Agroecology for Agricultural Soil Management

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N. C. Temegne, A. F. Ngome, A. P. Agendia, and E. Youmbi

Abstract

The ever-growing planet population will reach 10 billion in 2050 according to estimates. The current agricultural and food system demonstrates every day a little more its inability to feed this population adequately. More than 10.7% of the current world population suffers from chronic undernourishment. The soaring world population has resulted in multiple environmental damages: the destruction of forests, overconsumption of water reserves, extensive use of pollutants, soil degradation, etc. However, a majority (72%) of the worldwide food is cultivated and gathered by 2.5 million smallholder producers on small family farms (<1 ha). Agroecology offers concrete solutions to climate breakdown and contributes to the preservation of natural resources essential for sustainable agricultural production. The soil support for agriculture can be well managed by adopting cultivation techniques, associated with plant cover of the soil (green manures, alley or mixed cropping with agroforestry species) and vigorous biological activity, by limiting or eliminating chemical fertilizer use, prioritizing local inputs and recycling of farm by-products (manure, compost, bio-char, crop waste, household waste), maintaining inherent fertility of soil, conserving soil biodiversity, and enhancing plant nutrient availability.

Keywords

Food system · Manure · Natural resources · Nutrient availability · Soaring world population · Soil biodiversity

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Abbreviations

ADG	Aide au Développement Gembloux
AFOP	Agropastoral and Fishing Training Programme
AMF	Arbuscular Mycorrhizal Fungi
CEFRA	Centre de d'Enseignement, de Formation et de Recherche en Agroécologie
CEFREPADE	Centre Francophone de Recherche Partenariale sur l'Assainissement, les Déchets et l'Environnement
CIRAD	The French Agricultural Research Centre for International Development
ELD	Economics of Land Degradation
FAO	Food and Agricultural Organization
FNRS	National Fund for Scientific Research
GESCOD	Grand Est Solidarités et Coopérations pour le Développement
IFOAM	International Federation of Organic Agriculture Movements
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPM	Integrated Pest Management
IRAD	Institute of Agricultural Research for Development
ISSAEER	Institut Supérieur des Sciences Agronomiques, de L'Environnement et de l'Entrepreneuriat Rural
N	Nitrogen
NGO	Nongovernmental organization
OC	Organic carbon
OM	Organic matter
P	Phosphorus
PGPR	Plant growth-promoting rhizobacteria
SOCLA	Latin American Scientific Society of Agroecology
UN	United Nations
UNCCD	United Nations Conventions to Combat Desertification

9.1 Introduction

In 2100, the world population intended to attain 11.2 billion. However, more people (9 million) are dying of hunger each year than from AIDS, malaria, and tuberculosis altogether (UN 2018). One child (under 15 years old) dies every 5 s from hunger or related causes in 2017 (Sidhu 2020). The tremendous increase in food productivity during the past 50 years has decreased the frequency of acutely hungry people in the world. But, this agricultural system has shown many limits, among which excessive specialization and the tendency to gigantism. We can also note the explosion in the use of energy-consuming inputs and equipment and the decrease in the efficiency of the use of chemical inputs. For example, there has been stagnation in cereals (winter wheat, barley, oats, durum wheat), sunflower (*Helianthus* spp.), and vine yields in France since the late 1990s (Schauberger et al. 2018).

The substantial gains in the production of conventional farming have been also accompanied by high environmental costs/problems, which have affected the health of soils and ecosystems (FAO 2015; Kumar et al. 2020). Thus, 12 million hectares (i.e., 23 per minute) of agricultural land are damaged broadly to soil deterioration each year which represents over half (52%) of fertile soils food producers in the world (UNCCD 2015), with 78% of overall deteriorated soil localized in earthly ecosystems other than arid areas (UN 2012). Land degradation affects 1.9 billion hectares. It is costing each year between 6.3 and 10.6 trillion US dollars taken as a whole (ELD 2015). Twenty-four billion tons of fertile land is irreversibly laved or carried away (3.4 tons for each person on the earth) each year because of the erosion of the world's cultivated land (Young et al. 2015). Thus, soil deterioration has diminished the productivity of 23% of the worldwide land surface, and up to US $577 billion in annual cultivated plants of the world are at riskiness from pollinator loss (Brondizio et al. 2019; Díaz et al. 2019).

Soil degradation is a worldwide problem which is currently receiving a lot of attention (Xie et al. 2020; Khan et al. 2021a, b). However, the agribusiness model remains the model mostly taught in schools and universities and widely promoted by research centers, most producer organizations, and technical services. Smallholder farmers remain the leading providers of food (72%) but paradoxically are the first to suffer from poverty and hunger. It is therefore essential to refocus our agricultural model, particularly on peasant women to sustainably feed the populations (ADG 2016). The current challenge for agricultural policy is to combine sufficient food production for a growing community ensuring environmental restoration (FAO 2015; Banerjee et al. 2020, 2021; Raj et al. 2020). By preserving soil health, agroecology, which regenerates the functioning of ecosystems, is an effective strategy for achieving food security (FAO 2015; Jhariya et al. 2019a, b, 2021; Meena et al. 2020a, b, c).

By mastering and laboring with the interactions between land, crops, beasts, human being, and the environment in farming systems, agroecology integrates manifold dimensions of the agricultural system, enclosing ecological rehabilitation, political and social steadiness, and economical sustainability. This chapter expands the principles of agroecology, soil conservation through the management of soil composition, cultural techniques and fertilization, the constraints to adoption of agroecology, agroecology versus conventional agriculture, agroecology towards soil management and sustainability, policy and legal framework, and future roadmap of agroecology for agricultural soil management

Table 9.1 Definition of agroecology

Definition of agroecology	Reference
The implementation of ecological tenets to agriculture	Altieri (1983a)
"The application of ecological science to the study, design and management of sustainable agroecosystems"	Gliessman (1997)
An interdisciplinary process that involves a redefinition of scientific and social boundaries, which constitutes an important intellectual defiance for agricultural research	Buttel (2003)
The integrative investigation of the ecology of all food systems, including ecological, economic, and social aspects	Francis et al. (2003)
It is defined neither exclusively by scientific disciplines, social movements, nor by practices	Wezel et al. (2009)
An intrinsically transdisciplinary practice, as it binds the organization and operating of agroecosystems and fills the ditch between various disciplines as good as between theory and practice	Caporali (2011)
New agricultural template that could allegedly conciliate the economic and environmental defiance in food production	Schaller (2013)
For Pierre Rabhi, it is more than a simple agronomic option; it is linked to a deep dimension of respect for life and places the human being in his responsibility towards the living; it is both an ethics of life and agricultural practice	Lion et al. (2009), ADG (2016)
The study, application, and defense of concepts, principles, and methods aimed at the establishment of agroecosystems and sustainable food systems from the point of view productive, environmental, social, cultural, and economic	Gliessman (1997), ADG (2016)
The development of agricultural techniques to safeguard the environment and to favor the utilization of ecological theory to promote "eco-friendly" means to make food	Saj et al. (2017)
A scientific search on coming ensuring the holistic investigation of agroecosystems and agricultural commodities systems	CIDSE (2018)
One of a family of varied methods sharing a usual feature in that they involve the ecological roles of farming systems to assure long-lasting production	CIRAD (2018)
A scientific discipline, an ensemble of processes, and a societal movement	FAO (2018)
The science and method of implementing ecological notions, tenets, and acquaintance to the investigation, designing, and management of sustainable agroecosystems	IPBES (2018)
An alternative template for promoting farming systems founded on every farm being a consolidated ecosystem, in which plants and animals interact to generate suitable provisos for cultivation	Lund University (2018)
The investigation of the ecology of earthly farming systems	Nature (2018)
An interdisciplinary merger of agronomy, agriculture, scientific ecology, economics, and social sciences	Youmatter (2020)

9.2 Agroecological Concept

Agroecology is a concept defined in various ways (Table 9.1). Agroecology combines practices such as ecological farming, regenerative farming, and certain features of permaculture and thus competes with sustainable development (Youmatter 2020). With the ambition of producing knowledge and methods that make agriculture more sustainable, agroecology concentrates on the whole farming system to go beyond the scale of the plot. Indeed, it focuses on the analysis of agroecosystems and their sustainability (Stassart et al. 2012; Raj et al. 2021). Therefore, a whole of agricultural practices are aimed towards imitating nature in its field. As a science, it investigates how various constituents of the agroecosystem interact. As a whole of operations, it searches long-lasting agricultural systems optimizing and hold steady yields. As a social movement, it prosecutes multifunctional purposes for agriculture, encourages societal justness, feeds identity and culture, and reinforces the economic viability of peasant zones (FAO 2018).

Based on traditional peasant practices, agroecology links several alternatives such as organic farming, permaculture, and natural farming, without being reduced to it. These practices being drawn mainly from the traditional knowledge of the agricultural populations allow agroecology to spread quickly through communities and small family farms. The application of ecological principles to these ancestral techniques is, therefore, the basis of agroecological practices (Altieri and Nicholls 2014; Meena et al. 2020a).

Agroecology was first used by Bensin 1928, a Russian agronomist, who used it to designate “gentle” agronomic techniques in cash crops. The meaning and scope of the term have evolved. At first, it was considered as a scientific discipline linked to agricultural production, which combines ecology and agronomy. Currently, it is defined as a whole of process, a scientific discipline, and a movement (ADG 2016).

The practices are very diverse. In tropical zones, they include fertility management, soil (and water) conservation, pest control, water management, management of crops on the farm, livestock, etc. In the 1980s, agroecology appeared as an ensemble of agricultural activities. Traditional farming systems in developing countries are beginning to be recognized for their benefits in the management of natural resources. Peasants from the south are capable of combining traditional knowledge and know-how and innovation and sometimes helped by international cooperation or the scientific community. They develop and adopt specific techniques, thus gradually generating a set of agroecological practices, demonstrating that the solutions also come “from below.”

As a scientific discipline, the field of study of agroecology has evolved considerably. It went from managing the plot to the ecology as well as agroecosystems management and the organization/structure of the food production system (three dimensions). In response to the green revolution, ecological movements were born in the 1960s and 1970s. It is a mixed discipline, at the crossroads of natural, social, and economic sciences which is today an alternative scientific referent. Indeed, agroecology entered into university courses in the USA in 1981 (Berkeley) and more generally from 2000, in Brazil (Santa Catarina in 2000), Belgium (University

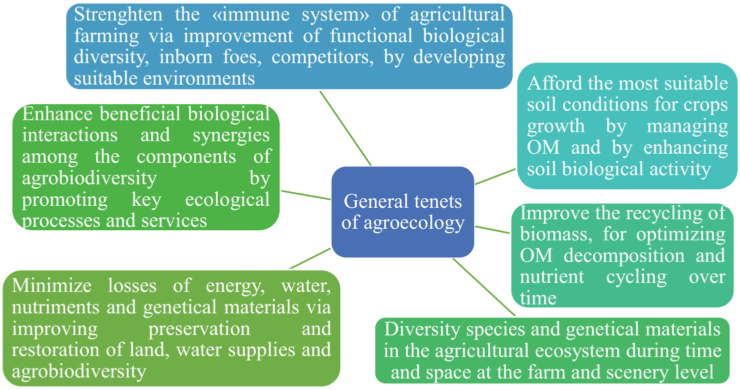

Fig. 9.1 General principles of agroecology (source: Migliorini and Wezel 2017)

Libre of Brussels in 2008), etc. Research groups like SOCLA (in 2007) in Latin America and FNRS (in 2009) in Belgium have shown their interest in this science (Altieri 1983b; ADG 2016).

