Agro-ecology and agricultural transformation: conceptual analysis and theoretical considerations

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Abstract

The sustainability of agricultural production systems is of growing concern. Agro-ecology has received considerable interest as an alternative to conventional farming. Clarity of both concepts is a precondition for any assessments. Large-scale adoption of agro-ecology could yield profound changes in rural Africa and on economic development of African countries due to the interlinkages between agriculture and the other sectors of an economy. Therefore, its promotion should be cautiously investigated and guided not only by its environmental effects but also by its ability to contribute to food systems sustainability, the development of rural economies, and economies as a whole. Consequently, the analysis of agro-ecology should be connected to the objectives of agricultural transformation as part of a process of structural transformation. Based on a meta-narrative review approach using multiple references from selected online reference databases, the concepts of agricultural transformation and agro-ecology are assessed, and a conceptual framework to guide future empirical analyzes of the role of agro-ecology on agricultural transformation as part of a process of structural transformation is proposed.

1. Introduction

Industrialization has been the historical path to economic development across the world. Industrialization happens when the share of agriculture in both income and employment decreases in favor of industrial sectors in urban areas, also referred to as the process of structural transformation (Syrquin, 1988). Stylized facts from developed countries have shown the stimulative role played by the agriculture sector in economic development (Johnston, 1970; Timmer, 1992). Indeed, in the past, technological improvements such as synthetic fertilizers, improved seed, mechanization have largely enabled increases in labor productivity in the agriculture sector (Johnston, 1970), thereby, allowing a "surplus" labor to migrate from the agriculture sector to modern industrial sectors, referred to as agricultural transformation and also allowing to feed a growing non-farm population (Timmer, 1988, 1992).

However, this traditional pathway to agricultural and structural transformation is today subject to a greater number of constraints such as health and environmental concerns. Indeed, it has not been without consequences on the environment and natural resources upon which agriculture depends (Zilbermann, 1997; Altieri and Nicholls, 2005) as well as health. This coupled with the current context of climate change and foreseen demographic growth has led to questioning the sustainability of agricultural production systems which plays a key role in the design of sustainable food systems. Agro-ecology has received a growing interest as an alternative to industrial agriculture. However, given the historical role of agriculture, large-scale adoption of agro-ecology could yield profound changes in rural Africa and have implications in economic development. Therefore, its promotion should be cautiously investigated and guided not only by its environmental benefits but also by its ability to contribute to the development of rural economies and economies as a whole. However, to date, there is no study trying to connect agro-ecology to agricultural transformation. This paper bridges these two concepts by first assessing each and then by providing a conceptual framework to analyze the role of agro-ecology on agricultural transformation in African contexts.

Antecedent to this paper is the conceptual and empirical literature on agro-ecology in Africa and agricultural transformation. The analysis of agro-ecology and its implications in rural Africa has gained momentum in recent years and has mainly concentrated on its adoption, impacts, and transition pathways (Ameur et al., 2020; D'annolfo et al., 2020; Kangmennaang et al, 2017; Kansanga et al, 2020; Nyantakyi-Frimpong et al., 2017; Tapsoba et al., 2020; etc.). Global literature has also focused on conceptual aspects of agro-ecology (Altieri and Nicholls, 2005; Gliessman, 2018; Wezel et al., 2009; Wezel et al., 2020). However, the empirical literature still suffers from a lack of clarity of the concept of agro-ecology. On the other hand, conceptual literature, still confines the analysis of agro-ecology within the agriculture sector, despite the latter being part of a broader process of economic development.

This paper fills this gap by analyzing agro-ecology in the broader process of agricultural transformation from an economist's perspective. To that end, besides the authors' knowledge of relevant literature, a systematic search of the literature has been done in multiple online reference databases on both concepts, their relationship, and empirical papers in Africa to minimize subjectivity in the exploitation of the literature. The idea is not to undertake all the steps of a systematic review as in the Cochrane framework (Moher et al., 2015) but to ensure an objective survey of the relevant literature. This literature is then analyzed using microeconomic theory and literature on agricultural sustainability and agricultural innovation from a systematic search in key journals of development and agricultural economics.

2. Methodology

This paper is based on a body of 192 studies selected using the systematic review approach (Grant et al, 2009; Moher et al., 2015) in terms of literature search and reference inclusion. The idea is not to perform all the steps of a systematic review from literature search to synthesis since the objective of this paper is not to synthesize the literature on agro-ecology or agricultural transformation but to use the relevant body of literature to analyze the relationship between agro-ecology and agricultural transformation. Therefore, this can be referred to as a semi-systematic review or a meta-narrative (Snyder, 2019).

The process followed a three-stage approach to search for papers and a definition of criteria to select the papers to include for our analysis. First, a search of papers on agricultural transformation and agro-ecology was performed to gather the relevant literature on the two concepts and their empirical applications in the African context using online reference databases (Econlit, AgEcon, Web of Science-WoS, and ConnectedPapers). For Econlit, AgEcon, and WoS, table A1 in the appendix summarizes the search criteria. For ConnectedPapers, which maps the literature based on an initially provided paper, the search departed from the seminal paper of Timmer (1988) on agricultural transformation. The same approach was used for agro-ecology departing from the comprehensive review on the historical development of agro-ecology as a science, a practice, and a movement of Wezel et al (2009). Second, to have the theoretical ground to assess and bridge the two concepts, key literature in development economics, and agricultural economics was selected on additional concepts such as sustainable agriculture, innovation in agriculture, using mainly the economic reference database Econlit and the main journals in the two fields. Table A2 in the appendix summarizes the search criteria used and the selected journals. To frame our search, the search criteria explicitly referred to the terms agro-ecology, agricultural transformation, and so on. Third, an additional internet search was performed on Google, and earlier efforts to summarize the literature on agriculture and development were used for citation tracking (Barrett et al., 2010; Anderson and Till, 2018) as well as the handbooks of development economics, agricultural economics, and economic growth.

This search led to a total of 2702 references. After the deletion of all the duplicates and after performing a title, abstract, and full-text screening, 192 references were included to support our analysis. During the screening stage, the papers were selected based on the following selection steps. First, conceptual papers were all included for full-text exploitation after which they were only selected if they were relevant for our purpose, that is to assess agricultural transformation, agro-ecology, and bridge them. Empirical papers were included if they covered some conceptual discussion, focused on multiple African countries simultaneously, or were relevant to illustrate our analyses. For the retained papers (conceptual and empirical), additional inclusion criteria were included, by order of importance: i) if it was published in a journal with at least an impact factor of 2; ii) Old books that were not accessible were excluded as well as non-English references. Figure 1 shows the flow chart.

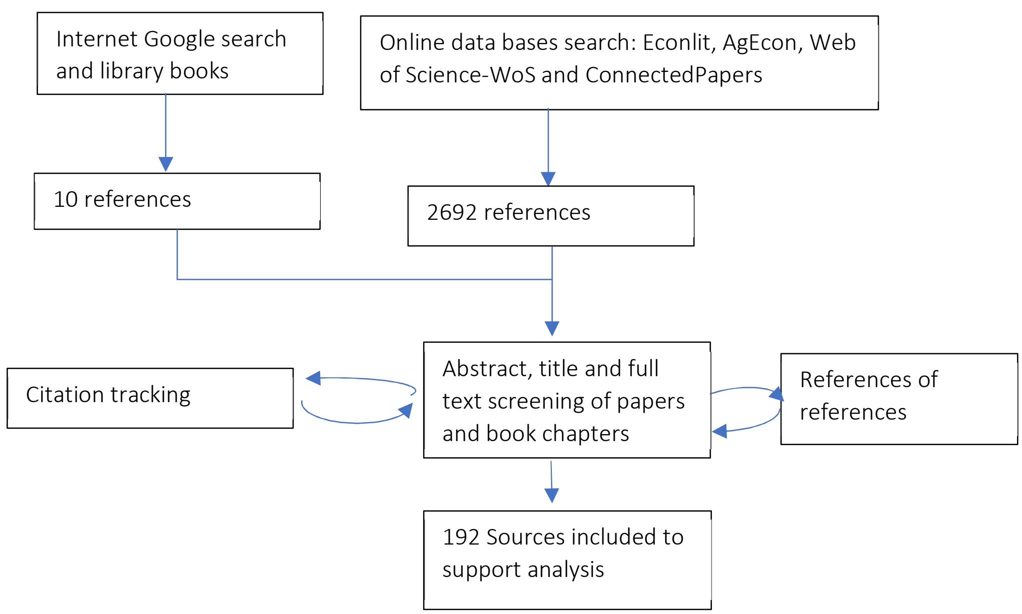

Figure 1: Flow chart

Source: Adapted from Wong et al (2013)

3. Conceptual analysis

3.1. Agricultural transformation

Agro-ecology and its implications on economic development cannot be understood without linking it to agricultural transformation and the historical role played by the so-called "conventional" or "industrial" farming in the process of industrialization of developed countries. Conventional farming is literally defined as the predominant type of farming system in a given area (Viaux, 1999, cited in Campion et al, 2020). However, in the literature, it is commonly associated with "high-input modern agriculture" characterized by the use of high-yielding technologies such as synthetic chemical fertilizers, fungicides, insecticides, herbicides, hybrid seeds (Campion et al, 2020), the use of mechanized techniques as illustrated by studies comparing mechanized practices (e.g. conventional tillage) to agro-ecology practices (Gotosa et al, 2021), etc. In this paper, this commonly used understanding of conventional farming is adopted, bearing in mind the diversity of conventional farming (Sumberg and Giller, 2022).

