05$.

The mean values of crop samples from *Gliricidia* + Groundnut (T5) were higher in fat, protein, tannin, and bulk density but lower in starch, CF, and CHO than with sole Groundnuts (T7). The implication is that T5 significantly increased the crop's fat, protein, and tannin levels. Goudiaby et al. (2020) reported a non-significant effect of groundnut intercropped with *Eucalyptus camaldulensis* tree on the proximate content of the crop except for the grain yield. This implies that the *Gliricidia*-groundnut intercropping improved nutritional properties of groundnuts compared to treatment using *E. camaldulensis*.

It can be summarized that the *Gliricidia* + Maize intercrop (i.e., T1) showed the highest mean value of ash, fat, protein, and total carbohydrate (CHO) contents. A higher mean value of protein, starch, amylose, crude fibre, and CHO contents was measured in *Gliricidia* + Soybean intercrop (T4). *Gliricidia* + Groundnut intercrop (T5) significantly increased the fat and protein contents of groundnuts. *Gliricidia* + Maize intercrop (T1) significantly ($P < 0.05$) reduced the tannin and phytic contents of maize samples compared to the control (sole Maize: T3). Lower mean values of tannin and phytic acid were observed in T4 than sole Soybean (T6). A lower value of phytic acid but increased tannin level was measured in T5. Thus, intercropping with the *Gliricidia* improves the nutritional quality of maize, soybean, and groundnut and decreases the antinutritional qualities of the legumes.

Optimal combinations of AE practices/approaches

Table 8.8 presents the different AE practices/approaches that have been implemented in the case study sites of eastern Zambia (AC systems *with Gliricidia agroforestry*). The AE practices/approaches addressed more than one element/principle of AE (see Table 8.2) and contributed to enhancing the sustainability of AE farming from the point of view of ecological, social, and economic dimensions.

For instance, crop diversification through intercropping of cereals with legumes and AC with *Gliricidia* trees enhanced diversity (in crops, trees, habitat, food diets, markets), synergies (combining annual and perennial plants), resilience (to climate change), and culture and food traditions (increasing healthy food production and consumption and supporting the right to adequate food).

Table 8.8 Matching the AE practices/approaches implemented in the case study sites with the most appropriate AE elements/principles

Matching	*AE practices/approaches*	*AE elements/principles*
a), b), e)	Crop rotation with legumes	a) Diversity
a), b), e), h)	Intercropping with legumes	b) Synergies
b), c), e)	Conservation agriculture	c) Efficiency
a), b), e), h)	Alley cropping with *Gliricidia*	d) Recycling
c), d)	Composting, leaf manuring	e) Resilience
c), d)	Residue mulching	f) Co-creation and sharing of knowledge
a), e)	Agrobiodiversity	g) Human and social values
f)	Multi-media platforms	h) Culture and food traditions
b), f), g), i)	Stakeholder engagement	i) Governance (responsible/effective)
d), g), j)	AE products value chain	j) Circular and solidarity economy

Source: Author's own analysis.

Climate change adaptation and mitigation

In the *Gliricidia*-treated plots (i.e., T1, T4, and T5), the main sources of addition of nitrogen into the soils were the incorporation of leaf biomass from *Gliricidia* trees, atmospheric N-fixation by legumes (in this case, groundnuts, soybeans, and *Gliricidia*), and atmospheric deposition by rain. Total N inputs from these organic sources were estimated at 468–500 kg N/ha (data not shown). However, only a small proportion of this organic N becomes plant-available during a growing season (Horneck et al., 2011). The remaining part of the organic N will be mineralized and made available for the succeeding crops.