The first agroecological social movements, in the south (particularly in Latin America) and the north (especially in the United States) appeared in the 1980s. It began in Mexico and Central America in the 1980s with associations (NGOs: World Neighbors, CLADES) and scientists (Bunch, Altieri) close to peasants and natives. It was presented as an alternative to industrial agriculture with high levels of chemical inputs. In Latin America, it is adopted by Via Campesina (food sovereignty, peasant agriculture, and agroecology), the network of producer actors and sympathetic organizations (Prolinnova), etc. (De Schutter 2011).

Based on the existing literature, Migliorini and Wezel (2017) summarized the principles of agroecology, as shown in Figs. 9.1 and 9.2. The success of novel farming systems depends on the application of the tenets of agroecology (Nicholls et al. 2016), making reference to the popularization of practices and serves ecology, enclosing land, water, air, and biological diversity dimensions. Thus, the straightforward implementation of a set of practices is not sufficient. Stassart et al. (2012) and Dumont et al. (2016) also append three socioeconomic tenets (Fig. 9.2) to the other tenets more linked to production and ecology.

Regarding the principles of agroecology for animal production systems, Dumont et al. (2013) complete the above tenets in Fig. 9.2. They can be summarized in two tenets: (a) adopting a management process aimed at improving animal health and (b) strengthening diversity in animal farming to enhance their resilience.

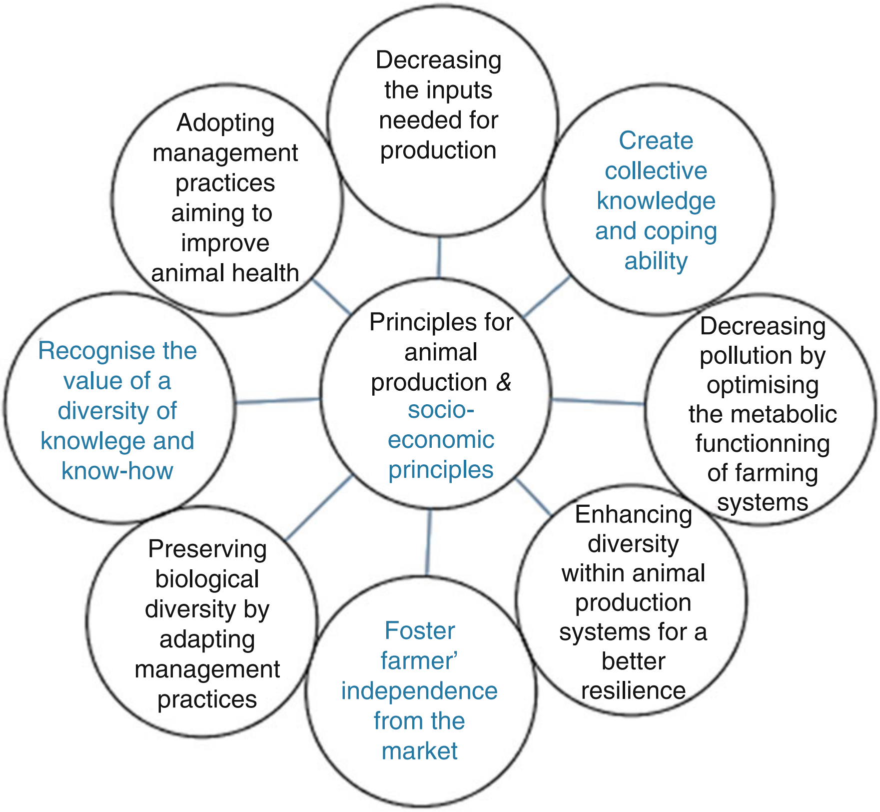

Fig. 9.2 Socioeconomic principles of agroecology and principles for animal production systems (source: Migliorini and Wezel 2017)

9.3 Agroecology and Soil Characterization

Soil is the substrate that nourishes and supports growing plants. It is composed of 25% air, 25% water, 50% solid components (by volume), and 0%, 17%, and 83% (by weight), respectively (Parker 2009). Soil is essentially a nonrenewable resource because the formation processes are prolonged while the degradation processes can be very rapid. It is a fusion between the mineral (clays) and organic (humus) with an average ratio of 16/1 by volume and 40/1 by weight. The living constitutes 0.15 to 0.2% of the soil (by weight). Soil contains 80% of the living organisms (by weight) on earth. The living organic components of the soil include the fauna (between 2.5 and 5 t ha^{-1}) consisting of earthworms, fungi, bacteria, nematodes, springtails, termites, and plants consisting mainly of roots and algae.

Soil microorganisms perform several ecosystem services and functions in the soil.

9.3.1 Soil Structuring Function

It is made through the development of stable aggregates, a macro- and a micro-porosity. Roots, mycelial hyphae, vertebrates, and invertebrates burrowing create numerous galleries in the soil resulting in high porosity of the surface layer of the soil (Huera-Lucero et al. 2020). AMFs secrete a glycoprotein (glomalin) which promotes aggregation (Vlček and Pohanka 2020). This substance cements clay particles and organic debris giving macroaggregates. Fungi and saprophytic bacteria produce exo-polysaccharides (Costa et al. 2018). Earthworms ensure the formation of the clay-humic complex. They come up every night to get litter and then they leave their droppings on the soil surface (formation of turricules). They continuously brew deep clay-rich soil with surface soil rich in humus. These earthworms consume the equivalent of their weight of soil per day (Misra et al. 2003). Termites are responsible for the creation of fecal pellets very resistant to the elements of the climate, which explains the high permeability of the oxysol from tropical rain forests. They feed on lignified plants and undecomposed wood. Their gut contains flagellated protozoa that digest cellulose and bacteria that digest lignin (Ali et al. 2019).

9.3.2 Nutrient Recycling Function

Bacteria oxidize NH_4^+ ions (*Nitrobacter*) and sulfur and ensure the chelation of trace elements (Fe, Al, etc.). The root systems of plants associated with mycorrhizae also participate in this recycling process through the networks (hyphae + roots) that they develop in the plant rhizosphere (Temegne et al. 2018, 2019; Giovannini et al. 2020).

9.3.3 Function of Decomposition, Mineralization, or Humidification of Soil Organic Matter

Many soil organisms feed on different trophic levels which abet to the intricacy of food dealings, and this conducts to effective recycling of organic matter and a net release of nutrients.

The grinding is mainly done by first- and second-order consumers. It accelerates the decomposition of residues because it blends fungi and bacteria with the residuals by increasing the zone colonizable by decomposers. The mesofauna (mites, springtail, termites, and enchytreid worms) and the macrofauna (woodlice, millipedes, beetles, ants, earthworms, snails, and slugs) abet in the grinding and recycling of organic residuals. They also drop off in the soil fecal pellets of 50–200 μm in diameter which are a prime substrate for decomposers (rich in energy and N) (Brussaard and Kooistra 2013). Earthworms also mix the upper mineral strata of the land with surface residuals (bioturbation phenomenon) and create pores and conduits allowing the passage of water and roots. Nematodes and small epigree earthworms eat the finer fractions as well as the excrement of other species.

Thysanoure, springtails, mites, myriapods, earthworms, and protoures eliminate dead roots, ensure porosity of the soil deep in the soil, and allow root respiration.

Saprophytic bacteria (first-order consumers) produce many exoenzymes (dehydrogenases, proteases, and cellulases) which allow them to degrade dead organic matter and draw their energy from a wide range of carbon products (Shalaby 2011). Numerous heterotrophic bacteria ease wrench changes of diverse nutrients other than carbon (N, P, S, K, Mg) in their cycles. They enhance and structure by generating exopolysaccharides and other metabolites that help to stick the particles together (Costa et al. 2018).

Fungi (first-order consumers) also produce many exoenzymes that break down dead organic matter. They are the primary agents for the decomposition of organic matter in exposed lands (saprophytes). They are the only organisms on earth, apart from a few bacteria in the rumen of cattle and the intestine of termites that can break down lignin from plants (the main source of humus). Fungi help to stabilize soil aggregates via their filamentous hyphae (Lehmann et al. 2020).

Actinobacteria (first consumers), less competitive than bacteria and fungi in breaking down fresh organic matter, continue to decompose the organic matter started by fungal and bacterial microflora (Matei et al. 2020). Thermophiles have a significant function in the manufacturing of compost. Between 50 and 75% of the strains secrete antibiotics which prepare ecological niches for fungi in composting (Carrasco and Preston 2020).

Browsers and shredders (first-order consumers, second-order predators) feed on bacteria, *Actinobacteria*, and soil fungi. They therefore carry out grazing. They can also consume organic matter. They feed on N-rich bacteria and reject great quantities of inorganic N and have a very important role in the recycling of mineral elements. They consist of protozoa which swallow up their prey; bacteria that enter and multiply in larger bacteria; nematodes that sweep or suck bacteria from the surface of the roots or minerals and suck the inside of the fungus with a stylus; and micro-arthropods (mites and springtails).

Micro-arthropods (second-order consumers) achieve fragmentation and restructuring physics of organic matter by chewing. This process leads to the aggregation of minerals followed by an increase of the soil surface components, which favors the bacterial activity and a more advanced decomposition of the residues (Culliney 2013).

The "grazing" nematodes (second-order consumers) are very beneficial in edaphic ecosystems. They help to control the size and structure of populations of bacteria and fungi (Ferris et al. 2004; Blanc et al. 2006). They help to speed up the recycling of nutrients.

Consumers of third-order and more (nematodes and arthropods) are the predators of different species of spiders, beetles, and ants (SWCS 2000; Menta and Remelli 2020). They can help to regulate populations of major pests.

9.3.4 Function of Facilitating the Removal of Water and Nutrients

Mycorrhizae (ecto- and endo-mychorizes) release the phosphate ions fixed by the clay-humic complex. They improve the water supply of plants through their hyphae which will draw water from the depths of the soil (Tsoata et al. 2015).

9.3.5 Atmospheric Nitrogen Fixation Function

Several soil microorganisms, free or symbiotic, have the ability to fix atmospheric N and allocate it to crops (Table 9.2).

9.3.6 Function of Protection of Plants Against the Invasion of Root Pests

Microorganisms protect plants by competing in the space in the soil. AMF creates a protective sleeve against pathogens. Beneficial nematodes compete with herbivorous nematodes. They produce the antibiotics that control *Pithium* sp. and *Pseudomonas* sp. For example, there is emission by the roots of corn in the event of insect attacks of molecules attracting entomophagous nematodes (Degenhardt et al. 2009).

The major component of soil OM is organic carbon (OC). It has a pivotal role in crop production and is the most useful single signpost of soil quality (Ngome et al. 2011a; Soil Carbon Initiative 2011). OM is a wrench element in the land, monitoring several fundamental functions (Jones et al. 2011; Kumar et al. 2020a). OC enhances the physical characteristics of land which raise the degree to which it can soak up rainfall and hold water, making it disposable for afterwards plant use, reduce leaching, and enhance microbial biomass activity and biodiversity of soil. The loss of OM in lands is caused by erosion and the raised rate of mineralization of OC in arable lands (Krasilnikov et al. 2015). Low OC level in soils leads to more crop susceptibility to disease (Altieri and Nicholls 2003; Stone et al. 2004).

Cultivation techniques have an impact on soil characteristics (Fig. 9.3). Tillage practices can be classified into three types of action: depth of fragmentation, soil turnover, and soil organic matter blending (Labreuche et al. 2007).