In the development economics literature, agricultural transformation is traditionally a process viewed as part of the overall transformation of a "traditional" or agriculture-led economy (Johnston, 1970) referred to as structural transformation. Structural transformation is observed when the structure of the economy changes with the reallocation of economic activities and labor across agriculture and modern industrial sectors (e.g. manufacturing, and services) (Herrendorf et al., 2014).

Reflexions on agricultural transformation have started as soon as the 1950s. Earlier work focused on labor movements from agriculture referred to as a "traditional" or "subsistence" or "informal" sector to a "modern" or "industrial" or "capitalist" sector (Lewis, 1954; Jorgenson, 1961). Agriculture is first considered as a passive sector from which an unlimited supply of labor with low marginal productivity is extracted to develop a modern sector (Lewis, 1954; Jorgenson, 1961; Anderson and Till, 2018). However, for such a movement of labor to be possible, the agriculture sector itself needs to grow simultaneously. This perspective recognizes both the contribution of agriculture to industrial development and the need for improvements in the agriculture sector for that contribution to happen (Lewis, 1954). However, agriculture plays a more active role in development by not only providing labor to the industrial sector but also by supplying food for domestic consumption, contributing to "market expansion" via increasing demand (resulting from increasing incomes) for industrial output, increasing the supply of domestic savings; and earning foreign exchange or exports, all these roles being equally important (Johnston and Mellor, 1961; Kuznets, 1961; Timmer, 1988). More recent studies add to this list the relative poverty-reducing power of agriculture. On average growth in agriculture tends to be more poverty reducing than an equivalent amount of growth outside agriculture, this effect being stronger for the poorest in society (Christiaensen, Demery and Kuhl, 2011; Ligon and Sadoulet, 2018; Ivanic and Martin, 2018) and ultimately disappears as countries become richer.

In an agriculture-dependent economy, these roles mainly require a continuous increase in labor productivity (output per worker) (Johnston, 1993). Also, labor productivity change is the main channel through which agriculture connects to the rest of the economy (Johnston, 1993). Timmer brought more structure to the concept of agricultural transformation which he formally defined as a process by which an agri-food system transforms over time from being subsistence-oriented and farm-centered into one that is more commercialized, productive, and off-farm centered; the off-farm economy being mainly manufacturing and services located in urban areas (Timmer, 1988). Therefore, an agricultural transformation triggered by a rapid and sustained increase in farm labor productivity has been considered as a key component of structural transformation and has led to the industrialization of many developed countries. In Asian countries, this transformation has been facilitated by conventional farming techniques during the green revolution where the productivity of staple crops has increased with productivity-enhancing technologies (seeds, fertilizers, irrigation…).

However, increasing labor productivity is not an easy task. It can only happen with appropriate government interventions in the agriculture sector to trigger technological progress, access to knowledge via education, and extension to improve on-farm management skills and well-functioning markets (Timmer, 1992; Johnson, 1993). For instance, in Asia, heavy investments have been made in irrigation "before the green revolution and by 1970 around 25 percent of the agricultural land was already irrigated" (Hazell, 2009). Such public interventions were key to the Asian green revolution. Therefore, the enabling policy environment is also important. Yet, the public sector's role in creating a favorable environment does not ensure success as the latter also depends on private decisions of the millions of farm-households involved in agriculture (Timmer, 1988). Indeed, as rational agents, farmers make decisions on the technologies and agronomic practices to adopt that maximize their utility (under non-separability assumption between consumption and production) given their economic, environmental, social, and institutional constraints. Furthermore, in today's world, increasing labor productivity faces more challenges for developing countries in Africa that are mainly agriculture-led as the sector employed on average 53 percent of the population of SSA in 2019 (WDI, 2021[1]) and is dominated by small-scale farmers. The challenges to labor improvement relate to the non-economic roles of agriculture such as the preservation of the environment and resources (soil, water) upon which it depends, its contribution to health and nutrition outcomes, as highlighted in sustainable development goals (SDGs), which restrain the pathways to labor productivity improvement. Fully conventional agriculture systems have led to adverse effects on the environment and production resources such as soil and water (Altieri and Nichols, 2005). This has led to the promotion of multiple alternative production systems, such as agro-ecology, to ensure sustainable agriculture. However, these systems usually advocate for low external inputs and can be labor-intensive (see examples of agro-ecological practices in Wezel et al. (2014)). Therefore, agriculture plays multiple roles that can easily become difficult to tackle simultaneously through public intervention.

To better analyze agricultural transformation and its linkages with agro-ecology, these new elements that constrain both policy options and private decision-making have to be explicitly accounted for in its conceptualization. Such an improvement is also necessary for its practicability when applied to the specific case of African countries. The previous discussion shows three key interacting elements of agricultural transformation: labor productivity, the enabling environment (both policies and the constraints to policy and private decision-making), and whether or not the roles of agriculture are fulfilled (the results of transformation).

Figure 1 shows the interactions among the three elements, which we discuss using the four phases of agricultural transformation as specified in Timmer (1988) and later elaborated in Jayne et al. (2019). The first phase of transformation starts with labor productivity increase which is affected by technical innovation as illustrated by the process of transformation in developed countries (Johnston, 1970), policy interventions, and decision-makers' choices (Johnston, 1993; Jayne et al, 2019). In the second stage, farmers with productivity gains generate surplus production and earn more income from the commercialization of farm output. To illustrate these two stages, at the micro-level, the availability of improved seed varieties can motivate households to adopt high-yielding varieties as in the case of the Asian green revolution (Hazell, 2009) which can lead to rising incomes. The latter is associated with food security, health, and education as income can facilitate access to food, health services, and education which can have complementarities and tradeoffs (Barrett, 2002). Also, an individual's health may affect the extent of enjoyment of consumption (Behrman and Deolalikar, 1988), which can have implications on his/her nutritional status. Likewise, education (e.g. nutrition education) and food security are related to health status (Barrett, 2002). At the macro-level, the type of policy intervention is ideally guided by the stage of transformation in which a country is (Timmer, 1988). Countries in the first stage might need different types of interventions than others in a later stage. In the third stage, households' money spending from their rising surplus production stimulates demand for goods, services, and jobs in the off-farm sectors of the economy. This, accompanied by the improved labor productivity, lead to the release of labor from farm to off-farm activities, rural-urban migration, and a slowdown of population growth in rural areas. This induces changes in the structure of the economy with a decline in the relative share of agriculture in the gross domestic product (GDP) over time (Jayne et al, 2019). In the fourth stage, economy-wide labor productivity rises resulting from intra-sectoral gains through productivity growth within agriculture and inter-sectoral gains as people move from less productive agriculture to more productive manufacturing and service sectors (McMillan et al., 2014).

[1] https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=ZG-ZQ-ZF&name_desc=false

Finally, following Engels' law, as income per capita increases, the budget share allocated to food declines which justifies a change in consumption orientation.