However, the AC systems with *Gliricidia* have improved the soils' organic matter content and increased carbon stocks (Figure 8.4). This will reduce the need for nitrogen-based fertilizers, which contribute to mitigating nitrous oxide (N_2O–N) emissions, a potent green-house gas. The average carbon sequestration in the soils was about 22 C t/ha (Figure 8.4). This implies that about 81 CO_2 equiv. t/ha was prevented from being released to the atmosphere, considering 1-tonne organic carbon reduces about 3.7-tonne atmospheric CO_2 equiv. In addition, reduced/no-tillage practices using animal-drawn rippers and hand seeding will also minimize carbon dioxide emissions in the long term. The AE practices such as intercropping legumes with *Gliricidia* agroforestry and soil mulching with residues can increase climate resilience to drought and dry spells.

In the following subsections, a brief discussion is given on how the AC systems with *Gliricidia* agroforestry project have addressed the key elements and principles of AE.

Addressing the ecological dimensions of agroecology

i *Diversity*: Regarding crop/tree and food diversity, farmers planted *Gliricidia sepium* seedlings in between maize, soybean, and groundnut fields (as AC) for food and sale and soil fertility improvements. Farmers in the project have diversified crop produce, of cereals (maize) and pulses (soybeans and groundnuts), contributing to diet diversity and improved nutrition. Multipurpose leguminous trees such as *Gliricidia* are used for improving soil fertility, reducing soil erosion, controlling striga weed, providing fuelwood (including charcoal), and forage for honey production. *Gliricidia* leaves are rich in crude protein (>20%) and highly digestible, and low in fibre and tannin contents, making it good fodder for livestock (refer Tables 8.5–8.7).

ii *Synergies*: The demonstration trials on AC with *Gliricidia* trees enhanced synergies of resource use such as nutrients. For instance, the maize plants received nitrogen from the nitrogen fixed by soybeans and/or groundnuts and decomposed leaf biomass of *Gliricidia* tree. Synergistic interactions between annual crops (maize, soybeans, and groundnuts) and the leguminous agroforestry trees (*Gliricidia*) enhance both soil and crop productivity resulting in increased crop yields. However, trade-offs such as competition for light in AC systems with agroforestry trees (e.g., *Gliricidia*) could be minimized by adopting good agronomic practices such as seedbed preparation, early planting, and weed management (Sida et al., 2018).

iii *Efficiency*: Incorporation of *Gliricidia* leaf biomass improves resource use efficiency. *Gliricidia* trees produce large quantities of leaf biomass and contribute to increased soil productivity and crop yields over time. The decomposing *Gliricidia* leaf biomass enriches the soils with macronutrients such as nitrogen that support crop growth. This eventually leads to reduced external inputs of chemical fertilizers. *Gliricidia* trees produce high-quality leaf biomass that contains as much as 4% total N in their leaves.

Implementing AC that consisting of maize, different legumes, and trees effectively contributes to improving land use efficiency where land equivalent ratios are greater than >1. This indicates AC practices are more productive in the use of land resources where landholding size is shrinking, e.g., in the case of Zambia.

iv *Recycling*: *Gliricidia sepium* is a fast-growing leguminous agroforestry tree with relatively deep root system that captures leached nutrients along the soil profile. Thus, nutrients accumulated in layers below the root zone of annual crops can be accessed. These nutrients absorbed by the root system of the trees become inputs when transferred to the soil surface in the form of litter and other plant residues. Incorporating nutrient-rich tree leaves, especially leaves of leguminous trees like *Gliricidia*, can be considered as a potential solution towards improving soil fertility due to its profuse growth, coppice nature, rapid decomposition rate, and higher nutrient contents. *Gliricidia*-maize/legume intercropping systems sequester more carbon in the soil via continuous application of tree prunings and root turnover. *Gliricidia sepium* can also replenish soil fertility through biological nitrogen fixation and enhance recycling of nutrients in the soil through incorporation of nitrogen-rich leaves as green manure (refer Figure 8.3).