Tillage or plowing is a deep working operation (between 15 and 40 cm) with turning of the soil and blending of its horizons (Labreuche et al. 2007). It distributes basal dressing and amendments throughout the topsoil, controls weeds and regrowth, buries crop residues, loosens surface layers, and improves drainage (drying) of wet or drained soils. It can also be used to destroy intermediate crops (Daniel and Galardon 2008).

Pseudo-tillage or pseudo-labor is a deep working operation (between 15 and 40 cm) with the blending of horizons without turning over. The absence of inversion results in some plant debris and unburied weeds on the surface (Daniel and Galardon 2008). The presence of surface residues sharply limits erosion which provides

Table 9.2 Atmospheric nitrogen fixation function of soil microorganisms (compiled from Kitamura et al. 2011; Munk et al. 2011; Yang et al. 2016; Zeng et al. 2017; Bhowmik and Das 2018; Troost et al. 2019; Contador et al. 2020; Giraldo-Silva et al. 2020; Inomura et al. 2020; Mahmud et al. 2020; Robledo et al. 2020; Silva et al. 2020)

Types	Hosts/traits		Examples
Free	Aerobic	Phototrophs	*Cyanobacteria*: *Nostoc* spp., *Anabaena* spp., *Calothrix* spp., *Tolypothrix* spp., etc.
		Heterotrophs	*Aeschynomene* spp., *Azoarcus* spp., *Azospirillum brasilense*, *Azospirillum lipoferum*, *Azotobacter vinelandii*, *Beijerinckia indica*; *Herbaspirillum seropedicae*, *Klebsiella pneumonia*, *K. oxytoca*, *Pseudomonas putida*, etc.
	Anaerobic	Phototrophs	*Chromatium vinosum*, *Rhodobacter capsulata*, *Rhodospirillum rubrum*, etc.
		Heterotrophs	*Clostridium*, *Azotobactor*, *C. pasteurianum*, *Desulfovibrio vulgaris*, *Desulfotomaculum* spp., *Methanobacterium* spp., *Pseudomonas stutzeri*, etc.
Symbiotic	Leguminous	With root nodules	*Allorhizobium* sp., *Azorhizobium* sp., *Bradyrhizobium elkanii*, *B. japonicum*, *Ensifer meliloti*, *Mesorhizobium ciceri*, *M. lot*., *Rhizobium etli*, *R. leguminosarum*, *R. lupine*, *R. meliloti*, *R. phaseoli*, *R. trifolii*, *R. tropici*, *Sinorhizobium fredii*, *S. meliloti*, etc.
		With stem nodules (*Sesbania*)	*Azorhizobium caulinodans*, etc.
	Cereal	Rice (*Oryza sativa* L.), sugar canes (*Saccharum* spp.)	*Azotobacter*, *Clostridia*, *Gluconacetobacter diazotrophicus*, etc.
	Others crops	Sweet potato (*Ipomoea batatas* L.), storage tubers	*Azospirillum* sp., *Bradyrhizobium* spp., etc.
	Actinorhizal symbiosis	*Casuarina* spp.	*Frankia* sp., *Parasponia* sp., etc.
	Cyanobacterial symbiosis	Azolla	*Anabaena azollae*, etc.
		Cycas	*Anabaena cycadeae*, etc.
		Lichens	*Nostoc* sp., etc.
		Mosses and liverworts	*Nostoc* sp., etc.

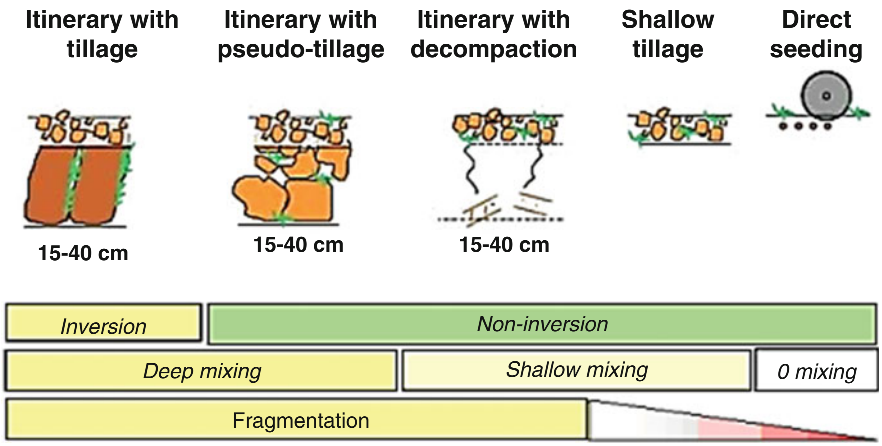

Fig. 9.3 Cultivation techniques (modified by: Daniel and Galardon 2008; Labreuche et al. 2008)

protection to the land (reducing the effect of raindrops) and the presence of more stable aggregates.

For the decompaction, the work of the soil is deep without turning, nor mixing. Like plowing, it is done at a depth of between 15 and 40 cm. This operation restructures the soil by fragmenting and lifting it. Many farmers talk about loosening or cracking, but in fact, loosening also induces soil fragmentation (Labreuche et al. 2008).

For shallow tillage, the tillage is between 0 and 8 (15) cm deep. It includes a mixture of crop residues in the volume worked but without reversal. There are several types of surface work, depending on the objectives sought: stubble cultivation, resumption of plowing, preparation of the seedbed, mechanical weeding, etc. (Labreuche et al. 2007).

Direct seeding (no tillage) is the sowing or planting of a crop without tillage. We can have three variables:

- Direct sowing without any work, i.e., no rotary hoe passing over the sowing line; the seeds are placed in the soil just after the opening disc(s); frequent cases for cereals
- Strip tillage, i.e., the passage of a rotary hoe on flat land, on a sowing strip 10 cm wide and a few centimeters deep just in front of the sowing organ; reasonably common case for weed crops
- Ridge tillage, i.e., identical to strip tillage but on hilly terrain; potato plantations and weed crops (Labreuche et al. 2007)

This minimum work results in the maintenance on the surface of almost all the crop residues and organic inputs. This technique reduces costs and time. It saves a lot of energy. The aim is to limit vertical disturbances to the ground as much as possible and to maximize the coverage by residues with minimum working technique (Daniel and Galardon 2008). But, this technique requires more technicality and observation because the most "simplified" implementations are the most demanding ones (Labreuche et al. 2014).

The characteristics of the soil have a significant influence on the effectiveness of the farming techniques adopted. In terms of soil texture, it is on clay soils that the efficacy of no-till cultivation techniques to limit erosion is most convincing (Rhoton et al. 2002). On sandy soils, their effectiveness seems lower (Quinton and Catt 2004) while on loamy soils, the results are very variable and depend mostly on other parameters such as soil cover. No-till farming techniques are useful in combating soil loss on clay soil. The effectiveness of direct seeding compared to plowing on limiting runoff is more convincing on clay soil than on loamy clay soil (77% less runoff volume with clay soil and 17% less volume runoff with loamy clay soil) (Rhoton et al. 2002). As for erosion, it is reduced to zero with direct seeding on both types of soil.

Structural stability is lower in conventional systems on all soils. However, with an augmentation of the clay content of soils, the differences between plowing and non-plowing become blurred. The less the soil is worked in-depth, the more the structural stability of the surface increases. This increase in structural stability results from the concentration of OM in the surface horizon and the increase in content in this horizon (Labreuche et al. 2007). It is the accumulation of OM on the surface by no-till farming techniques that improves the stability of aggregates. This accumulation phenomenon is directly reversible on first deep tillage or plowing (Rhoton et al. 2002). Thus, the use of occasional plowing cancels any accumulation effect on the soft soils. On clay soil, it is the high clay content which gives higher structural stability. The OM effect on the balance of aggregates is not very sensitive (Le Bissonnais and Arrouays 1997).

The stock of organic N in the soil is higher for direct seeding than for plowing whatever the horizon of the soil is considered (Mikha and Rice 2004; Wright and Hons 2005a, b).

9.4 Problems of Soil Environment

The cumulative mean loss of production during the post-World War II period caused by human-provoked land deterioration has been esteemed at 7.9% in Africa whereas it was 25% and 36.8% at Central America in accordance with ISRIC estimation (Krasilnikov et al. 2015). Each minute, 23 ha of land is lost to land degradation (12 million ha year^{-1}) (Rossi 2020). Twenty-four percent (350 lakh km^2) of the soil has deteriorated which is raising the proportion of 50–100 lakh ha year^{-1} (Vasu et al. 2020). The mean richness of indigenous species is most considered as land-based habitats have dropped by at least 20%, mainly since 1900 (Brondizio et al. 2019). So, several environmental constraints such as acidification, alkalinity, climate change, desertification, compaction, drought, erosion, nutrient deficiency, salinity, pollution, waterlogging, etc. affect the soil and reduce the area of soil available for agriculture. Most of them are caused by the intensification of food production (Altieri and

Nicholls 2015). However, to feed the growing world population, it is necessary to implement strategies to produce on these soils (Raj et al. 2019a, b).

Acidification implies the shedding of basic cations (e.g., Ca, Mg, K, Na) by leaching and their substitution with acidic compounds, primarily soluble complexes of Al and Fe, and Mn sometimes. It thus leads to aluminum, ferric, and manganese toxicity (Chérif et al. 2009; Mapiemfu-Lamaré et al. 2012; Tekeu et al. 2015). Acidification is constantly followed by a diminution in the land's ability to neutralize acid and a process of an irrevocable nature excluded during very long periods (Krasilnikov et al. 2015). An augmentation in pH and acid neutralization capacity associated with higher concentrations of basic cations, in turn, would enhance the potentialities for biological recuperation. But, given the retard in the land's reply to the diminutions in acid deposition, it will likely take several decenniums for the impacted zones to recuperate wholly (Krasilnikov et al. 2015). Soil acidity is generated by climate, acidic parent material supplying Al and Si ions, NH_4 fertilizers, OM breaking down, abduction of nutrients via harvesting of high yielding plant, and weak tampon ability from little clay and OM and Al_2SiO_5 minerals (Getachew et al. 2019).

Climate change is presumably to influence land grade and generate soil degradation by modifications in land water content (Wong et al. 2011; García-Ruiz et al. 2011; Khan et al. 2020a, b). It aggravates land deterioration, especially in low-lying coastal regions, river deltas, drylands, and permafrost regions. Climate change, land-use change, and land-use intensification have abetted to desertification and land deterioration (IPCC 2019). Across the North and the Centre of Europe, evapotranspiration raised through approximately 0.3 mm day^{-1}, which has the potential to exhaust the generally suitable land water reservoir and restrict crop growth. More recurrent and drastic droughts can conduct to a reduction in plant cover leading to the start of erosion and desertification (Jones et al. 2011). But, the precise effects of climate change on land deterioration are still unclear (Kovats et al. 2014).

Desertification is soil deterioration in arid, semiarid, and dry subhumid regions, generally recognized as drylands, arising from several elements, encompassing human actions and fluctuations of climate (UNCCD 1994; Mirzabaev et al. 2019). The range and loudness of desertification have risen in certain arid regions for the past few decades. Arid soils presently extend over about 47% worldwide and are residence of about 39% of the worldwide population (3 billion people). Desertification hotspots, as distinguished by a decrease in flora production in the space separating the 1980s and 2000s, expanded to nearly 10% of drylands influencing 620 million people in 2015 (Mirzabaev et al. 2019). According to Prince and Podwojewski (2020), desertification results in the following:

- Gulley erosion due to loss of soil cover engendered by overgrazing
- Sheet erosion exhibiting roots and slaying trees
- Forest defacement and deforestation
- Wildfire which generates biomass loss, nutrient losses via volatilization, quickened erosion, forming of water repulsive surfaces inclined to water runoff and

erosion, and rising CO_2 release and is occasionally accompanied by invasions of alien species

- Soil compaction alongside cattle paths particularly where they assemble to drink, diminished precipitation permeation, and raising runoff, which, in turn, can generate erosion
- Habitat loss that imperils indigenous species
- Dust storms and loss of topsoil engendered by bare soil in farms, particularly extensive, motorized, dryland agriculture
- Salt efflorescence generates by over-irrigation
- Unmonitored populations of savage animals that pasture and nibble helpful flora
- Bush encroachment, frequently assigned to overgrazing in dryland, modifications in fire regimes, land surrender, and CO_2 rise
- Alien species establishing
- Reduction of biological diversity engendered by habitat loss
- Overgrazing by livestock causing erosion and loss of soil C.