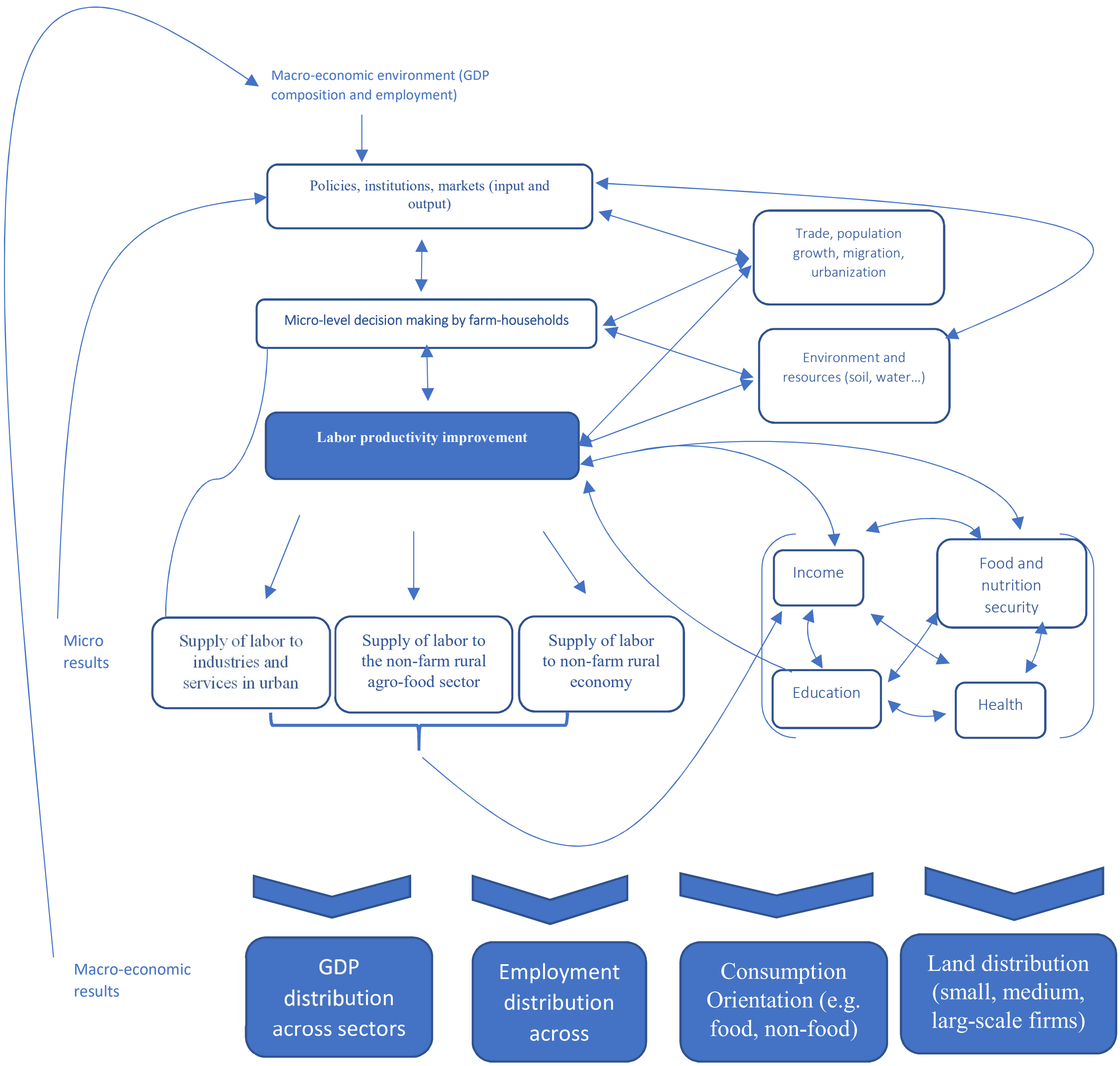

Figure 2: Conceptual framework of agricultural transformation

Source: Authors elaboration

3.2. Agro-ecology

The first use of "agro-ecology" was tracked back to 1928 by Bensin to describe the use of ecological methods in research on commercial crops (Wezel et al., 2009; Tapsoba et al., 2020). Agro-ecology "would hence be defined as the application of ecology in agriculture" (Wezel et al., 2009: p.3). In the period 1930-1970 agro-ecology was mainly considered as a science and gradually both as a movement and as a set of practices in the 1980s. This evolution of the concept toward movements and practical applications has varied geographically across the world (Wezel et al., 2009). Its historical evolution across space and time (Wezel et al., 2009) explains why agro-ecology is considered as a science, a practice, and a movement.

Over the last decade, the concept has gained more attention and has different meanings to different actors (scientists, NGOs, farm movements…) in different geographical locations (ref.). More recent definitions from leading scholars in the field have been proposed. Altieri and Nicholls (2005: p.31) define it as "the holistic study of agroecosystems, including all environmental and human elements" or at a broader scale as "the application of ecological concepts and principles to the design and management of sustainable food systems" (Gliessman, 2007) and as "the integration of research, education, action and change that brings sustainability to all parts of the food system: ecological, economic and social […]" (Gliessman, 2018: p2).

These definitions are different in the scale considered, from crop or field level to farm, agroecosystems, agriculture, and food systems level. Their common point is their broadness that makes agro-ecology ambiguous and leaves room for many interpretations. However, for rigorous theoretical and empirical analysis, an operational definition of agro-ecology is needed. Such a definition would ideally distinguish between the different scales involved, including the plot and farm-household levels and a more aggregate level (village, regional…). Looking at the keywords, these definitions further highlight the three main concepts involved in the word agro-ecology: agriculture, ecology and agronomy. The first being an occupation and the latter two being scientific disciplines. "Ecology is the study of the relationships between living organisms (vegetations, animals and humans) and their physical environment". Agriculture is defined as "the science, art, or occupation concerned with cultivating land, raising crops, and feeding, breeding, and raising livestock". "Agronomy is the science and technology of producing and using plants for food, fuel, and fiber". Therefore, conceptually, agro-ecology can be interpreted as a being at the interface of the three concepts, mainly by drawing from the science of ecology and agronomy to ensure sustainable agriculture. Also, among these definitions, the three objectives of agricultural sustainability, i.e. economic, social and environmental, are only explicit in Gliessman (2018).

To frame agro-ecology and facilitate its measurement, principles have been defined and have evolved from agricultural and environmental principles in the 1960s-1990s broadening to social, cultural in the 1990s, economic in the early 2000s, and political principles in the 2000s (Wezel et al., 2020).

The five initial principles of agro-ecology (Altieri and Nicholls, 2005: p31) were mainly related to the application of the ecological principles to agriculture. They were then complemented i) by the French National Agricultural Research Institute's (INRA) researchers to include a principle related to the agro-biodiversity of production systems considered as an entry point for ensuring food sovereignty and farmers' freedom of action (Dumont et al, 2016) and three others on methodological principles; ii) by the Interdisciplinary Agroecology Research Group (GIRAF) of Belgium's FNRS who added four principles. One methodological, stressing the importance of participatory research, and three stressing the importance of knowledge creation and collective adaptation abilities, favoring autonomy and valorizing the diversity of knowledge in the construction of the problems as well as the search for solutions (Dumont et al, 2016).

Dumont et al. (2016) gathered and tested a list of socio-economic principles from the literature that, combined with the previously discussed principles were further used to build a consolidated set of agro-ecology principles as displayed in the High-Level Panel of Experts (HLPE, 2019) report and table 1. Before the HLPE report, FAO (2018) had also defined 10 elements of agro-ecology that resulted from agro-ecology principles, the five levels of agro-ecology transition as defined in Gliessman (2016) and a multi-stakeholder consultation process.

The first five principles and the biodiversity principle can be, by their nature and from the above definitions, considered as pure agro-ecology principles as they are at the interface of agriculture, agronomy, and ecology. For instance, considering the recycling principle, local resources are considered as the world around the living things or as the resources from the living things themselves: e.g. biomass from plants, animal waste from animals which can also relate to the synergy among the elements of an agroecosystem. The term “use” can refer to the action of using such resources, probably through specific agronomic practices such as mulching, thereby bringing the agronomic part and also the “occupation” as it implies that there is a user (the farmer). The same reasoning can be applied to the other principles. However, the last seven principles are more difficult to directly relate to the agro-ecology concept as they relate more to economic and social factors than purely ecological or agronomic factors. However, they play a role in creating a conducive environment for the first six principles to be adopted and applied properly. They also relate more to the social and economic dimensions of sustainable agriculture. Conceptually, their absence would disqualify agro-ecology as a sustainable agriculture approach; the latter being defined as “ecologically sound, economically viable, socially just and human” (Francis and Youngberg, 1990). Nevertheless, their sole presence (without any of the six principles) cannot qualify a farm or agricultural system as one that displays agro-ecological features. For instance, diversifying on-farm incomes does not necessarily lead to applying ecological principles to agriculture. A farmer can produce a diversity of staple and cash crops leading to diversified on-farm income in a very unsustainable manner. The same applies to co-creation of knowledge which depends on what knowledge is created and shared. Finally, these 7 principles can also apply to conventional systems. For instance, in almost any empirical investigation of the determinants of adoption of a given agricultural technology, variables such as the “membership to a farm organization” which fosters horizontal sharing of knowledge, farmer-to-farmer exchange, are present. Also, other principles such as fairness, connectivity are also characteristics of approaches such as permaculture, organic farming, sustainable intensification…, although they have some differences. Therefore, in what follows, to better grasp the implications of agroecology on agricultural transformation this paper mainly analyzes the implications of the first six core principles. Due to the importance of the non-farm economy, the seventh principle will also be analyzed.