v *Resilience*: Interplanting of *Gliricidia* and incorporation of its leaf biomass enhance resilience of farming systems to climate change. *Gliricidia sepium* is a drought-resistant tree as it sheds most of its leaves during the dry season, thus reducing water loss at the time of transpiration. When properly incorporating the leaf biomass into the soils, *G. sepium* increases the organic matter content of soils, improves soil aeration, reduces soil temperature, reduces soil erosion, and contributes to weeds control (Akinnifesi et al., 2010). Thus, integrating *G. sepium* in the AC systems will build up resilience to climate change adaptation and mitigation. The farmers in the demo trials implement conservation agriculture (CA) practices that include reduced tillage using animal-drawn tillage implements called ripper, and retain crop residues to cover the soils in ripper lines. These CA practices reduce soil erosion and improve moisture content by avoiding water stress during dry periods (Thierfelder and Wall, 2009). However, there are challenges that hinder widespread uptake of the *Gliricidia* agroforestry technology by small holder farmers. This includes land shortage, insecure land tenure system, lack of tree seeds, and knowledge-intensive nature of the *Gliricidia* agroforestry technology.

Addressing the socio-economic dimension of agroecology

vi *Co-creation and sharing of knowledge*: Farmers in the study areas used to collect the leaves of *Gliricidia* and apply it as mulch (by spreading the leaves/biomass on the surface of soils) to fertilize their soils. Incorporation of the leaves into the soil was not practised in the study areas due to lack of knowledge. The farmer-led demo trials were used to showcase the benefits of incorporation of leaf biomass into the soils, e.g., in terms of increasing plant-available N, organic matter in the soils, carbon storage (see Figure 8.4), increasing crop yields (refer Table 8.4), and enhancing co-creation of knowledge and resilience to climate change. In this regard, a range of multimedia platforms (e.g., radio broadcast, newspaper, better-life booklets, and video documentaries) were used to increase awareness and disseminate information about the advantages of on-farm *Gliricidia* tree plantings, leaf manure incorporation, and general farm management. These platforms have reached out others like neighbouring farmers, traditional leaders, district officials, and other stakeholders who are not involved in the project. It was possible to reach out to 230,000 small-scale farmers (about 50% of them women) who are currently practising agroforestry in the eastern districts of Zambia where the study was undertaken. Social learning, and integrating scientific and local knowledge were important for increased adoption of AE practices and the development of *Gliricidia* agroforestry systems in the eastern Zambia.

vii *Human/social values (including gender integration, labour cost)*: Women farmers in the study areas are actively participating in a range of activities such as raising/planting of the seedlings, incorporation of leaf biomass (see Figure 8.3), and participation in leadership at the community level. Agroforestry with *Gliricidia* intervention can empower rural women and smallholders with additional products that generate income. Access to seedlings and water will promote the adoption of agroforestry. It appears that additional farm labour is needed to plant the seedlings, to implement prunings of the coppice, and to incorporate the leaf biomass into the soils. The costs of seedlings and their availability, opportunity costs, and low capacity of women farmers to carry out tree plantings might pose limitations for increased adoption of the AE practices. Although the total cost of *Gliricidia* agroforestry interventions (CA practices, farm inputs inclusive of labour) is challenging in the initial year, the cost is negligible in the subsequent years. It provides multiple benefits in terms of ecological and socio-economic aspects (refer Table 8.2). Once farmers observe the benefits of *Gliricidia* agroforestry, they will be motivated to adopt the technology and build up resilience to climate change.

viii *Policy/governance (measures for increased AE adoption)*: AC systems with agroforestry tree such as *Gliricidia* is one alternative intervention for farmers in the study area to increase AE adoption. However, AE transition requires farmer motivation and capacity (Schoonhiven and Runhaar, 2018). A collective effort is needed between state and non-state agencies/actors to increase the scale of AE adoption. These actors need to create enabling environments through provision of incentives, credit facilities that provide access to quality seeds, and market opportunities such as carbon credits sales. These are channelized through carbon offset scheme (by the government) where communities are then paid for their conservation efforts related to AE practices. In this regard, the Community Markets for Conservation (COMACO: a project partner) is assisting farming communities/cooperatives in the case study districts of eastern Zambia in collaboration with the local government. COMACO is a social enterprise that supports small-scale farmers in Zambia by promoting the adoption of AE practices such as conservation agriculture, AC with agroforestry, and other income-generating activities (e.g., honey production). This shows that interventions by such non-governmental organizations are necessary to promote agroecology approaches.