Human and nonhuman provoked land salinity is being an important worldwide menace to farming around. This salinization happens in watered and pluvial farming areas with the most important rates in the arid and semiarid ecosystems. Human and nonhuman induced land salinity is becoming an important worldwide menace to farming. The nonhuman-provoked land salinity are salts initially present into parent materials, mineralized floor and surface waters as well as wind-blown depots (Vargas et al. 2018). Poor irrigation and the utilization of extremely mineralized irrigation water impact approximately 3.8 million ha in Europe (Masters et al. 2005; Krasilnikov et al. 2015). Salinization has a severe effect on land functions like its capacity to proceed as a tampon and filter versus pollutants. Its involvement in the water and N cycles and its ecosystem services favor the healthiness of the environment and biological diversity (Vargas et al. 2018). Land salinization affects the agricultural production by entraining disturbances to the processes of N uptake and crop growing. The reduction of biological activity of lands is combined with the diminution of food provided by land microflora requisite for ecosystem functioning. The surrender of arable lands is linked with a high risk for land and environmental health and important ecological stress. An augmentation in land salinity further damages land ecosystem services and reduces incomes for farmers and smallholders. The loss of original vegetation and forests is the final result of the salinization of arid agricultural soils (Vargas et al. 2018). To maintain or colonize saline soils, it is recommended:

- To select and use salt-tolerant plants
- Promote the salt-tolerant pastures where livestock can help in the management and restoration of soil
- Enhance the land for growth of substitute less salt-tolerant crops
- Employ a surplus of water to rinse off salts from the land (flushing)
- Optimize the irrigation and drain management

- Make the mulching, alone or with amendments, it usually conserves yield with satisfying outcomes diminishing salinity
- Add biological land conditioners, it raises yield while diminishing salinity and can proceed better in association with other land amendments
- Reduce tillage, it lessens salinity and rises productivity
- Realize phytoremediation, it augments productivity but does not ensure positive impacts on land salinity
- Advise rotation systems
- Utilize the trees and shrubs with the ability to efficaciously proceed as bio-drains in saline (Clarke et al. 2002; Masters et al. 2005; Jhariya et al. 2018a, b; Cuevas et al. 2019).

Most hopeful for salinity is an association of amendments, conditioners, and mulching, whereas implementing rising and maintaining cover plants or rotation. Most auspicious for productivity is phytoremediation and biological conditioners whereas maintain cover crops or/and rotation (Cuevas et al. 2019).

Soil degradation and water deficiency are narrowly associated. Healthy soil has a natural ability to conserve and filter water, but this ability is lost when soil has deteriorated. Likewise, land-use modifications, like the conversion of wetlands and forests to other soil uses, disturb the water cycle and hydrological roles. Inversely, water scarcity and droughts may hasten the processes of soil deterioration (EU 2019), for example, caused by weak irrigation management and drainage and modified hydrology, leading to weaker grade lands.

9.5 Agroecology and Soil Conservation

Well-managed soils by smallholder farmers contribute to all four aspects of food security: availability, by providing the nutrients needed for plant growth (Dagnachew et al. 2020); access, by enhancing the income of family farms across more reliable crops; stability, by preserving water to allow plants to be grown almost year-round; and use, by gathering healthy and nutritious food on healthy soils (FAO 2015). Soil conservation in agroecology must promote soil protection through various techniques limiting the negative impact of harmful human intervention on the inherent structure of the soil and that of raindrops, sun, and wind. It recommends the maintenance of diversified and permanent vegetation cover, the use of mechanical or crop anti-erosion measures, and the limitation or elimination of tillage and pesticides (ADG 2016).

Soil erosion rates are higher in Asia, Africa, and South America agroecosystems (30–40 t ha^{-1} $year^{-1}$) than in the USA and Europe (17 t $ha^{-1}year^{-1}$) at the landscape level (Barrow 1991; Taddese 2001). The estimation shows that ten million ha of cropland are lost each year due to erosion (Faeth and Crosson 1994; Pimentel and Burgess 2013). The soil surfaces covered by crop biomass, the appropriate tillage, and the installation of natural anti-erosion devices (based on coconut fiber for example) contribute to fight effectively against erosion and to protect the soil.

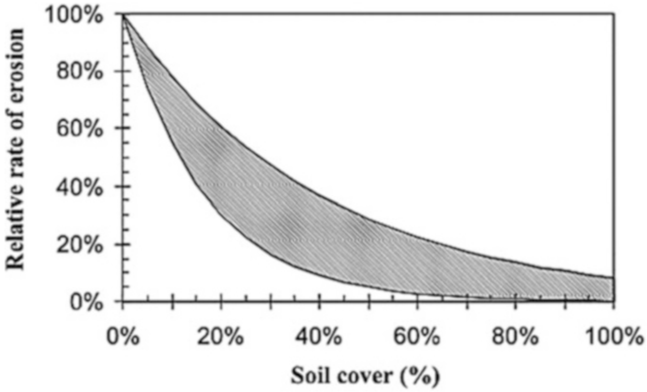

Fig. 9.4 Influence of vegetation on the relative rate of erosion (data source: ADG 2016)

High vegetation and bedding on the soil surface, whether or not linked to the use of no-till cultivation techniques, decrease the surface degradation of the soil, limit the formation and extension of a crust, and reduce the speed of diffuse runoff and water erosion (Fig. 9.4). Vegetation, therefore, helps to control runoff (Kwaad et al. 1998). Indeed, including natural and seminatural landscape components, using green manure, setting up cover crops, and relying on agroforestry are agroecological practices that contribute to soil conservation (Wezel et al. 2014; Hatt et al. 2016; Nuemsi et al. 2018). Cover crops and mulch supply nutrients to the soil. Leguminous cover crops also abet to the fixation of nitrates in the soil, the fight against weeds, the preservation of soil structure, and the conservation of humidity in the dry season or arid regions (Ngome et al. 2011b). The vegetation cover improves the porosity of the land surface. Indeed, residues kept in the upper layer of the land provide food for earthworms which rise to the surface to seize it, thus creating a natural porosity. This increased porosity makes it easier for rainwater to infiltrate, reducing runoff and erosion (Schubetzer et al. 2007). Trees, when growing among annual crops, not only change the microclimate but maintain and improve soil fertility, since their roots transport nutrients from profound land layers and make them disposable to annual plants to through their litter. This litter feeds the complex nourishing tissue of the soil. Besides, some trees enrich the soil with N and their ability to fix this element in the air (ADG 2016). For adequate soil cover, a threshold cover rate of the soil surface of 25–40% should be exceeded. In the absence of soil cover, the effectiveness of no-till farming techniques seems controversial (Kwaad et al. 1998; Heddadj et al. 2005). But, under certain conditions, no-till cultivation techniques favor the presence of plants or cover residues compared to a plowed system. In rotations with a lot of cereals, no-tillage increases the percentage of residues on 0–5 cm compared to plowing (Tebrügge and Düring 1999).

Land conservation is influenced by the type of tillage it undergoes (Fig. 9.5). Today, tillage is known as a powerful driver of the composition of microbial communities across its effect on land features (Souza et al. 2013; Degrune et al.

Fig. 9.5 Effect of cultivation techniques on soil conservation (source: Greenotec Asbl)

2017). Several authors agree that tillage, whether deep or shallow, is a threat to soils and leads to their degradation (Säle et al. 2015; Novara et al. 2019) and advocates adequate tillage (no-tillage, no turning of the soil). Tillage and secondary tillage tend to make land uniform and decrease the single microenvironments where microbial communities can live (Sengupta and Dick 2015). In no-tillage system, low soil disruption and the presence of surface residue create favorable conditions for the development of biodiversity in the soil (Daniel and Galardon 2008; Meena et al. 2020b).

But, Degrune et al. (2019) emphasize that, even if agroecological systems can favor the presence of profitable microorganisms and decrease the pressure of pathogens (Table 9.3), we cannot ultimately predict whether it will enhance agricultural productivity or other ecosystem services. There is yet sparsely proof that agricultural system favors greater microbial diversity which raises the output of agroecosystem by insuring more ecosystem roles and making it less susceptible to uttermost calamities. It emerges from the synthesis of several experimental results made by Labreuche et al. (2007) that in the absence of cover, the effectiveness of no-till farming techniques is much more controversial. Many authors agree that the

Table 9.3 Abundance and activity of earthworms according to the tillage (adapted from Tebrügge and Düring 1999; Arvalis Institut du Végétal)

Tillage practices	Number of organisms (m^{-2})	Tube volume (cm^3 m^{-2})	Biomass (g m^{-2})	Rejection of earthworms (kg m^2 $year^{-1}$)
Tillage	25	18	98	1.4
Pseudo-tillage	36	45	240	3.5
Decompaction	32	41	218	3.3
Shallow tillage	45	51	270	3.9
Direct seeding (no-tillage)	153	147	1100	11.1

use of cultivation techniques without plowing limits the formation of rills and gullies (Labreuche et al. 2007).

Unlike plowing, which tends to dilute OM in the worked horizon, no plowing concentrates OM in the surface layers. In fact, in the tests of the Arvalis Institute carried out in Boigneville from 1970 to 1998, the rate of OM was 3.6% on the surface in direct sowing whereas it was only 2% for plowing. Overall, the no-till system tends to decrease the soil porosity. Studies carried out at the Kerguéhennec experimental station, and the Boigneville station has shown a reduction in porosity of 5–10% in the unworked layers (Daniel and Galardon 2008). But, the work of Schubetzer et al. (2007) revealed that no-till cultivation techniques do not contribute to soil compaction for two main reasons: (1) this reduction in porosity remains generally limited; (2) no-till cultivation techniques favor specific mechanisms creating porosity and stabilizing the structural state which can help to reverse this trend.

According to the years, within the same experimental context, there is substantial variability in the rate of effectiveness of the same modality of cultural technique without plowing. The difference between the 2 years is 66% on average (Quinton and Catt 2004; Heddadj et al. 2005; Labreuche et al. 2007). The impact of practice can even be reversed from year to year. The test by Kwaad et al. (1998) in the Netherlands shows that for a given year, direct sowing and strip-till limit runoff on grain corn monoculture compared to plowing (−27% and −19%, respectively), while in the following year, they run more than the control mode (+15% and +50%). These differences can be linked to the variability even of the climatic years or to the crops in place at the time of the test (Quinton and Catt 2004; Rhoton et al. 2002).

The use of biopesticides in agroecology instead of the chemical pesticides commonly used in conventional agriculture contributes to the preservation of land biodiversity and therefore to land preservation. For example, the weight of earthworms is twice as high and their numbers three times higher in agroecology farming (Mader et al. 2002). Table 9.4 summarizes some biopesticides or potential biopesticides used in agroecology or organic farming in Central Africa.