Table 1: Consolidated principles of agro-ecology

Principles	
1. *Recycling*. Preferentially use local renewable resources and close as far as possible resource cycles of nutrients and biomass.	Ecological principles with economic implications
2. *Input reduction*. Reduce or eliminate dependency on purchased inputs and increase self-sufficiency	
3. *Soil health.* Secure and enhance soil health and functioning for improved plant growth, particularly by managing organic matter and enhancing soil biological activity.	
4. *Animal health*. Ensure animal health and welfare.	
5. *Biodiversity*. Maintain and enhance diversity of species, functional diversity and genetic resources and thereby maintain overall agroecosystem biodiversity in time and space at field, farm and landscape scales.	
6. *Synergy*. Enhance positive ecological interaction, synergy, integration and complementarity among the elements of agroecosystems (animals, crops, trees, soil and water).	
7. *Economic diversification*. Diversify on-farm incomes by ensuring that small-scale farmers have greater financial independence and value addition opportunities while enabling them to respond to demand from consumers.	Socio-economic principles
8.*Co-creation of knowledge*. Enhance co-creation and horizontal sharing of knowledge including local and scientific innovation, especially through farmer-to-farmer exchange.	
9. *Social values and diets*. Build food systems based on the culture, identity, tradition, social and gender equity of local communities that provide healthy, diversified, seasonally and culturally appropriate diets.	
10. *Fairness*. Support dignified and robust livelihoods for all actors engaged in food systems, especially small-scale food producers, based on fair trade, fair employment and fair treatment of intellectual property rights.	
11. *Connectivity*. Ensure proximity and confidence between producers and consumers through promotion of fair and short distribution networks and by re-embedding food systems into local economies.	
12. *Land and natural resource governance*. Strengthen institutional arrangements to improve, including the recognition and support of family farmers, smallholders and peasant food producers as sustainable managers of natural and genetic resources.	
13. *Participation*. Encourage social organization and greater participation in decision-making by food producers and consumers to support decentralized governance and local adaptive management of agricultural and food systems.	

Source: Adapted from HLPE report (2019) and Wezel et al. (2020)

4. Agro-ecology and agricultural transformation

This section analyzes agro-ecology principles using the framework of agricultural transformation in figure 1.

4.1. Labor issues

Ecological principles

In the historical path to transformation, many farm inputs formerly produced on the farm have been replaced by productivity-enhancing inputs produced off-farm by the industrial sector at a large scale thanks to scientific progress. Therefore, the production of farm inputs has been transferred from the agriculture sector (farmers) to the industry (Johnston, 1970). The ecological principles of agro-ecology could be interpreted as a process of full restoration of such functions to farmers. However, although this allows reducing the dependency on industrial inputs which are costly to farmers, it could have implications on labor dynamics in agriculture. Indeed, many empirical studies in Africa reported increases or decreases in labor use per unit of land depending on the agro-ecological practices considered, crops, and locations (Guto et al, 2012; Corbeels et al, 2014; Schader et al, 2021). Therefore, labor use changes from agro-ecological practices at the farm-household level seem empirically ambiguous. However, a comprehensive analysis of the advantages and constraints of agro-ecological practices highlighted that many of them require increased labor needs (Wezel et al, 2014), demonstrating that agro-ecology will more likely than not have huge implications on labor demand. For instance, soil conservation practices such as minimum soil disturbance may lead to a higher infestation of perennial weeds (Vogel, 1994) and require complementary weeding and thus more labor which adds burden to available family labor in smallholder systems, especially for women who are more involved in weeding activities (Giller et al., 2009). Yet, there are limited empirical studies that have assessed the labor productivity of agro-ecology (D'Annolfo et al, 2017).

Four elements are important when analyzing the labor implications of sustainable agriculture approaches: the extent to which the practices are labor-intensive, the opportunity cost of labor, the complementarity or substitutability between labor and other inputs (Lee et al, 2006), and households' shadow value of labor (or shadow wage) (Sadoulet et al., 1998).

Based on Sadoulet et al. (1998) analysis of household behavior with imperfect labor markets, to better grasp the implications of agro-ecology on labor productivity, let us consider a household that has two categories of family labor: unskilled labor in quantity f^{us} with an opportunity cost w_0^{us} and skilled labor in quantity f^s with an opportunity cost w_0^s. The household can participate in the labor market as a seller, buyer, or be autarkic. The opportunity cost of labor is assumed to be the wage rate at which labor can be sold in the labor market. The household can hire unskilled workers at a wage of w_h that have identical productivity with unskilled family labor. Assume that $w_h > w_0^{us}$ as the household incurs transaction costs τ associated with searching and supervising hired labor, that is $w_h = w_0^{us} + \tau$. Naturally, it can be assumed that the market wage for skilled workers is higher than the hired workers' cost, that is $w_0^{us} < w_h < w_0^s$. Total family labor $f^{us}+f^s$ can be used for on-farm activities f_{onf}^{us} and f_{onf}^s, off-farm activities f_{off}^{us} and f_{off}^s, and for leisure f_l^{us} and f_l^s. The household produces an output q with a fixed amount of asset A (land, human capital…) and labor. The household has an exogenous income E and maximizes his/her utility which depends on his leisure time and his income (y):

$$\max_{h, f_{onf}^{us}, f_{off}^{us}, f_{onf}^{s}, f_{off}^{s}} \quad u(f^{us} - f_{onf}^{us} - f_{off}^{us}, f^s - f_{onf}^s - f_{off}^s, y)$$

Subject to income and non-negativity constraints:

$$y = pq(A, h + f_{onf}^{us}) - w_h h + w_0^{us} f_{off}^{us} + w_0^s f_{off}^s + E$$

$$h, f_{onf}^{us}, f_{off}^{us}, f_l^{us}, f_{onf}^s, f_{off}^s, f_l^s \geq 0$$

Sadoulet et al. (1998) showed that skilled labor is only used off-farm, that is $f_{onf}^s = 0$ and that the time spent working off-farm is a fixed part (k) of the available time for skilled workers, that is $f_{off}^s = kf^s, k$ between $[0,1]$. However, this is mainly due to their specification which does not allow skilled labor to be used or hired for on-farm activities. We only consider this as an assumption for now which will be relaxed and its implications will be discussed later given the knowledge-intensive nature of agro-ecology.

By defining a shadow wage w^*, as its marginal productivity, if the household was autarkic in unskilled labor, the equilibrium labor allocation, f_{onf}^{us*} and the shadow wage w^* are defined by the following equations:

$$\frac{\partial u(f^{us} - f_{onf}^{us*}, (1-k)f^s, y^*)}{\partial f_{onf}^{us}} = \frac{\partial u(.)}{\partial y} * p * \frac{\partial q(A, f_{onf}^{us*})}{\partial f_{onf}^{us}},$$

$$w^* = p\frac{\partial q(A, f_{onf}^{us*})}{\partial f_{onf}^{us}},$$

$$y^* = pq\left(A, f_{onf}^{us*}\right) + w_0^s f_{off}^s + E$$

The shadow wage is shown to be a function of farm asset, labor, and exogenous income: w^*=$w^*(A, f^{us}, f^s, E)$**.** Sadoulet et al (1998) show four labor regime decisions depending on asset, shadow wage and the opportunity cost of unskilled labor, and the wage to hire labor in. For heuristic reasons, we assume, for now, that asset is fixed and thus we mainly concentrate on the remaining factors.

If the opportunity cost of unskilled labor is higher than the shadow wage ($w^* < w_0^{us} < w_h$) then the viability of labor-intensive agroecological practices could be questioned. Indeed, in this case, the family labor would bring higher returns if used off-farm but also hiring labor in would cost more than the gains it would generate. In this situation, one can argue that if conventional approaches that can increase labor and land productivity (and thus asset) are available, then a household might be tempted to substitute labor for inorganic inputs to raise the marginal productivity of labor (provided that the gains exceed the costs of acquiring such inputs). Labor could then be freed to gain income that can be reinvested to buy inorganic inputs and increase the productivity of the remaining on-farm labor.

If the shadow wage is higher than the opportunity cost of labor but lower than the wage paid to labor hired in ($w_0^{us} < w^* < w_h$), then the household would neither hire labor in nor out (autarkic) because labor generates higher returns on-farm, and any additional labor hired in would be too costly compared to its marginal value product. In this case, labor-intensive agroecological practices would require the family labor to be sufficient enough to cover the high labor needs. If the shadow wage is higher than both the opportunity cost of labor and the wage for labor hired in ($w^* > w_h > w_0^{unskilled}$), the household will work on-farm and hire labor in. In this case, labor-intensive practices might be viable and can be an opportunity to reduce unemployment in labor-abundant settings discussed below.

The model shows that the marginal productivity of labor determines the shadow wage. However, the opportunity cost of labor depends on the labor market. Where labor is scarce (low labor supply compared to demand), the opportunity cost will be high and labor productivity from agro-ecology adoption would need to be high enough for the shadow wage to surpass the opportunity cost and for the labor-intensive systems to be viable (as in situation one discussed above). In labor-abundant environments, the opportunity cost of labor is more likely to be low. Paid unskilled labor might also cost less as transaction costs are likely to be lower. In this case, unless labor productivity is very low, agro-ecological practices might be appropriate. There might also be implications on the ability of agriculture to free labor for the other sectors of an economy if they are also growing.