ix *Culture/food traditions (traditional foods, nutrition quality)*: The small-scale farmers in the study areas are facing food and nutrition insecurity due to a range of ecological and socio-economic factors. Crops produced under AC systems (legumes) with *Gliricidia* are organic as chemical inputs are not added to the soil. Such systems improved the soil health, crop health, and food quality as shown in Tables 8.5–8.7 and qualify for better market opportunities. In contrast, maize-based monocropping systems that rely on external inputs have resulted in poor soil health, lower yield, and poor nutritional quality. Thus, AC with *Gliricidia* plays a vital role in re-balancing traditional and modern food habits by promoting healthy food production and consumption, while ensuring the right to adequate food.

x *Circular solidarity economy (including value chain improvements)*: Social and institutional innovations play a key role in increasing AE production and consumption. One such example is the role played by COMACO in the case study area. COMACO connects producers and consumers, increases the value addition of farmer produce, and opens new markets. The innovative markets respond to consumers' growing demand for healthier diets while encouraging AE production. This approach makes food value chains shorter and more resource efficient. It also reduces food production losses or wastage by enhancing FNS while reducing pressure on natural resources.

Conclusion

This chapter reviewed literature related to the key principles/elements of agroecology (AE) and elaborated their implications to science, practice, and policy. One of the main barriers to adopting AE is the lack of evidence on the interactive effects of the practices on AE elements. The case study (i.e., *Gliricidia* agroforestry project in Zambia) has implemented a range of AE practices and approaches that include intercropping, leaf manure incorporation, residue mulching, and value addition on the AE farming products. The results demonstrated the synergistic effects on adaptation and mitigation to climate change. More specifically, the farmer-led demonstration trials on AC systems with *Gliricidia* agroforestry showed positive impacts on the ecological/environmental and socio-economic dimensions of AE elements and principles:

i *Ecological dimension of AE elements/principles*: Soil health and crop nutrition were improved by incorporating bio-degradable leaf biomass of *Gliricidia sepium* in the AC systems. Combining maize-legume-agroforestry conservation practices with *Gliricidia* provided multiple benefits and reduced risks to smallholders. The use of AC practice with *Gliricidia* increased the production of nutritious food crops (such as groundnuts and soybeans) and has improved the quality of the crops. It enhanced the overall food and nutrition security and resilience to climate change adaptation and mitigation, as evident from the data.

ii *Socio-economic dimensions of AE elements/principles*: Farmers implemented conservation agriculture practices (reduced tillage using rippers, residue mulching, and crop rotations), as an adaptation strategy to mitigate the effects of erratic rainfall. The *Gliricidia* leaf biomass incorporation into the soils has provided an alternative for small-scale farmers to apply a low-cost organic fertilizer into their soils. The introduction of AC systems with *Gliricidia* agroforestry in the eastern province of Zambia has prompted the adoption of AE farming practices, despite additional labour costs required in the initial year of the tree establishment due to the benefits it generated. In general, the AC systems with *Gliricidia* agroforestry practices proved to be effective on the key element of AE. However, good AE practices that could minimize trade-offs in crop-tree-animal interactions in vulnerable farming systems in different agroecological settings are recommended for further investigation.

Acknowledgement

The authors would like to thank the farmers and field enumerators of the Gliricidia-Zambia project and the NORAD/Ministry of Foreign Affairs, Norway for funding the project.