Table 9.4 Some biopesticides (or potential biopesticides) used in Central Africa for sustainable agricultural production

Biopesticides	Type	Pathogen agents	Host plant	Source
Acorus calamus (L.) oil	Plant	*Prostephanus truncatus*	Corn (*Zea mays* L.)	Schmidt and Streloke (1994)
Bacillus thuringiensis	Bacteria	*Andrector ruficornis*	Potato (*Solanum tuberosum* L.)	Ambang et al. (2002)
Pseudomonas sp. (*P. fluorescens*, *P. putida*) and *Glomus deserticola*	Bacteria, fungi	*Pythium aphanidermatum*	Cowpea (*Vigna unguiculata* (L.) Walp)	Nwaga et al. (2007)
Thevetia peruviana (Pers.) K. Schum	Plant	*Cercospora arachidicola*	Groundnut (*Arachis hypogaea* L.)	Ambang et al. (2011)
Trichoderma asperellum	Fungi	*Pythium myriotylum*	Cocoyam (*Xanthosoma sagittifolium* (L.) Schott)	Mbarga et al. (2012)
Thevetia peruviana (Pers.) K. Schum	Plant	*Phytophthora megakarya*	Cocoa (*Theobroma cacao* L.)	Ngoh Dooh et al. (2014)
Streptomyces cameroonensis sp. nov.	*Actinobacteria*	*Phytophthora megakarya*	Cocoa (*Theobroma cacao* L.)	Boudjeko et al. (2017)
Trichoderma asperellum	Fungi	*Phytophthora megakarya*	Cocoa (*Theobroma cacao* L.)	Tchameni et al. (2017)
Thevetia peruviana K.	Plant	*Phytophthora infestans* and insects	Potato (*Solanum tuberosum* L.)	Dida Lontsi et al. (2019)
Trichoderma harzianum and *T. aureoviride*	Fungi	*Phytophthora colocasiae*	Taro (*Colocasia esculenta* (L.) Schott.)	Ntah et al. (2018)
Streptomyces spp. (*S. albulus*, *S. albus*, *S. gandoceansis*)	*Actinobacteria*	*Pythium myriotylum*	Cocoyam (*Xanthosoma sagittifolium* (L.) Schott)	Djuidje et al. (2019)
Eagle fern (*Pteridium aquilinum* (L.) Kuhn) and Ricin (*Ricinus communis* L.)	Plant	Fungi and insects	Lettuce (*Lactuca sativa* L.), African nightshades (*Solanum nigrum* L.), and radish (*Raphanus sativus* L.)	Mala et al. (2019)

(continued)

Table 9.4 (continued)

Biopesticides	Type	Pathogen agents	Host plant	Source
Trichoderma sp. (*T. asperellum*, *T. koningiopsis*, *T. erinaceum*, *T. gamsii*, *T. afroharzianum*, and *T. harzianum*)	Fungi	*Fusarium oxysporum*, *F. solani*, *Macrophomina phaseolina*, and *Pythium ultimum*	Common bean (*Phaseolus lunatus* L.)	Boat et al. (2020)
Dry tobacco (*Nicotiana tabacum* L.), garlic cloves (*Allium sativum* L.), onion (*Allium cepa* L.), chili fruits (*Capsicum annuum* L.), neem (*Azadirachta indica* A. Juss.) leaves and seeds, etc.	Plant	Bacteria, fungi, and insects	Okra (*Abelmoschus esculentus* (L.) Moench), lettuce (*Lactuca sativa* L.), onion (*Allium cepa* L.), eggplant (*Solanum melongena* L.), and celery (*Apium graveolens* L.).	Kacou-Amondji (2020)

9.6 Fertilization in Agroecology

The principles of land fertility management in agroecology are founded on:

- Maintaining the natural fertility of the land and the soil life through a raise in soil microbial activity to a high quantity of OM which is continuously decreasing (less than 2%)
- Minimizing external inputs by limiting considerably the use of synthetic, chemical, and harmful products to the environment, which promotes soil health (Altieri and Nicholls 2014).
- Prioritizing local inputs and the recycling of farm by-products (manure, compost, biochar, crop waste household waste) as the primary source of inputs
- Fertilization without external input is done using N-fixing species and trees. The most widely used nitrogen fixers are:
  - Symbiotic and heterotrophic bacteria like *Allorhizobium* sp., *Azorhizobium* sp., *Bradyrhizobium* sp., *Mesorhizobium* sp., *Rhizobium* sp., *Sinorhizobium* sp. (Kamtchoum et al. 2019; Mahmud et al. 2020) found in leguminous (pulses crops), *Frankia* (*Actinobacteria*) found in filao trees (*Casuarina* spp.) (Carrasco and Preston 2020)
  - Symbiotic and phototrophic bacteria (*Azolla* sp.)
  - Associative and heterotrophic bacteria (*Azospirillum* sp.) (Bhowmik and Das 2018). They can colonize many (~100) plant species
  - Nonsymbiotic and heterotrophic bacteria such as *Azotobacter* (Bhowmik and Das 2018), *Bacillus subtilis* (Efremova et al. 2020), etc.

– Nonsymbiotic and phototrophic bacteria as *Cyanobacteria* (green-blue algae)
– The best-known phosphorus solubilizers species are:
– Symbiotic fungi (mycorrhizae) as *Rhizophagus* sp., *Acaulospora* sp., *Gigaspora* sp., *Scutellospora* sp., etc. (Ngakou et al. 2012; Temegne et al. 2017, 2019; Agnolucci et al. 2019). AMF communities were influenced by the type of fertilization (Mbogne et al. 2015; Säle et al. 2015)
– Nonsymbiotic fungi like *Aspergillus* sp., *Penicillium* sp., etc.
– Nonsymbiotic and heterotrophic bacteria as *Bacillus pseudomonas* (Bhowmik and Das 2018) Fertilization with input is done by adding humus, organic/ mineral elements that can be assimilated more or less quickly and microorganisms. Manure, conventional compost, earthworm humus (lombri- or vermicompost), residues from various agro-industries, shredded greenwood branches (fragmented branch wood), biochar, brush compost, fresh (green manure, tree leaves), and dry plant debris (straw in particular) are used as substantial amendments in fertilization in agroecology (Temgoua et al. 2014; Njukeng et al. 2017; Sharma et al. 2017; Billa et al. 2018). They are applied by incorporation into the top layer of the land and as a land cover with an anti-erosion and sun protection effect (but the loss of mineral elements, especially N).

The fertilization can also be carried out by the contribution of liquid manures like Supermagro, Biol, various decoctions, and purines (nettle, excrement, urine, compost, legumes, aromatic plants, ripe fruit) (Favorito et al. 2019). It is also made by adding Bokashi, natural lime or rock powders (Van Straaten 2006), growth activators, microbial inoculators, or microorganisms through all the amendments. Bokashi is an organic fertilizer based on animal fertilizer, to which straw, ash, and molasses are added. Liquid mountain microorganism and Biol is a liquid biofertilizer composed of different plants and manure (ADG 2016). The technique of Sachi also used in agroecology consists in gathering animals during a long period (e.g., 3 months), on the plot which will be cultivated to fertilize it (ADG 2016).

Figure 9.6 gives the practical indications for better use of OM. The dark green color indicates a richness in N of the soil and excellent enrichment power (type A or B). The yellowish color, on the other hand, underlines poverty in N as well as a poor enrichment quality (type C or D) of the soil. It is important to underline that the leaves with rapid decomposition have low lignin content (type A or C). The odor is also an indicator of soil quality. Indeed, an astringent smell refers to a high richness in phenols (type B or D).

9.7 Constraints to the Adoption of Agroecology

The low OM content of the soil and the imbalance of ecosystems are among the major ecological constraints of agroecology. Also, low biodiversity and the disappearance of natural enemies due to the excessive use of pesticides, aggressive

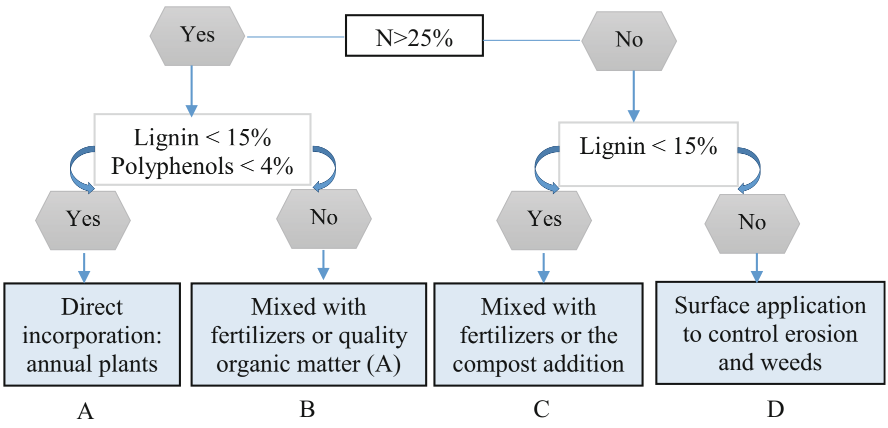

Fig. 9.6 Guide for use of organic matter (source: ADG 2016)

irrigation techniques (skate or flood irrigation), inadequate tillage practices, overgrazing, and monocultures make the soil increasingly fragile.

Adoption of agroecology is generally weak because of many technical reasons (Tittonell et al. 2012). The technical constraints of agroecology are:

- The availability of inputs (N source for humus production, seeds/plantlets for agroforestry and cover crops, water) at the local level
- The availability of equipment/tools to make and apply fertilizers (sprayer, storage of preparations (cans))
- The transport of raw materials (for compost, manure, etc., the grinder)
- The availability of labor
- The absence/insufficiency of technical knowledge
- The drop-in yield during the transition period

The scarceness of natural enemies owing to the abuse of the use of pesticides by neighboring producers who still practice conventional agriculture is also an obstacle to the adoption of agroecological practices by an ecological producer. Indeed, this producer cannot implement specific agroecological techniques since it is limited by the depletion of the ecosystem (ADG 2016).

Agroecology is a labor-intensive agriculture. The migration of young people and humans to cocoa and coffee enterprises and the mines associated with peak workloads makes the availability of labor difficult. This labor necessary for the manufacture and application of organic manure and for the control of weeds is essential only during the transition phase when a temporary fall in yields takes place (ADG 2016).

The additional cost of labor for weeding and manufacturing inputs, as well as the unattractive price (little or no differential compared to conventional), is the main economic constraint hampering the development of agroecology. The length of the transition period from conventional farming to agroecological practices is also an essential factor to take into account in raising awareness. Indeed, the drop-in yield is almost inevitable, and the duration of the transition can be extended. It varies according to the previous crop, the past practices, the state of fertility, degradation or health of the plots, the presence or absence of hedges and trees, topography, etc., with recovery being more or less rapid, but not always total. The length of the transition period can hurt the economy of producers and, therefore, their ability to provide for their families. This period is nevertheless essential for the soil to regain its balance, biodiversity, and natural fertility (ADG 2016).

Many people still think today that agroecology is an archaic form of agriculture. Moreover, pressure from agro-industrial companies and the chemical sector does not contribute to the development of this research field. The attractiveness of exogenous and higher workloads is also part of the sociocultural constraints that make difficult the adoption of agroecological practices. Also, agroecology has often been vulgarized as a whole, without appropriate tailoring to local conditions (Tittonell et al. 2012). Resistance is also psychological. The producers prefer the slight comfort of a conventional system which is not perfect but because they have mastered the workings. Many of them do not have scientific proof of the profitability of agroecological methods. Nevertheless, studies have shown that the yield was equal or even higher than that of traditional methods in the developing nations. The yield losses observed in temperate regions do not exceed 20% (ADG 2016). The lack of popularization of the results is one of the main constraints to adoption. Scientists share hardly their acquired beyond universities and research facilities. Communication with the media and decision-makers is not easy, which restricts the effect of this study (Anderson et al. 2020; DeLonge et al. 2020).