Economic diversification principle

This model also highlights the interactions between on-and-off-farm economies which leads us to discuss the principle of on-farm economic diversification. As illustrated by the process of agricultural transformation, the agriculture sector is not confined in itself and is part of a broader macroeconomic environment with off-farm sectors that interact with it. The different sectors share the resources available in a country such as land and labor, just to name few. The latter is the channel through which economic diversification happens at the farm-household level where households, as a collective unit, decide how to allocate labor among on-farm activities and between on-farm and off-farm activities, taking into consideration the possible tradeoffs and synergies. This is illustrated by the labor market participation model with the household deciding whether to hire in or out or be autarkic and also empirical evidence. For instance, Start (2001) shows that households engage in non-farm activities that represent on average 40-45 percent of rural households' income in SSA. Additionally, in the 2000-10 decade and early 2010s, a survey of nine African countries shows an increase in the rate of migration from on-farm to off-farm activities (Jayne et al., 2019). Keeping in mind the heterogeneity across countries, they also found that in off-farm segments, the share of employment within agri-food systems has increased in percentage terms. However, in absolute terms, activities outside of agri-food systems are by far the major source of off-farm employment in rural areas. Therefore, economic diversification goes beyond on-farm income which questions the relevance of such a confining principle that fails to consider farm-households as decision-makers facing constraints and opportunities.

The battle of capitals

To discuss the other implications of the principles, let us now consider improvements in household assets. The 13 principles, altogether, implicitly imply that human, natural, and social capital are the main mechanisms through which labor productivity can be improved in agro-ecology.

Indeed, some empirical studies in Africa point out the human skill requirement of agro-ecology at the farm level (Kangmennaang et al., 2017; Isgren, 2016). This implicitly suggests that some agro-ecological practices yield better performance if applied skillfully. Using the same model, one can consider that skilled family labor can also be used on-farm and both skilled and unskilled labor can be hired in (h^s, h^{us}). One can extend the model by assuming that skilled labor contributes to the enhancement of unskilled labor productivity by improving the human capital dimension of asset A, through extension-like assistance. In that case, the asset A would be a function of both on-farm and hired in skilled labor: $A = A(f_{onf}^s, h^s)$. Skilled workers can be hired at a wage $w_h^s > w_0^s$ for the same reasons as for unskilled hired labor. Therefore, if τ^s is the transaction costs associated with searching and supervising hired skilled labor $w_h^s = w_0^s + \tau^s$. The optimization is now written:

$$\max_{h^{us}, h^s, f_{onf}^{us}, f_{onf}^s, f_{off}^{us}, f_{off}^s} u(f^{us} - f_{onf}^{us} - f_{off}^{us}, f^s - f_{onf}^s - f_{off}^s, y)$$

Subject to income and non-negativity constraints:

$$y = pq\big(A(f_{onf}^s, h^s), h^{us} + f_{onf}^{us}\big) - w_h^{us} h^{us} - w_h^s h^s + w_0^{us} f_{off}^{us} + w_0^s f_{off}^s + E$$

$$h^s, h^{us}, f_{onf}^{us}, f_{off}^{us}, f_l^{us}, f_{onf}^s, f_{off}^s, f_l^s \geq 0$$

Now, the marginal productivity of unskilled labor can be increased via the use of skilled or hired family labor. This could also increase accounting costs (through hired skilled labor) or economic costs (if skilled family labor is used on-farm) unless the opportunity cost of skilled labor is low enough compared to the marginal productivity of unskilled labor generated by the use of skilled labor. Also, it is more likely that the transaction costs associated with searching for skilled labor can be very high in rural Africa where skilled labor is scarce. However, in Africa, this function of skilled labor is currently played by extension agents. Agro-ecology adoption would need to rethink these issues. Will farmers bear the burden of the knowledge-intensive systems or will extension services play an intensive role via public policy? The social capital dimension could play a role here with knowledge sharing. However, the aforementioned labor market dynamics will still be relevant.

Furthermore, the improvement of management skills can increase farmers' productivity resulting from improved efficiency in resource use. For instance, farmers might be trained to better combine natural resources in agro-ecological practices to get the most out of them. However, this might not necessarily shift upward the production possibility frontier without any technological improvement. Shultz (1954) and subsequent research (Barrett et al, 2010) have shown the importance of improving both farmers' management skills and technological progress to improve their performance as efficiency is not just related to management skills but also exogenous, stochastic environmental factors. However, agro-ecology principles are mute about technological improvements that could increase productivity in agro-ecological farming systems. This raises two questions. First, how about the complementarity (not substitution) between agro-ecological systems and other methods of production? In Africa, this depends very much on location-specific features such as natural resources such as organic matter and soil quality For instance, some complementarity could exist between agro-ecological practices and conventional technologies provided that the latter are used wisely (Epule et al., 2015; Chivenge et al., 2009). Chivenge et al. (2009) concluded, through a four-year experiment, that with high-quality organic resources (in terms of initial nitrogen -N- content), yields tend to increase and sometimes more than with sole N fertilizer use. However, combining organic resources with N fertilizer is essential for intermediate and low-quality organic resources (especially in coarse-textured, low-fertility soils) which are found in larger quantities than high-quality organic resources in smallholder farms in Malawi.

Concerning natural capital, agro-ecology depends on local resources, which is one of its praised advantages, that also leads to farmers' autonomy (Altieri and Nicholls, 2005). What about the availability of local resources? What about the feasibility of agro-ecology in areas less favored by nature where the opportunities of using local resources are scarce? Will this not create markets for such resources? The input reduction principle raises multiple concerns that can illustrate the relevance of these questions. First, this principle does not necessarily guarantee the reduction or elimination of the dependency on purchased inputs. It is likely that if agro-ecology was to be adopted at a large scale, the demand for organic inputs or crop residue biomass for mulching, just to name few, might increase while local resources might not be sufficient. In such situations, such inputs might need to be commodified which could reduce farmers' autonomy. This leads to the second concern as the principle refers to the word "purchased" inputs, which implicitly includes commercial organic inputs. What if such organic inputs were produced by local industries using human and other household waste in an environmentally friendly way and made financially accessible to poor farmers? Would they have the same treatment as purchased inorganic inputs? Also, the quality of organic inputs such as compost could be improved if dedicated industries were committed to using research, traditional knowledge, and leveraging wastes to manufacture them while limiting environmental damage. Therefore, the availability and quality of local resources should also be paid attention to.

Finally, these principles are mute about man-made capital such as mechanization. Adapted machinery can increase labor productivity and reduce the labor burden from agro-ecology. Using the same model, it can be shown that mechanization can improve household assets and indirectly affect unskilled labor productivity. Therefore, mechanization adapted to local farming specificities has a huge role to play in the sustainability of agro-ecology and therefore should not be occulted. Unquestionably, one should bear in mind the costs of mechanization.

4.2. Welfare issues

The principles of agro-ecology and empirical analyses of its practices hint that it can have implications on food and nutrition security (Kangmennaanng et al., 2017; Madsen et al., 2020; Gambart et al., 2020), income (Corbeels et al, 2014; Tambo and Mockshell, 2018; Schader et al., 2021) and human, animal, and environmental health. For instance, human health can improve through dietary diversity resulting from crop diversification (Nyantakyi-Frimpong et al., 2017). Environmental health, soil quality, water storage, infiltration, and water use efficiency can be improved through the adoption of agro-ecological practices such as residue retention, legume cultivation, no-till, mulching (Rodenburg et al., 2020). However, some benefits are usually obtained through a long-term process and the effects on climate mitigation through soil carbon sequestration and reduction in GHG emissions are dependent on agroecological contexts and the availability of crop residue biomass (Thierfelder et al., 2017).

However, these will very much depend on the productivity potential of agro-ecological practices discussed above and their time dimension. Concerning the latter, let us consider the example of soil health. Stevens (2018, 2019) illustrates the interrelations between farmers' actions in one period and outcomes in future periods. Indeed, farm inputs and management practices in a given year affect soil health in the following years. The effect is certainly not automatic but happens over time. Therefore, when a farm-household adopts agro-ecological practices that improve soil health in a period t, the benefits are obtained in period $t + n$, n being an integer. For instance, there is often a time delay before observing yield increases for approaches such as conservation agriculture that can go from two to five cropping seasons (Thierfelder et al, 2017) to a longer-term setting (up to 15 years) as a result of a gradual increase of overall soil quality (Corbeels et al; 2014). Therefore, agro-ecology can not only be labor-intensive but also some of its benefits are not immediate which creates a tradeoff between present and future outcomes. Economic theory tells us that when faced with intertemporal choices, decision-makers can be myopic, meaning that only the past outcomes are considered when maximizing current gains or forward-looking, that is future gains are also considered. A forward-looking farmer will react differently compared to a myopic farmer. The adoption of one of these behaviors will depend, among others, on asset ownership, farmers' knowledge of the health of their soil and the implications it has on yields, accurate knowledge on soil health evolution over time in response to production practices (Stevens, 2019), their financial situation. For instance, empirical studies in Uganda and West Africa show that farmers might hesitate to adopt activities such as agroforestry due to land tenure insecurity associated with the risk of getting evicted without notice (Isgren, 2016; Tapsoba et al., 2020).