Note

1 https://www.nibio.no/en/projects/gliricidia?locationfilter=true

References

AGRA (Alliance for a Green Revolution in Africa) (2016) 'Africa Agriculture Status Report 2016: Progress Towards Agricultural Transformation in Africa'. Available at: https://agra.org/aasr2016/public/assr.pdf

Akinnifesi, F.K., Ajayi, O.C., Sileshi, G., Chirwa, P.W. and Jonas, C. (2010) 'Fertilizer Trees for Sustainable Food Security in the Maize-based Production Systems of East and Southern Africa: A Review', *Agronomy for Sustainable Development* , vol. 30, pp. 615–629.

Alamu, E.O., Gondwe, T., Akinwale, G., Suzuki, K., Chisonga, C., Chigeza, G. and Busie, M.D. (2019) 'Impact of Soil Fertility Management Practices on the Nutritional Quality of Soybean (Glycine max (l.) Merr.) Varieties grown in Eastern Zambia', *Cogent Food & Agriculture*, vol. 5, pp. 10–13.

Altieri, M.A. and Nicholls, C.I. (2018) 'Urban Agroecology: Designing Biodiverse, Productive and Resilient City Farms', *AgroSur*, vol. 46, pp. 49–60.

Anderson, C.R., Pimbert, M.P., Chappell, M.J., Brem-Wilson, J., Claeys, P., Kiss, C., Maughan, C., Milgroom, J., McAllister, G., Moeller, N. and Singh, J. (2020) 'Agroecology Now—Connecting the Dots to Enable Agroecology Transformations', *Agroecology and Sustainable Food Systems*, vol. 44 (5), pp. 561–565.

Ayala-Orozco, B., Rosell, J.A., Merçon, J., Bueno, I., Alatorre-Frenk, G., Langle-Flores, A. and Lobato, A. (2018) 'Challenges and Strategies in Place-Based Multi-Stakeholder Collaboration for Sustainability: Learning from Experiences in the Global South', *Sustainability*, vol. 10, p. 3217.

Asibuo, J.Y., Akromah, R., Safo-Kantanka, O., Adu-Dapaah, H.K., Ohemeng-Dapaah, S. and Agyeman, A. (2008) 'Chemical Composition of Groundnut, Arachis hypogaea (L) landraces', *African Journal of Biotechnology*, vol. 7 (13), pp. 2203–2208.

Atasie, V.N., Akinhanmi, T.F. and Ojiodu, C.C. (2009) 'Proximate Analysis and Physico-Chemical Properties of Groundnut (Arachis hypogaea L.)', *Pakistan Journal of Nutrition*, vol. 8(2), pp. 194–197.

Bernard, B. and Lux, A. (2017) 'How to Feed the World Sustainably: An Overview of the Discourse on Agroecology and Sustainable Intensification', *Reg Environ Change,* vol. 17, pp. 1279–1290.

Bezner Kerr, R., Young, S.L., Young, C., Santoso, M.V., Magalasi, M., Entz, M., Lupafya, E., Dakishoni, L., Morrone, V., Wolfe, D. and Snapp, S.S. (2019) 'Farming for Change: Developing a Participatory Curriculum on Agroecology, Nutrition, Climate Change and Social Equity in Malawi and Tanzania', *Agric Hum Values,* vol. 36 (3), pp. 549–566.

Brady, N.C. and Weil, R.R (2002) *The Nature and Properties of Soils*, 13th Edition. Upper Saddle River, NJ: Prentice Hall; 960 p; ISBN: 13-016763-0.

CNS-FAO (2021) 'Pathways to advance agroecology. Overcoming challenges and contributing to sustainable food systems transformation. Swiss National FAO Committee (CNS-FAO), March 2021'. Available at: https://www.oneplanetnetwork.org/sites/default/files/cns-fao_working-document_advancing_agroecology_march_2021.pdf

Deaconu, A., Berti, P.R., Cole, D.C., Mercille, G. and Batal, M. (2021) 'Agroecology and Nutritional Health: A Comparison of Agro-ecological Farmers and Their Neighbours in the Ecuadorian Highlands', *Food Policy* vol. 101, pp. 1–14.