The change of political regime can be an important constraint since politics is not fixed. So, the legalization of agroecological laws and practices by the public authorities is not a guarantee of its sustainability (Murguia Gonzalez et al. 2020). Agroecology is generally considered non-priority by politicians who see it as small-scale agriculture practiced in marginal areas with few resources available for research and few trained and even fewer experienced technicians. Indeed, knowledge and practices are still very empirical, which leads to its denigration or disinterest. The absence or insufficiency of vulgarization of experience and training of farmers is also an essential constraint to the adoption of agroecology. Indeed, the subject is still poorly documented, and few scientific programs have lingered on the subject for lack of funding or interest (ADG 2016). Achieving results is dependent on substantial public funding, more specifically those that support the human aspect of the movement. They could accompany a conversion towards this movement and its associated benefits (DeLonge et al. 2020). Training is all the more complex as the agroecological solutions are local and specific to each context. This specificity is also an asset by promoting local environmental know-how and potential (ADG 2016).

9.8 Potential Solutions

Some possible solutions to address constraints to the adoption of agroecology are set out in Table 9.5.

9.9 Agroecology Versus Conventional Agriculture

Agroecology is a holistic way of farming that is less harmful to the environment as well as a natural method of food production with several economic, social, and environmental benefits (Crowder and Reganold 2015; Boeraeve et al. 2020). The primary aim of conventional agriculture is based on the use of synthesized chemicals and fertilizers to increase the productivity of a given or more plants, characteristically genetically modified in other to satisfy the ever-growing population. This technique necessitates a considerable quantity of chemicals and energy and tends to affect the natural surroundings, damages land quality, and destroys biodiversity (Savci 2012; Hooper 2016). However, to compare these two agricultural systems, several points need to be considered, i.e., production, biological diversity, land composition, erosion, water use, energy use, greenhouse gas emissions, and effect on health and environment (Table 9.6).

Conventional agriculture is carried out to fulfill the population in terms of yield since the demand in calorie- and meat-intensive regimes is estimated to double human food requests by 2050 (Mueller et al. 2012). Globally, agroecological approaches produces lower (19–41%) than conventional yield but this is dependent

Table 9.5 Potential solution for agroecological constraints (FAO 2015; ADG 2016; DeLonge et al. 2020; Murguia Gonzalez et al. 2020)

Level	Potential solutions
Ecological viewpoint	It will be needful to start the conversion with plots that are still biologically alive and to remineralize the soil by using rock powders
Economic level	Establishing a form of "labor" credit and designing and developing markets, if possible, more profitable niche markets are possible
Political level	• Increase knowledge
	• Form communal technicians
	• Reduce the distance between places of innovation (research, universities, etc.) and the places where they are applied
	• Set up a program to stake on the expertise
	• Advocating for increased capacity in agroecological research is issues to be explored
Technical level	• Facilitating access to inputs by creating farmers' enterprises or microenterprises to manufacture inputs (rock powder, seedlings and seeds, biofertilizers, phytosanitary prevention/control products, etc.)
	• Considering the human dimension of knowledge and preexisting agricultural practices
	• Paying a subsidy to the transition period by creating a conversion assistance fund

Table 9.6 Agroecology versus conventional agriculture

	Characteristics	Conventionnel agriculture	Agroecology system	References
Soil	Biodiversity	–	+	Degrune et al. (2019)
	Root length infected by AMF	–	+ (40%)	Mader et al. (2002)
	AMF spore abundance and species diversity	–	+	Oehl et al. (2004), Verbruggen et al. (2010)
	Biomass, abundance of earthworm	–	+ (1.3 to 3.2 times)	Mader et al. (2002)
	Biological activities	–	+	Peano et al. (2020)
	Nutrients	–	+	Marinari et al. (2006)
	Quality	–	+	Delate et al. (2013), Magdoff (2018)
	Water use	High quantity of water for irrigation	Organic soil retains much more water	West et al. (2014), Altieri et al. (2015), Mekonnen and Hoekstra (2016)
	Aggregate stability, respiration rates	–	+	Boeraeve et al. (2020)
	Erosion and degradation	+	–	Gomiero et al. (2011)
Production	Cropping system	Monocultures	Temporal and spatial diversification of crops	Lorenz and Lal (2014), Castellano et al. (2015), Rahman et al. (2020)
	Fertilizers	Chemical	Organic, biological	Altieri and Nicholls (2014), Mahmud et al. (2020)
	Energy to produce	+	–	Herrero et al. (2016)
	Pesticides and chemical inputs	+	–	Pfiffner and Luka (2003) Barrios et al. (2012)
	Pest abundance	+	–	Boeraeve et al. (2020)
	Cost of labor	–	+	Andriamampianina et al. (2018)
	Yield	+	– (19–41%)	Kremen and Miles (2012), Andriamampianina et al. (2018), Jouan et al. (2020)

(continued)

Table 9.6 (continued)

	Characteristics	Conventionnel agriculture	Agroecology system	References
	Prices of products	–	+ (34%)	Andriamampianina et al. (2018)
	Economic value added	–	+ (10–110%)	van der Ploeg (2020)
Environment	Pollution (water, soil, air, etc.)	+	–	Herrero et al. (2016)

on crop types and farming systems (Kremen and Miles 2012; Andriamampianina et al. 2018; Boeraeve et al. 2020). Even though common agriculture is renowned for its high returns, many environmental benefits are attached to agroecological approaches of farming (Crowder and Reganold 2015; Jouan et al. 2020). In some cases, organic agriculture has demonstrated higher yield in drought conditions and more water retention. For example, in the farming trial carried out at The Rodale Institute for 21 years (Moyer 2013), Pimentel et al. (2005) observed that in 1999, throughout the severe drought, the organic animal farming gave meaningfully higher yield (1511 kg ha^{-1}) of *Zea mays* than the conventional (1100 kg ha^{-1}) or organic legume (412 kg ha^{-1}). Besides some exceptions, agroecology generates economic value added (+10 to 110%) on farms in Europe (van der Ploeg 2020).

Agricultural health and performance are highly dependent on biodiversity. The higher the biodiversity, the more crops are naturally immune to pests and diseases without any chemical input advocated by conventional agriculture (Gomiero et al. 2011). Beyond 426 million kilograms of pesticides are being used each year with just 10% of that achieving the intended goal; this could be substantially diminished if conventional agriculture were to move to sustainable options (Sustainable Lafayette 2013). Crops in agroecological systems depend on biodiversity as it is crucial in enhancing ecological cycles. Organic farming is more abundant in nutritional elements and organisms than common farming with an increased level of biological activity (bacteria, fungi, springtails, mites, and earthworms), because of its versatility on plant rotations, diminished spreading of nutriments, and the prohibition on pesticides (Haas et al. 2001; Gomiero et al. 2011; Peano et al. 2020).

Agroecological systems are directly associated with better soil quality (Delate et al. 2013; Magdoff 2018). Sound soil ecology is observed since it promotes biodiversity, unlike monoculture, as is prescribed in conventional agriculture. Increased levels of total and OC, total N, and soluble OC are noticed in all the organic land (Wang et al. 2012). This is mainly due to the depth of the food web and quantity of biomass in the systems. The study carried out for 7 years in Italy concluded that the ecological approach exhibited meaningfully improved land nutritional and microbiological status, through an augmented level of total N, NO_3^-, and accessible P and a raised microbial biomass content and enzymatic activities (Marinari et al. 2006). Due to the global rising of agricultural production and soil becoming less disposable for plant growth, soil management is essential for the existing farms. Long-lasting techniques practiced like no-tillage system, agroforestry, and IPM help to improve the quality of the soil. Trees planted on agricultural soil aid to alleviate many of the adverse effects in agriculture, like modifying the quality of land, water, and air, preserving biological diversity, diminishing inputs by natural regulation of pests and more efficacious cycling of nutriment, and changing regional and worldwide climates (Barrios et al. 2012; Lorenz and Lal 2014).

Land erosion occurs due to nutrient loss, run-off, salinity, and drought (Issaka and Ashraf 2017). Land erosion is a menace to the growth of agriculture, particularly under uttermost climatic calamities like droughts (Gomiero et al. 2011). Agroecological agriculture improves the land composition and precludes land erosion caused by the more considerable quantity of crop material and biomass found in the land. Common agriculture, however, handles land instead of adapting to it. Lands using organic farming exhibited <75% land damage confronted to the maximum tolerance value in the area (the utmost rate of land erosion which can happen without jeopardizing sustainable plant productivity or environmental quality -11.2 t ha^{-1} year^{-1}). In contrast, in conventional land, the utmost tolerance value observed showed a percentage of three-time land loss (Gomiero et al. 2011). Confronted to the agroecological system, traditional plants are inefficacious at sustaining the wholeness of arable soils. Usual farming is, whereof, incapable to satisfy the requests of the increasing populations without ingurgitating an extensive quantity of soil and nonrenewable resources (Holt-Giménez et al. 2012).

Water is a renewable resource that can encounter the requirements of our present population. Water must be used efficiently because it is scarce (Mekonnen and Hoekstra 2016). Approximately 70% of water in the world is used in the agricultural sector (West et al. 2014). Cumulative demand for freshwater is pressurizing worldwide stocks. To preserve this resource, a dire renovation of methods to save water, peculiarly in agriculture, has to be developed. The richness of flora and fauna in sustainable agriculture causes organic land to characteristically hold much more water compared to that of conventional land. This augmented retention rate allows agroecological farming to generate better returns than conventional for water deficiency (Altieri et al. 2015). Nearly, 20–40% in the water holding capacity of organic farming lands when compared to conventional farming lands was recorded in heavy loess lands in a temperate climate in Switzerland. Thus, one of the main reasons for higher output in organic plants is believed to be caused by the higher water-holding capacity of the lands under ecological management (Gomiero et al. 2011).

The use of natural processes for inputs and nutrient recycling is advocated by agroecological systems to abolish the use of nonrenewable resources. The conventional system involves a significant quantity of energy to generate, prepare, and transport food (De Ponti et al. 2012). The fossil fuel-based industrial agriculture abets to greenhouse gas emissions in many ways:

- Directly by the fuel burned by farm machinery, in food processing and in transporting the mean ounce of food over a thousand miles “from farm to fork”

- Indirectly by the production of its synthetic inputs, such as N fertilizers from N and natural gas
- Finally by the breakdown of soil OM into CO_2 (through large-scale tillage and excessive synthetic inputs), which is liberated into the atmosphere as a greenhouse gas (Herrero et al. 2016)

Besides, large-scale industrial livestock farming releases massive amounts of methane (CH_4) (Eckard et al. 2010; Knapp et al. 2014). Energy effectiveness is vital to food production as it can diminish the mission of greenhouse gases and costs. About 5% of emissions of CO_2 resulting from the influence of human beings is generated by agricultural actions (Gomiero et al. 2011; Balogh 2020). The 10–12% of total worldwide emissions of greenhouse gases (5.1–6.1 Gt CO_2 eq. year^{-1} in 2005) relates from the influence of human beings, accounting for almost all the anthropogenic CH_4. One- to two-thirds of all N_2O emissions resulting from the influence of human beings is caused by agricultural actions (Gomiero et al. 2011; Balogh 2020). Therefore, agroecology can reduce this tendency than conventional agriculture. Due to land composition, conventional agriculture is ineffectual at catching C, steady production, and energy utilization to sustain the plants. Lots of machinery, pesticides, irrigation, processing, and transportation reveals that for each calorie arriving at the table, ten calories or energy has been spent. C can be stockpiled in land by the soil OM and by above the ground biomass via methods like using rotations combined to cover plants and green manures to raise soil organic material, agroforestry, and conservation-tillage agriculture (Castellano et al. 2015; Rahman et al. 2020).