These time-related tradeoffs may also have welfare implications through market dynamics. At the aggregate level, if many producers adopt such practices and observe temporary stagnant or decreasing yields, the aggregate supply curve might shift upward and prices increase. This might lead to a decrease in producers' or consumers' welfare depending on the elasticity of their demand for agricultural food. If consumers' demand is highly elastic, then they might decrease drastically their demand for those goods which will lead to a decrease in producers' welfare resulting from lower demand. If their demand is highly inelastic, i.e. demand is less sensitive to price changes, then consumers' welfare is more likely to decrease due to higher prices while producers' welfare might increase because consumers will buy the good anyway as a result of their inelastic demand. Given the context-specific nature of agro-ecology, the movement of the supply curve will certainly depend on the dominant farming system (conventional, traditional, a combination, etc.), the quality of local resources at baseline, and the time dimension. If conventional farming was dominant, then the shift can be upward in some contexts in the short run. If traditional agriculture, which is closer to agro-ecology in spirit, was dominant maybe the curve would shift downward or remain unchanged depending on previous management skills. This illustrates the difficulty to generalize as there is a diversity of agro-ecologies, environmental, social, and institutional constraints in Africa.

Welfare implications also depend on consumers' preferences for potential non-economic attributes of the goods generated by agro-ecological approaches such as their environmental preservation, their health implications highlighted previously. Therefore, for such consumers, market prices that do not account for the true cost of food are not appropriate metrics to analyze welfare changes generated by wide agro-ecological adoption. For example, although organic farming products are sold at higher prices (compared to comparable conventional agriculture products) that reflect the non-economic features of the goods, some consumers still choose to buy them.

This illustrates the heterogeneity of potential welfare effects on both consumers and producers with possible winners and losers which should not be ignored when upscaling agro-ecology to avoid policy failure. Empirical analyses of agro-ecology approaches should be complete enough to account for unintended welfare consequences. This also highlights the need for a public policy role in accompanying the transitions to sustainable agriculture to minimize welfare losses and the need for an active role of research in generating knowledge that can help reach the multiple goals of sustainable agriculture approaches.

Other tradeoffs exist between activities. The synergy and recycling principles illustrate the existence of tradeoffs between the different activities at the household level such as livestock and crop production which can alter their outputs. Considering that crop residue can be used for both mulching and livestock feed (Guto et al, 2012), the more it is used for mulching, the less its availability for livestock feed which can affect animals' weight and thus livestock output. Using the idea of the production possibility frontier (PPF) as in Ranganathant (1991), figure 3 illustrates this tradeoff. The production possibility frontier represents the range of maximum levels of outputs attainable considering the outputs from all possible allocations of crop residue between crop production and livestock feed. The frontier, represented by the solid line curve, thus gives the best allocation of crop residues between the two activities. Every other use is technically inefficient. Technically inefficient allocations of crop residue use are represented in dotted line curves. Considering that the farm is efficient, point A represents the allocation of crop residues that maximizes the farm's profit $\pi(p_1, p_2) = p_1 y_1 + \ p_2 y_2$, where y_1 and y_2 represent animal and crop outputs, respectively. p_1 and p_1 represent the unit prices of the outputs y_1 and y_2, respectively. A lies on the iso-profit line (a line along which all points generate equal profits) which is tangent to the PPF at point A. p_1/p_2 is the slope of the iso-profit line tangent to the frontier. Assuming crop residues are free (no input cost), if p_1 increases while p_2 remains constant, the slope increases and the iso-profit line will be steeper and the optimum point closer to B, reflecting the need to use more crop residues for livestock feed to maximize profits. Similarly, a price increase in crop output, holding livestock output price constant, will decrease the slope and result in a flatter curve and the optimum point closer to C, reflecting the need to use more crop residues for livestock feed to maximize profits. This illustrates the necessity to investigated such tradeoffs when designing agro-ecological systems. This framework also provides some insights on how to investigate them.

This illustration mainly represents the tradeoffs between the two outputs. Synergies also exist between the activities. For instance, animal waste can be used for crop fertilization.

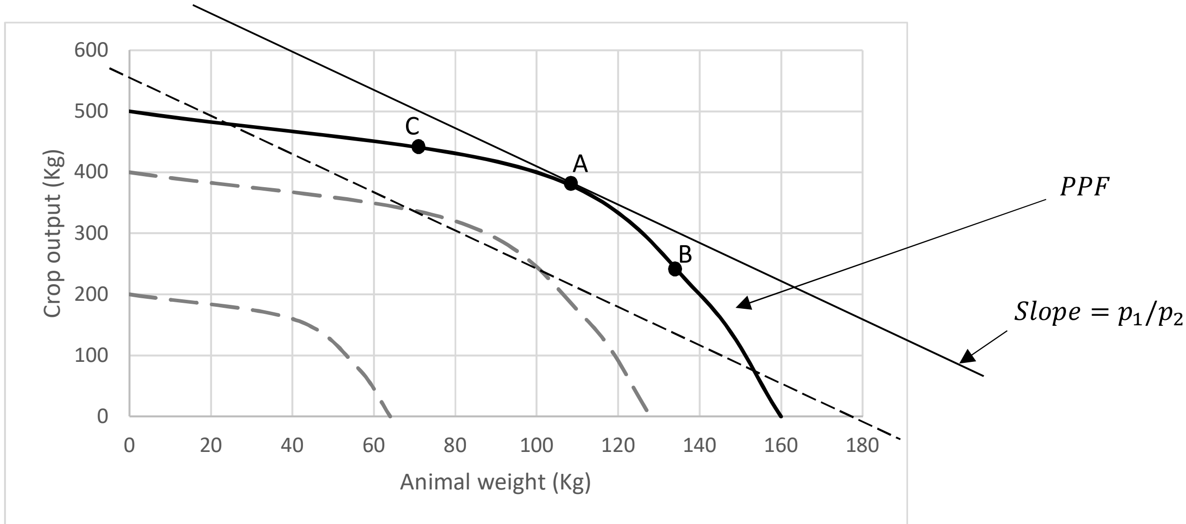

Figure 3: Tradeoffs between livestock and crop production

Based on the above discussion and figure 1, figure 3 summarizes the linkages between agro-ecology and agricultural transformation. Compared to figure 1, this figure assumes that if agro-ecology is adopted, its effect on labor productivity goes through improved soil health which improves land productivity in a way that affects productivity positively. Also, agro-ecology affects health, food and nutrition security, and income through its impact on food diversity.

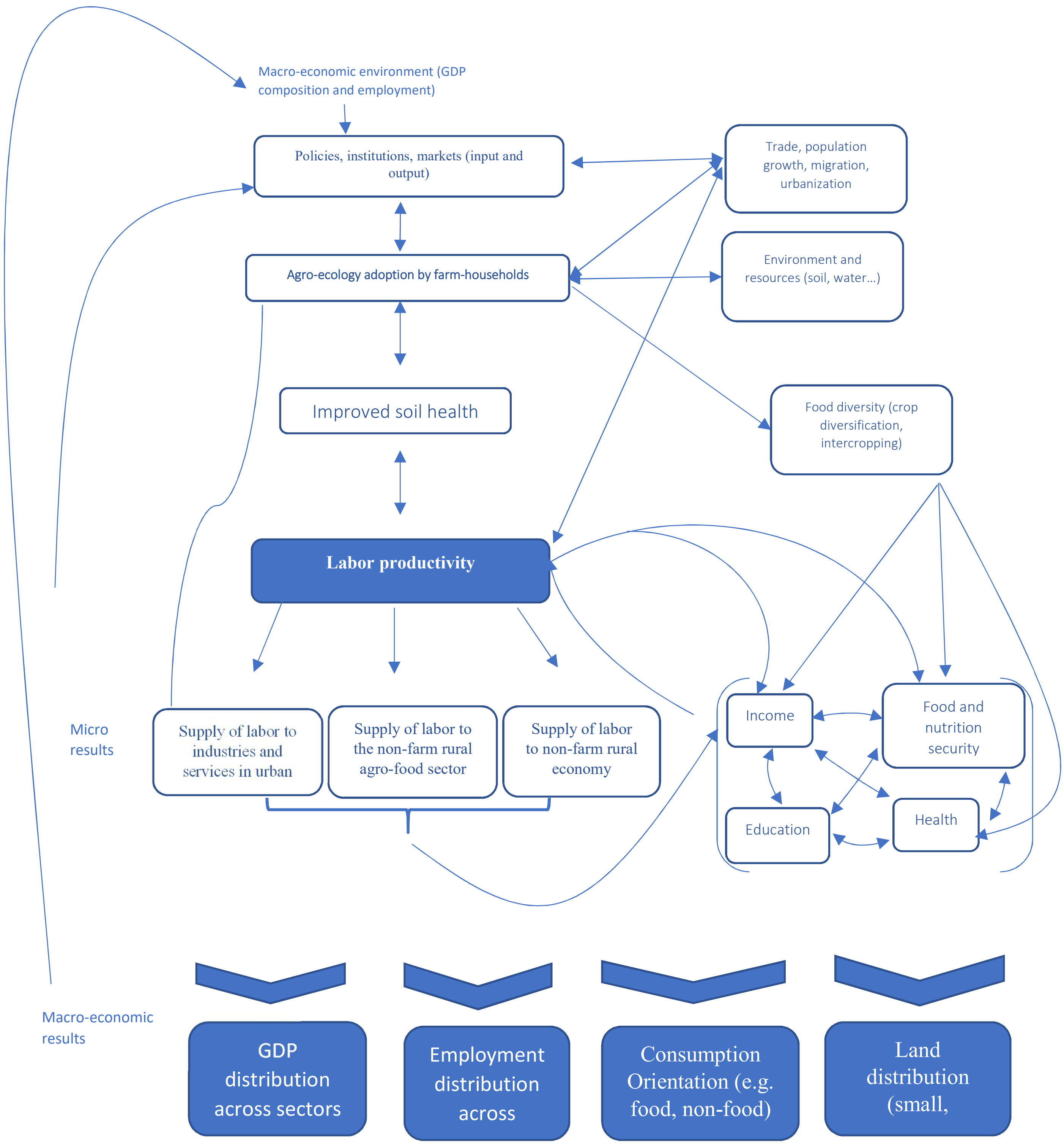

Figure 4: Interaction pathways between agro-ecology and agricultural transformation at farm-level