Etiosa, O.R., Chika, N.B. and Benedicta, A. (2017) 'Mineral and Proximate Composition of Soya Bean', *Asian Journal of Physical and Chemical Sciences*, vol. 4 (3), 1–6.

EC (European Commission) (2021) Soil Deal mission implementation plan, section 8B. Available at: https://ec.europa.eu/info/publications/implementation-plans-eu-missions_en

EC (European Commission) (2020) Available at: https://ec.europa.eu/info/news/46-new-projects-start-their-research-agroecology-and-ocean-observation-2020-sep-28_en

FAO (Food and Agriculture Organization) (2018) *The 10 Key Elements of Agroecology – Guiding the Transition to Sustainable Food and Agricultural Systems*. Rome: FAO. Available at http://www.fao.org/3/i9037en/I9037EN.pdf

FAO (Food and Agriculture Organization) (2019) *TAPE Tool for Agroecology Performance Evaluation 2019 – Process of Development and Guidelines for Application, Test Version*. Rome: FAO. Available at: https://www.fao.org/documents/card/en/c/ca7407en/

FAO (Food and Agriculture Organization) (2020) 'FAOSTAT'. Available at: http://www.fao.org/faostat/en/#home

Goudiaby, A.O.K, Diedhiou, S., Diatta, Y., Badiane, A., Diouf, P., Fall, S., Diallo, M.D. and Ndoye, I. (2020) 'Soil Properties and Groundnut (*Arachis hypogea L.*) Responses to Intercropping with Eucalyptus camaldulensis Dehn and Amendment with Its Biochar', *Journal of Materials and Environmental Sciences*, vol. 11, pp. 220–229.

HLPE (High Level Panel of Experts) (2019) 'Agro-ecological and Other Innovative Approaches for Sustainable Agriculture and Food Systems That Enhance Food Security and Nutrition', High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome. Available at: http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/

Horneck, D.A., Sullivan, D.M., Owen, J.S. and Hart, J.M. (2011) 'Soil Test Interpretation Guide', Oregon State University Extension Service, EC 1478, USA. Available at: https://ir.library.oregonstate.edu/concern/administrative_report_or_publications/2b88qc45x

IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development) (2009) 'Agriculture at a Crossroads: Global Report', Island Press, Washington, DC.

ILO (International Labor Organization) (2018) 'Decent Work and the Sustainable Development Goals: A Guidebook on SDG Labour Market Indicators', Department of Statistics, Geneva, ISBN 978-92-2-132117-0.

IPCC (Intergovernmental Panel on Climate Change) (2019) 'Climate Change and Land. IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems'. Available at: https://www.ipcc.ch/srccl/

IPES-Food (2016) 'From Uniformity to Diversity: A Paradigm Shift From Industrial Agriculture to Diversified Agro-Ecological Systems', *International Panel of Experts on Sustainable Food Systems*. Available at: https://ipes-food.org/reports/

Lampkin, N.H., Pearce, B.D., Leake, A.R., Creissen, H., Gerrard, C.L., Girling, R., Lloyd, S., Padel, S., Smith, J., Smith, L.G., Vieweger, A. and Wolfe, M.S. (2015) 'The Role of Agroecology in Sustainable Intensification', Report for the Land Use Policy Group, Organic Research Centre, Elm Farm and Game & Wildlife Conservation Trust. Available at: http://publications.naturalengland.org.uk/publication/6746975937495040

Leippert, F., Darmaun, M., Bernoux, M. and Mpheshea, M. (2020) 'The Potential of Agroecology to Build Climate-resilient Livelihoods and Food Systems', Rome. FAO and Biovision. Available at: https://doi.org/10.4060/cb0438en

Makumba, W., Janssen, B., Oenema, O., Akinnifesi, F.K., Mweta, D. and Kwesiga F (2007) 'The Long-term Effects of a Gliricidia-maize Intercropping System in Southern Malawi on Gliricidia and Maize Yields and Soil Properties', *Agriculture, Ecosystems & Environment*, vol. 116, 85–92.