Agroecology limits the usage of pesticides which is advocated in conventional agriculture. Agrochemical industries informed farmers on the profit they would make by using agrochemicals on vast scale monoculture. But, pesticides have been pointed out to have severe negative impacts on the farm farmers and consumers of the farm products (Calvert et al. 2008; Páyan-Renteria et al. 2012; Damalas and Koutroubas 2016). Also, they have negative effects on both the aquatic and terrestrial ecosystems (Sánchez-Bayo 2011; Stehle and Schulz 2015; Chagnon et al. 2015). Agroecology discourages the total eradication of pests because it will also wipe out the natural predators that are needed to keep the pests in check in a healthy ecosystem. So, agroecology tends to enrich the soil by using manure and tilled in plant residue that is using OM to maintain the biological cycle (Ge et al. 2011). The higher nutritional value such as vitamin and mineral content of crops produced from agroecological systems has been reported when compared to conventional agriculture (Rembialkowska 2007; Barański et al. 2014). Again, agroecological products have been reported to have high sugar content and have a superior structure and high metabolic integrity which makes them last longer (Bourn and Prescott 2002; Shafie and Rennie 2012; Yu et al. 2018). Agroecology can raise agricultural yield in ways that are economically, environmentally, and socially viable (Crowder and Reganold 2015).

9.10 Agroecology Towards Soil Management and Sustainability

The global level of soil degradation observed is leading to the need of managing soils in ways that maintain and improve soil resources to continue providing food, fiber, and freshwater, achieving significant inputs to energy and climate sustainability and aiding in preserving biological diversity and the whole safeguard of ecosystem goods and services (Koch et al. 2012, 2013). Soil management requires a whole method concentrated on how the soil and plants are managed, instead of an output approach that concentrates predominantly on delivering chemical solutions to nutrient and pest problems. The health and fertility of soils are essential to sustainable agriculture. If this ability is lost, then indicators like the waning in fertility, loss of species in soil biota, soil erosion, and changes in the water holding capacity can be detected (Veresoglou et al. 2015; Kay 2018). Soil health or quality is defined as the capability of the land to sustain the production and ecosystem services (Kibblewhite et al. 2008), while soil fertility is the availability of nutrients in the ground (Troeh and Thompson 2005). On the one hand, a healthy land is typified by the availability of nutrients, suitable structure, low level of salinity and toxic elements, and high resilience to harmful events (drought and flooding), resists degradation (e.g., erosion and compaction), supplies appropriate aeration and rapid water infiltration, and accepts, holds, and liberates water to crops and groundwater. On the other hand, soil richness is the balance of critical nutrients. Agroecology fosters the improvement and maintenance of physical, chemical, and biological features of the land through a set of sophisticated interrelated practices.

Primarily, the choice of plants favors the expansion of beneficial microorganisms (Hartmann et al. 2009). Microorganisms principally reside in the land rhizosphere. They quicken plant growth by various mechanisms such as boost nutrient procurement, defense versus pathogens, and modulation of phytohormone synthesis. AMF forms a significant cluster which favors plant growth, hence the sustainability of agroecosystem (Yang et al. 2014; Moreira et al. 2020). The land characteristics and land management practice applied improve their growth and efficiency in crop yield (Gianinazzi et al. 2010). The use of biofertilizers consists of applying living microorganisms to seed, crop surfaces, or land and has been reported to improve the availability of nutrients (Bhavikatti 2020). Conventionally managed agricultural lands tender to be low in AMF diversity; this has been assigned to the harmful influences of fertilization, fungicides, land cultivations, and weakness of host diversity. It has been indicated that low-input, conservation, and organic farming may improve AMF richness confronted to conventional farming (Mahmood and Rizvi 2010; Schneider et al. 2015). Some research has reported about the crop growth, raised productivity, and uptake of N and other components by inoculation with AMF (Ortas 2012; Pellegrino et al. 2011) and PGPR inoculation (Singh et al. 2011). Also, organic fertilizers like compost and manure increase the general soil richness, enhance the soil biological activity, and increase soil mineralization (Steenwerth and Belina 2008; Tao et al. 2015). The soil respiration rates, movement, and inoculum of native AMF from plots with permanent plant cover are generally higher than those from plots with shallow tillage. Maintaining permanent crop cover seems to be a better alternative than working the surface soil as a land management practice to conserve the biological fertility of the land (Turrini et al. 2017). Land content of OM and land microbial activity may impact the quantity of soil-borne pathogens and the resistance of plants to them. Some studies have revealed that organic land amendments like compost may improve the elimination of soil pathogens (Chen and Jiang 2014). OM supplies nutriments and energy to sustain various land microbial communities which rivaled with pathogens and impede their growth. Compost and various organic amendments equally have high quantities of microorganisms which can improve the diversity. Plants grown with high OM content and various active microorganism communities usually exhibit tolerance to maladies (Altieri and Nicholls 2003). Therefore, methods of agroecology like natural and little-input system may raise soil OM and improve microbial features (Ge et al. 2011).

Kirkby et al. (2014) stated that crop rotation could be used to enhance the nutrient availability of soils, thereby favoring plant growth. For instance, including legume species in the rotation permits the fixation of atmospheric N_2 and makes available a source of facilely absorbable N for the next planting season. Soil conservation and protection can be optimized by introducing cover crops which also improves the carbon content in the soil; decreased leaching, via the immobilization of N predominantly on freely drained, lighter lands; and promotes land steadiness (Dogliotti et al. 2004; Guzmán et al. 2019). Richardson et al. (2009) showed that about 40% of the assimilated microbial C occurs at root systems. Therefore, adding cover plants in the rotation is a hypothetically good idea (Wu et al. 2010; Kirkby et al. 2014). Furthermore, practicing rotation may alleviate NO_3^-leaching and enhance the effectiveness of nutrient use (Larsen 2019; Bai et al. 2020). Celette et al. (2008) reported that in temperate climates, they may also increase water infiltration over the winter period and raise water availability for the next plants. Other cropping practices like intercropping and relieve intercropping have proven to be effective in increasing soil health. For example, root exudates of some leguminous plants can enhance land P availability, solubilizing land organic P, also enhancing organic fertilization (Li et al. 2005; Darch et al. 2018). This system also enhances the land physical structure and land fertility (Darch et al. 2018). Interestingly, soil penetration and compaction resistance are weaker in these systems, and amelioration in structural steadiness is observed (Carof et al. 2007). The use of soil cover in an intercropping system reduces soil crusting and erosion (Le Bissonnais et al. 2004; Liu et al. 2017). Numerous studies have shown raised microorganism diversity, enzyme activities, and more excellent steadiness in alley cropping farming which were due to alterations in litter amount and quality and root exudates (Udawatta et al. 2008; Lacombe et al. 2009).

In agroforestry farming, nutriments are taken up and stopped from inferior land levels by tree roots and sent back to the land via falling of leaves (Rigueiro-Rodrígues et al. 2009). Thevathasan and Gordon (2004) concluded that in an agroforestry farming, fall of leaf from 6-year-old poplars ensued in mean land NO_3^- production rates in the head-to-head crop alley up to twice that confronted to lands situated 8–15 m from the tree row, and N liberate from the litter of poplar leaf was equal to 7 kg N ha^{-1} $year^{-1}$. Also, trees of red alder in the silvopastoral test farm at Henfaes near Bangor were considered to evaluate the possibility for increasing and sustaining land fertility, and the outcome revealed that the degree of N fixing was projected at 31 kg ha^{-1} $year^{-1}$ in the silvopasture treatment with densities of 400 tree stems ha^{-1} and the entire quantity of N that might hypothetically be appended to the land as an outcome of dead leaf, root, and nodule decomposition was assessed at approximately 41 kg ha^{-1} $year^{-1}$ (Teklehaimanot and Mmolotsi 2007). Roots and trunks of trees also play a role as physical barricades to diminish the flow of water on the surface and sediment (Udawatta et al. 2008).

Excepting lowland OM content, land compaction is due principally to high machinery traffic, especially tillage and intense animal treading in humid land conditions which is an important problem in modern agriculture (Hamza and Anderson 2005; Hobbs et al. 2008). The main goal of reduced or no tillage is to lessen soil disturbance and conserve OM at the top of the land surface or in the first few centimeters. Diminished CO_2 emissions, energy use and erosion, or raised land fertility and land biota activity/diversity have been mentioned as advantages for no-till or reduced tillage approaches (Gadermaier et al. 2011; Karlen et al. 2013). Mäder et al. (2012) obtained an increase in yields with reduced tillage for corn, winter, wheat, and grass-clover mixes while Berner et al. (2008) showed returns below organic conditions were 97% than the ones beneath common tillage. Also, land OC and microbial biomass were improved. Berner et al. (2008) again confronted that diminished tillage with traditional tillage in wheat and spelt plants during 3 years was capable to show an augmentation in land OM by 7.4% in the 0–10 cm land horizon. Also, they showed an up to 70% higher richness of endogeic, horizontally burrowing adult earthworms below shallow tillage, confronted to common tillage which raised land porosity, and thus enhanced water and root penetration into the land (Peigné et al. 2009).

Newer agroecological practices and approaches such as drip irrigation give an increased potential to restrict water inputs, to enhance the effectiveness of water use, and to improve satisfaction in time and space for the plant water request. It has also been found to limit the risk of soil salinization (Sun et al. 2012). Combining this irrigation technique and cover plants is beneficial and feasible by appending the cover crop rows between plants to decrease evaporation from bare land, increase land OM, decrease soil erosion, and if leguminous species are utilized increase N concentration (Lopes et al. 2011). Conclusively, protection versus wind and land erosion and surface water pollution is achieved by the integration, or reintegration, of unadulterated or seminatural landscape components like hedges and plant strips, either in or around the farm (Baudry and Jouin 2003; Wu et al. 2010). Besides, they usually ensure biological diversity preservation in soils.

9.11 Compost Manufacturing Unit, Dschang, Cameroon: A Case Study

The manufacture of inputs being one of the stages which makes agroecological systems difficult, the city of Dschang has managed to combine sanitation of the town and manufacture of compost. Indeed, Dschang is one of the most important cities in the west region of Cameroon. It is not only an agricultural production zone but a university municipality with nearly 220,000 inhabitants. Like the main Cameroonian metropolises (Yaounde and Douala), Dschang faces a significant challenge that of the management of household waste with an annual production of 40,000 tons, i.e., around 108 tons day^{-1} (CEFREPADE 2016). The city, which has only two compaction bins and two trucks for the collection of waste throughout the city, is experiencing enormous technical difficulties in removing only 20% of the deposit and bringing it back to the municipal controlled landfill. Thus, the collection rate decreased from 40% in 2007 to 10% in 2011. Furthermore, the waste produced is composed of around 80% of biodegradable materials with high humidity (65%) which makes their combustion difficult, however with a good C/N ratio (≈40) favorable for composting. It is in this context that a composting project initiated in 2010 by the nongovernmental organization (NGO) ERA-Cameroon to meet a need for organic amendment and improvement of the sanitation of the city of Dschang (Temgoua et al. 2014). This project was carried out by the NGO ERA-Cameroon in partnership with the Francophone Center for Partnership Research on Sanitation, Waste and the Environment (CEFREPADE). The relay was taken in 2014 by Africompost program (2017) and Gevalor (2020) to ensure continuity.