Source: Authors elaboration
Note that the direct and feedback effects can be negative or positive

5. Conclusion

This paper assessed the concepts of agro-ecology and agricultural transformation, discussed the possible implications of the former on the latter, and provided a conceptual framework to analyze the role of agro-ecology on agricultural transformation. The assessment of agricultural transformation illustrates that agriculture is not a confined sector and the strategies deployed for its development should take into consideration the stage of transformation in which the country is. Also, the historical path to transformation that currently developed countries have adopted to increase their productivity and release labor off-farm might no longer be an option in Africa due to the environmental and health-related challenges of today's world. Therefore, farmers in Africa will more likely than not have to integrate these new constraints in their production decisions.

The paper shows a very ambitious concept in agro-ecology and yet very ambiguous. Conceptually, our analysis points out the need to better specify the principles of agro-ecology to avoid unintended consequences of its adoption and also provide a clearer and more practical definition of agro-ecology for its empirical assessment. Otherwise, it risks becoming a controversial concept and prevent from leveraging its positive attributes and the positive role it can play in building sustainable farming systems.

This paper also suggests a conceptual framework that shows the pathway through which agro-ecology can play a role in agricultural transformation. Agro-ecology affects labor productivity, the main element of transformation, through the practices or approaches adopted. However, its effects on labor productivity will more likely than not depend on the labor intensity of its practices, their knowledge intensity, and the availability and quality of the local resources upon which it depends. These combined with the opportunity cost of labor, the cost of hired labor, and whether or not labor is abundant or scarce in rural areas will determine its viability in Africa. Our analysis also shows that agro-ecology will also have welfare consequences on both consumers and producers with possible winners and losers which should not be ignored when upscaling agro-ecology to avoid policy failure. Finally, tradeoffs between activities at the household level and between current and future outcomes should be taken into consideration.

This puts clear implications for research and policy. First, given the non-homogeneous nature of agro-ecologies and markets in Africa, the implications of agro-ecology on labor productivity should be investigated in many case studies to assess its relevance in specific contexts and its need for adaptation. Policy-makers and donors need to integrate these dynamics in their quest to scale up agro-ecology. Second, its implications on micro-economic agents' welfare as well as economic development should not be ignored and this requires more comprehensive analyses of agro-ecology. This implies, for instance, to not just look at its implications on yields but also on both input and output markets. Third, public knowledge on soil health, policy measures to ensure land security, etc., need more attention to account for intertemporal tradeoffs. Therefore agro-ecology-like approaches demand effort not only at the farm level but also on researchers, policymakers, consumers, and industry. This also highlights the need for a public policy role in accompanying the transitions to sustainable agriculture to minimize welfare losses and the need for an active role of research in generating knowledge that can help reach the multiple goals of sustainable agriculture approaches.

References

Altieri, M. A., & Nicholls, C. I. (2005). *Agroecology and the Search for a Truly Sustainable Agriculture* (1 st editi). United Nations Environment Programme. http://www.agroeco.org/doc/agroecology-engl-PNUMA.pdf

Ameur, F., Amichi, H., & Leauthaud, C. (2020). Agroecology in North African irrigated plains? Mapping promising practices and characterizing farmers' underlying logics. *Regional Environmental Change*, *20*(4). https://doi.org/10.1007/s10113-020-01719-1

Andersson, M., & Rohne Till, E. (2018). Between the Engine and the Fifth Wheel: An Analytical Survey of the Shifting Roles of Agriculture in Development Theory. *Agricultural Development in the World Periphery*, 29–61. https://doi.org/10.1007/978-3-319-66020-2_2

Barrett, C. B. (2002). Chapter 40 Food security and food assistance programs. *Handbook of Agricultural Economics*, *2*(PART B), 2103–2190. https://doi.org/10.1016/S1574-0072(02)10027-2

Barrett, C. B., Carter, M. R., & Timmer, C. P. (2010). Acentury-long perspective on agricultural development. *American Journal of Agricultural Economics*, *92*(2), 447–468. https://doi.org/10.1093/AJAE/AAQ005

Behrman, J. R., & Deolalikar, A. B. (1988). Chapter 14 Health and nutrition. *Handbook of Development Economics*, *1*, 631–711. https://doi.org/10.1016/S1573-4471(88)01017-4

Chivenge, P., Vanlauwe, B., Gentile, R., Wangechi, H., Mugendi, D., Kessel, C. van, & Six, J. (2009). Organic and Mineral Input Management to Enhance Crop Productivity in Central Kenya. *Agronomy Journal*, *101*(5), 1266–1275. https://doi.org/10.2134/AGRONJ2008.0188X

Christiaensen, L., Demery, L., & Kuhl, J. (2011). The (evolving) role of agriculture in poverty reduction-An empirical perspective. *Journal of Development Economics*, *96*(2), 239–254. https://doi.org/10.1016/J.JDEVECO.2010.10.006

Corbeels, M., de Graaff, J., Ndah, T. H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, H. D., & Adolwa, I. S. (2014). Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems & Environment*, *187*, 155–170. https://doi.org/10.1016/J.AGEE.2013.10.011

D'Annolfo, R., Gemmill-Herren, B., Amudavi, D., Shiraku, H. W., Piva, M., & Garibaldi, L. A. (2020). The effects of agroecological farming systems on smallholder livelihoods: a case study on push–pull system from Western Kenya. *International Journal of Agricultural Sustainability*, *19*(1), 56–70. https://doi.org/10.1080/14735903.2020.1822639

D'Annolfo, R., Gemmill-Herren, B., Graeub, B., & Garibaldi, L. A. (2017). A review of social and economic performance of agroecology. *International Journal of Agricultural Sustainability*, *15*(6), 632–644. https://doi.org/10.1080/14735903.2017.1398123

Dumont, A. M., Vanloqueren, G., Stassart, P. M., & Baret, P. V. (2016). Clarifying the socioeconomic dimensions of agroecology: between principles and practices. *Agroecology and Sustainable Food Systems*, *40*(1), 24–47. https://doi.org/10.1080/21683565.2015.1089967

Epule, E. T., Bryant, C. R., Akkari, C., & Daouda, O. (2015). Can organic fertilizers set the pace for a greener arable agricultural revolution in Africa? Analysis, synthesis and way forward. *Land Use Policy*, *47*, 179–187. https://doi.org/10.1016/j.landusepol.2015.01.033

Gambart, C., Swennen, R., Blomme, G., Groot, J. C. J., Remans, R., & Ocimati, W. (2020). Impact and Opportunities of Agroecological Intensification Strategies on Farm Performance: A Case Study of Banana-Based Systems in Central and South-Western Uganda. *Frontiers in Sustainable Food Systems*, *4*, 87. https://doi.org/10.3389/FSUFS.2020.00087/BIBTEX

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34. https://doi.org/10.1016/J.FCR.2009.06.017

Gliessman, S. (2018). Defining Agroecology. In *Agroecology and Sustainable Food Systems*, Vol. 42, Issue 6, pp. 599–600. https://doi.org/10.1080/21683565.2018.1432329

Gliessman, S.R. 2007.Agroecology: the ecology of sustainable food systems. CRC Press, Taylor & Francis, New York, USA, 384 pages

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/J.1471-1842.2009.00848.X

Hazell, P. B. R. (2009). The Asian Green Revolution. *IFPRI Discussion Paper 00911*, 1–40. www.ifpri.org/millionsfed

Herrendorf, B., Rogerson, R., & Valentinyi, Á. (2014). Growth and Structural Transformation. *Handbook of Economic Growth*, *2*, 855–941. https://doi.org/10.1016/B978-0-444-53540-5.00006-9

HLPE. 2019. Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Isgren, E. (2016). No quick fixes: four interacting constraints to advancing agroecology in Uganda. *International Journal of Agricultural Sustainability*, *14*(4), 428–447. https://doi.org/10.1080/14735903.2016.1144699

Ivanic, M., & Martin, W. (2018). Sectoral Productivity Growth and Poverty Reduction: National and Global Impacts. *World Development*, *109*, 429–439. https://doi.org/10.1016/J.WORLDDEV.2017.07.004

Jayne, T. S., Benfica, R., Yeboah, F. K., & Chamberlin, J. (2019). Agricultural transformation and Africa's economic development. *African Economic Development*, 349–375. https://doi.org/10.1108/978-1-78743-783-820192018

Johnson, D. G. (1993). Role of agriculture in economic development revisited. *Agricultural Economics*, *8*(4), 421–434. https://doi.org/10.1016/0169-5150(93)90044-D

Johnston, B. F. (1970). Agriculture and structural transformation in developing countries: a survey of research. *Journal of Economic Literature*, *8*(2).