Moebius-Clune, B.N., Moebius-Clune, D.J., Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., Ristow, A.J., van Es, H.M., Thies, J.E., Shayler, H.A., McBride, M.B., Kurtz, K.S.M., Wolfe, D.W. and Abawi, G.S. (2016) *Comprehensive Assessment of Soil Health – The Cornell Framework*, Edition 3.2. New York: Cornell University.

Mockshell, J. and Kamanda, J. (2018) 'Beyond the Agro-ecological and Sustainable Agricultural Intensification Debate: Is Blended Sustainability the Way Forward?', *International Journal of Agricultural Sustainability*. Available at: https://doi.org/10.1080/14735903.2018.1448047

Newton, P., Civita, N., Frankel-Goldwater, L., Bartel, K. and Johns, C. (2020) 'What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes', *Frontiers in Sustainable Food Systems*, vol. 4, p. 577723.

Niggli, U., Sonnevelt, M. and Kummer, S. (2021) ‘Pathways to Advance Agroecology for a Successful Transformation to Sustainable Food Systems’, *Food Systems Summit Brief prepared by Research Partners of the Scientific Group*. Available at: http://doi.org/10.48565/

Nguyen, H. (2018) ‘Sustainable Food Systems Concept and Framework’, Food and Agriculture Organization of the United Nations: Rome, Italy. Available at: https://www.fao.org/publications/card/en/c/CA2079EN/

Ogunyemi, A.M., Otegbayo, B.O. and Fagbenro, J.A. (2018) ‘Effects of NPK and Biochar Fertilized Soil on the Proximate Composition and Mineral Evaluation of Maize Flour’, *Food Science & Nutrition,* vol. 6, pp. 2308–2313.

Parmentier, S. (2014) ‘Scaling-up Agro-ecological Approaches: What, Why and How?’ Oxfam Solidarité.

Pretty, J.N., Toulmin, C. and Williams, S. (2011) ‘Sustainable Intensification in African Agriculture’, *International Journal of Agricultural Sustainability,* vol. 9 (1), pp. 5–24.

Schader, C., Grenz, J., Meier, M. and Stolze, M. (2014) ‘Scope and Precision of Sustainability Assessment Approaches to Food Systems’, *Ecology and Society,* vol. 19 (3), p. 42.

Schoonhiven, Y. and Runhaar, H. (2018)’ Conditions for the Adoption of Agro-ecological Farming Practices: A Holistic Framework Illustrated With the Case of Almond Farming in Andalusia’, *International Journal of Agricultural Sustainability*, vol. 16 (3), pp. 1–13.

Sida, T.S., Baudron, F., Hadgu, K., Derero, A. and Giller, K.E. (2018) ‘Crop vs. Tree: Can Agronomic Management Reduce Trade-offs in Tree-crop Interactions?’ *Agriculture, Ecosystems & Environment*, vol. 260, pp. 36–46.

Struik, P.C. and Kuyper, T.W. (2017) ‘Sustainable Intensification in Agriculture: The Richer Shade of Green. A Review’, *Agronomy for Sustainable Development*, vol. 37, p. 39.

Thierfelder, C. and Wall, P.C. (2009) ‘Effects of Conservation Agriculture Techniques on Infiltration and Soil Water Content in Zambia and Zimbabwe’, *Soil & Tillage Research Journal,* vol. 105, pp. 217–227.

von Braun, J., Afsana, K., Fresco, L.O. and Hassan, M. (eds.) (2021) ‘Science and Innovation for Food Systems Transformation and Summit Actions’, Papers by the Scientific Group and its partners in support of the UN Food Systems Summit. Available at: https://sc-fss2021.org

Wezel, A. and Silva, E. (2017) ‘Agroecology and Agro-ecological Cropping Practices’, pp. 19–51: In: *Agroecological Practices for Sustainable Agriculture: Principles, Applications, and Making the Transition,* World Scientific, New Jersey, USA, 978-1-78634-305-5.