The first composting unit in Dschang was installed in the Ngui District and the second later in the Siteu District. Ngui's unit covers an area of 3000 m^2. It is made up of a waste reception and weighing area; a sorting table; a composting area (heap fermentation and maturation area); a sieving and bagging area; an 81 m^2 drying and storage shed; and a 1000 m^2 experimental field (Temgoua et al. 2014). The working equipment consists of a sieve (12 mm), wheelbarrows, tarpaulins, buckets, forks, shovels, rakes, and machetes.

Household waste is collected using 120 kg carriers (handcrafted) and trucks in around 800 households in the city (Temgoua et al. 2014). When the waste arrives at the site (Fig. 9.7a), it undergoes a manual sorting operation (Fig. 9.7b). Then the biodegradable materials are put in heaps of 2–5 m^3 while the non-fermentable return to the landfill (Vermande et al. 2012). The technique used here is heap composting. During the process, the temperature is read daily in each pile with a metal probe thermometer. The turning is done at a frequency of once a week during the first month, then once every 2 weeks (Fig. 9.7c).

The heap is watered when the need arises, due to the presence of mold on top of the waste. During the first week of composting, the temperatures in the heaps reach 70 °C and begin to drop after 10 days. Mature compost is obtained on the platform after 90 days. Since the start of the project, compost production has continued to increase on the site through the support of Africompost and Gevalor, who ensure the continuity of the project.

Fig. 9.7 Composting process. (**a**) Waste supply, (**b**) sorting of waste and piling up, (**c**) turning heaps, (**d**) pile of compost under shelter, (**e**) compost dry sieved. Source: (**a**)–(**c**) (Ngnikam 2013); (**d**) and (**e**) (author's picture)

Some production data recorded during the project:

- From June 2013 to June 2014, 935.53 tons of waste was treated, to produce 1384 bags of compost of 50 kg each, or 69.2 tons.
- In 2016, 1750 tons of waste was processed to produce and market 136 tons of fertilizer.
- In 2018, 2,817.44 tons of waste was processed, for 402.2 tons of fertilizer. The forecast for 2019 is 6000 tons of waste managed to produce 600 tons of fertilizer. This objective was achieved through the production of the Ngui unit and the second composting unit located in the Siteu District.

To ensure the grade of the final product, at the end of the procedure, the compost is dried and sieved, and samples are taken and analyzed at the soil laboratory of IRAD in Yaounde. Thus, the total OM; total N, P, K, Ca, and Mg; as well as the heavy metals (Cd, Zn, Pb, Cu, Ni, Se) are determined. The results showed that the

Fig. 9.8 Compost marketing. (**a**) Compost weighing and packaging, (**b**) compost marketing poster in Dschang. Source: (**a**) (Ngnikam 2013; CEFREPADE), (**b**) sinotables.com

compost produced in the city of Dschang contains heavy metals (Cd, Zn, Pb, Cu) with relatively high contents but which remains below the limit values of French and Swiss standards, except for Cd, Cr, and Se. The OM rate is 20% dry matter, the total N content equal to 11 g kg^{-1}, and the C/N ratio 10.26 (Temgoua et al. 2014). Today, the center is working on optimizing the manual sorting of waste to improve the quality of the compost.

After the drying and sieving operation, the compost is weighed and packaged in 50 kg bags stored in the hangar ready for sale (Fig. 9.8). The price of a bag is set at 2000 FCFA ($1 US ~615 FCFA) and a ton at 35,000 FCFA. The period of high demand for compost was identified during the main cropping season in the locality. This leads to large volumes of compost sales from mid-January to the end of February (crop sowing period) (Vermande et al. 2012). Although the demand is sometimes higher than the supply from the Ngui unit, promotions are sometimes launched to increase farmers' awareness of the use of compost and avoid long storage periods. A plot highlighting the effect of compost use on the production of vegetables is visible next to the composting site (Fig. 9.9).

The project is not yet achieving its objectives because of many constraints encountered at several levels of the chain.

- At the collection level, the primary obstacle is technical, because of the breakdown of trucks from the municipality; there is a reduction in the volume of incoming waste and saturation of the waste disposal site.
- In terms of marketing, the delivery of compost to farmers is often limited by the availability of transport means.
- Finally, the site has no water point, and this makes the work more difficult for the workers.

In Cameroon, the composting remains in an embryonic state despite its proven advantages in waste recovery and agriculture. Several composting projects in major cities in Cameroon have failed due to investment costs and the lack of political will

Fig. 9.9 Demonstration plot with cabbage located next to the composting site (source: Scidev.net)

on the part of the competent authorities. Very tiny composting units are identified in private homes, but these do not have a real follow-up of the process. The Dschang composting platform remains one of the few that continues to operate to this day because it benefits from the support of a Partnership Agreement between the Nantes City of France and the Dschang City Council with the help of Africompost and Gevalor. Monitoring of the production chain is ensured from waste collection to the use of compost in the fields through product quality analyzes. The quantity of compost produced in Dschang remains insufficient to meet the demand of farmers. However, its quality continues to be improved by optimizing sorting to reduce the heavy metal contents. Cameroon does not have regulations on the quality of compost. Therefore, French and Swiss standards are those which are applied.

9.12 ISSAEER: A Case Study

Although agroecology is an ancestral practice in Africa, its entry into universities as a discipline was there later than in the west. ISSAEER with the support of its partners (CEFRA, AFOP, GESCOD), in its prospective, believes in agroecology as a relevant futuristic trend. It integrates agroecological practices in the training of future agropastoral entrepreneurs and the recycling and supervision of producers in the locality of Sa'a. Indeed, the institute has delimited a mini agroecological route within it for the training of students and as a demonstration plot for visitors. Figure 9.10 shows the students in the implementation of some agroecological practices. For example, the town's hilltop relief leads to the establishment of devices to combat erosion. Limiting the use of chemical pesticides resulted in a rich diversity of insects, which favor the production of good quality honey. Within its campus, it organizes workshops on agroecology and capacity building for the CEFRA team working at

Fig. 9.10 Some agroecological practices within the ISSAEER. (**a**) Establishment of crop beds by students under the supervision of experts from CEFRA and Alsace. (**b**) Arrangements of the space subject to a double slope (U-shaped ridges). (**c**) Ecological beekeeping practices—CEFRA. Source: ISSAEER

ISSAEER. The main difficulty currently facing the structure is the lack or insufficiency of funds/grants. Several of the institute's projects are seeking funding for implementation.

9.13 Policy and Legal Framework

A specialized database on various lawful structures, practices, strategies, and programs on agroecology in various nations exists at the FAO level. It is called AgroecologyLex. This database created in coordination with FAOLEX is the largest database on agriculture and renewable natural resources policies and legislation in the world. It is regularly updated. The information provided by AgroecologyLex allows users to have the full text of the document as well as a detailed summary of the content, focused mainly on the specific goal and objectives, institutional frameworks, and primary forms of support, to support transitions from conventional agriculture to agroecological approaches (FAO 2020).

Monteduro et al. (2015) stated that it was necessary to embrace a transdisciplinary oncoming to multifunctional husbandry to include the paradigm of agroecology into lawful regulations. They emphasized that this does not need an extraordinary law which aims hierarchically to integrate and unsettle current lawful areas, instead of calling for the creation of a trans-law. The trans-law gradually works to coordinate inter-legalities between the various lawful fields, while preserving their independence and by underlining their mutual historical origins.

Poyyamoli (2017) wrote that by encouraging farmers to adopt resource conservation technologies, the government has a substantial part to play. Among the areas of government intervention, he cited a few:

- Advance national policies and legal frameworks to encourage agroecological production, including the adoption of IPM. This may include adopting a national definition of agroecological production and a policy statement in support of measures to facilitate the transition to agroecological output.
- Relaunch public research in agroecology and extension programs adapted as per the requirement and situation of smallholder producers, their organization, and their connections.
- Promote convergence and collaboration between the ministers of agriculture, livestock, fisheries, environment, and forests.
- Establish a general ecological fertilization policy to support and promote all the components of ecological fertilization that the government must undergo for achieving sustainability. It should launch a green fertilization mission with sufficient financial expenditure to restore and maintain soil health.
- Public procurement of organic products should be encouraged, including the presentation of natural products at important public events.

In 2018, the FAO, in partnership with IFOAM—Organics International and the Future Policy Award of the World Future Council, worked to highlight legal and policy frameworks. These latter create environments conducive to the implementation of agroecological approaches, to help realize the plans of the 2030 Agenda for Sustainable Development and several long-lasting developing purposes (Da Silva 2018). These lawful and policy frames help protect the lives and livelihoods of smallholders and family growers and guarantee long-lasting and including systems of food production. These also perform sustainable agricultural practices that facilitate preserve and improve the natural resource base and build the ability to accommodate global warming, as well as contribute to dimming (Da Silva 2018).

9.14 Future Roadmap of Agroecology for Agricultural Soil Management

Two challenges remain to be taken up for the development of agroecology, according to De Schutter (2011). These are the increase in cultivated areas and the creation of a favorable environment for farmers. It establishes different principles capable of promoting the agroecological transition that governments should consider. These principles are nevertheless to be applied with the flexibility to be tested and reassessed according to local circumstances (environment, climate, soil condition, etc.). They must also be developed in collaboration with the beneficiaries of this development. Priority should also be given to public goods by popularizing knowledge, building storage facilities, rural infrastructure, facilitating access to resources (insurance against climate risks, education, support for farmers' organizations, and cooperatives). These investments can, in the long run, be much more sustainable than simple private goods provided to farmers/growers, when they are informed and thought out. Automating women through specific mechanisms to encourage their participation in the construction of knowledge and organizing markets (use of packaging, processing, marketing, value chains, bringing farmers together in cooperatives, etc.) to protect farmers against fluctuating prices and dumping are objectives to be achieved to ensure adoption of agroecological practices by all (De Schutter 2011).

Society must, therefore, not only be attentive to the action of agriculture on the environment but, equally, make sure to encourage it to strengthen these interactions, which means:

- The restoration of the natural agronomic functions of cultivated ecosystems
- Combating soil erosion and preserving its fertility
- Diminution in the consumption of energy, water, chemical inputs
- The use of biological interactions, ecosystem services, and potentials offered by natural resources (biodiversity, photosynthesis, etc.) while maintaining their capacity for renewal from a qualitative and quantitative point of view (Claveirole 2016)

9.15 Conclusion

Agroecology is a scientific discipline with enormous potential and the ability to lead the transition to a more inclusive, sustainable model of society based on more robust and more united social ties by relocating the economy. It embodies a credible, efficient, and human alternative while fully participating in the objectives of food sovereignty. It offers a real social transformation project that does justice to the proletariat of the countries of the south as the first food suppliers in the world through better management of agricultural soils. Agroecology improves soil fertility, biodiversity, and productivity, while reducing dependence on energy-intensive inputs. However, most agroecological techniques have, so far, a feeble integration in nowadays farming for various reasons, one being that it is described as labor-intensive. In order to satisfy the increasing request for and press on soil and water resources, it will be required to not only expand but implement eco-friendly, eco-specific, and system reposed land management techniques. Research and other support services will require to be reoriented to assist farmers better comprehend agroecology farming and perform suitable choices for land management. To nourish an increasing earth inhabitant, we need practices that supply smug feeding while preserving the environment especially the soil and that guarantee economic viability for peasants. For this reason, practices of agroecology can and should play a vital function.

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