Johnston, B. F., & Mellor, J. W. (1961). *The Role of Agriculture in Economic Development*. *51*(4), 566–593.

Jorgenson, D. W. (1961). The Development of a Dual Economy. *The Economic Journal*, *71*(282), 309–334. https://doi.org/10.2307/2228770

Kangmennaang, J., Kerr, R. B., Lupafya, E., Dakishoni, L., Katundu, M., & Luginaah, I. (2017). Impact of a participatory agroecological development project on household wealth and food security in Malawi. *Food Security*, *9*(3). https://doi.org/10.1007/s12571-017-0669-z

Kansanga, M. M., Kangmennaang, J., Bezner Kerr, R., Lupafya, E., Dakishoni, L., & Luginaah, I. (2020). Agroecology and household production diversity and dietary diversity: Evidence from a five-year agroecological intervention in rural Malawi. *Social Science and Medicine*. https://doi.org/10.1016/j.socscimed.2020.113550

Le Campion, A., Oury, F. X., Heumez, E., & Rolland, B. (2020). Conventional versus organic farming systems: dissecting comparisons to improve cereal organic breeding strategies. *Organic Agriculture*, *10*(1), 63–74. https://doi.org/10.1007/S13165-019-00249-3/TABLES/3

Lee, D. R., Barrett, C. B., & McPeak, J. G. (2006). Policy, technology, and management strategies for achieving sustainable agricultural intensification. *Agricultural Economics*, *34*(2), 123–127. https://doi.org/10.1111/J.1574-0864.2006.00112.X

Lewis, W. A. (1954). Economic Development with Unlimited Supplies of Labour. *The Manchester School*, *22*(2), 139–191. https://doi.org/10.1111/J.1467-9957.1954.TB00021.X

Ligon, E., & Sadoulet, E. (2018). *Estimating the Relative Benefits of Agricultural Growth on the Distribution of Expenditures*. https://doi.org/10.1016/j.worlddev.2016.12.007

Madsen, S., Bezner Kerr, R., Shumba, L., & Dakishoni, L. (2021). Agroecological practices of legume residue management and crop diversification for improved smallholder food security, dietary diversity and sustainable land use in Malawi. *Agroecology and Sustainable Food Systems*, *45*(2). https://doi.org/10.1080/21683565.2020.1811828

Nyantakyi-Frimpong, H., Kangmennaang, J., Bezner Kerr, R., Luginaah, I., Dakishoni, L., Lupafya, E., Shumba, L., & Katundu, M. (2017). Agroecology and healthy food systems in semi-humid tropical Africa: Participatory research with vulnerable farming households in Malawi. *Acta Tropica*, *175*, 42–49. https://doi.org/10.1016/J.ACTATROPICA.2016.10.022

Ranganathant, R. (1992). Production possibility frontiers and estimation of competition effects: the use of a priori information on biological processes in intercropping. *Expl Agric.*, *28*, 351–367. https://edepot.wur.nl/216571

Rodenburg, J., Büchi, L., & Haggar, J. (2020). Adoption by adaptation: moving from Conservation Agriculture to conservation practices. *International Journal of Agricultural Sustainability*, 1–19. https://doi.org/10.1080/14735903.2020.1785734

Sadoulet, E., De Janvry, A., & Benjamin, C. (1998). Household behavior with imperfect labor markets. *Industrial Relations*, *37*(1), 85–108. https://doi.org/10.1111/0019-8676.731998036

Schader, C., Heidenreich, A., Kadzere, I., Egyir, I., Muriuki, A., Bandanaa, J., Clottey, J., Ndungu, J., Grovermann, C., Lazzarini, G., Blockeel, J., Borgemeister, C., Muller, A., Kabi, F., Fiaboe, K., Adamtey, N., Huber, B., Niggli, U., & Stolze, M. (2021). How is organic farming performing agronomically and economically in sub-Saharan Africa? *Global Environmental Change*, *70*, 102325. https://doi.org/10.1016/J.GLOENVCHA.2021.102325

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/J.JBUSRES.2019.07.039

Start, D. (2001). The Rise and Fall of the Rural Non-farm Economy: Poverty Impacts and Policy Options. *Development Policy Review*, *19*(4), 491–505.

Stevens, A. W. (2018). Review: The economics of soil health. *Food Policy*, *80*, 1–9. https://doi.org/10.1016/J.FOODPOL.2018.08.005

Stevens, A. W. (2019). Economic Theory Provides Insights for Soil Health Policy. *CHOICES*, *34*(2).

Syrquin, M. (1988). Chapter 7 Patterns of structural change. *Handbook of Development Economics*, *1*, 203–273. https://doi.org/10.1016/S1573-4471(88)01010-1

Tambo, J. A., & Mockshell, J. (2018). Differential Impacts of Conservation Agriculture Technology Options on Household Income in Sub-Saharan Africa. *Ecological Economics*, *151*, 95–105. https://doi.org/10.1016/J.ECOLECON.2018.05.005

Tapsoba, P. K., Aoudji, A. K. N., Kabore, M., Kestemont, M. P., Legay, C., & Achigan-Dako, E. G. (2020). Sociotechnical context and agroecological transition for smallholder farms in benin and Burkina Faso. In *Agronomy* (Vol. 10, Issue 9). https://doi.org/10.3390/AGRONOMY10091447

Timmer, C. P. (1988). Chapter 8 The agricultural transformation. *Handbook of Development Economics*, *1*, 275–331. https://doi.org/10.1016/S1573-4471(88)01011-3

Timmer, C. P. (1992). Agriculture and economic development revisited. *Agricultural Systems*, *40*(1–3), 21–58. https://doi.org/10.1016/0308-521X(92)90015-G

Vogel, H. (1994). Weeds in single-crop conservation farming in Zimbabwe. *Soil and Tillage Research*, 31(2-3), 169–185. https://doi.org/10.1016/0167-1987(94)90078-

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., & David, C. (2009). Agroecology as a science, a movement and a practice. A review. *Agron. Sustain. Dev*, *29*. https://doi.org/10.1051/agro/2009004

Wezel, A., Casagrande, M., Celette, F., Vian, J. F., Ferrer, A., & Peigné, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development*, *34*(1), 1–20. https://doi.org/10.1007/S13593-013-0180-7/FIGURES/6

Wezel, A., Herren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., & Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, *40*(6), 1–13. https://doi.org/10.1007/S13593-020-00646-Z/FIGURES/5

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards: Meta-narrative reviews. *BMC Medicine*, *11*(1), 1–15. https://doi.org/10.1186/1741-7015-11-20/FIGURES/1

Zilberman, D., Khanna, M., & Lipper, L. (1997). Economics of new technologies for sustainable agriculture. *Australian Journal of Agricultural and Resource Economics*, *41*(1), 63–80. https://doi.org/10.1111/1467-8489.00004

Appendix

Table A 1: Search criteria

Domain	Search criteria/Seminal work	Database	Hits	Selected
Agricultural transformation	"agric* transform*"	Econlit	94	13
		AgEcon	40	
	("concept* framework" OR definition) AND "agric* transform*"	WoS	8	
	"agric* transform*" AND "Afric*"		122	
	Timmer (1986, 1988)	ConnectedPapers	61	
Agro-ecology	"agro-ecolog*" OR "agroecolog*"	Econlit	315	155
		AgEcon	98	
	("concept* framework" OR "definition") AND "agro$ecolog*"	WoS	114	
	(Agroecolog* OR Agro-ecolog* OR Agro$ecology) AND (Afric*)	WoS	1759	
	Wezel et al (2009)	ConnectedPapers	63	
Agricultural transformation and agro-ecology	("agro-ecolog*" OR "agroecolog*") AND "agric* transform*"	Econlit	3	All were duplicates
		AgEcon	0	
		WoS	0	

Source: Authors elaboration

Table A 2: Additional search criteria

Domain	*Search criteria*	*Selected journals*	*Hits*	*Selected*
Agricultural sustainability	"sustainab*" for agricultural economics journals	•American Journal of Agricultural Economics •Food Policy •Journal of Agricultural Economics	411	12

		•Agricultural Economics •Australian Journal of Agricultural and Resource Economics		
	"sustainab*" AND "agric*" for the journals on development economics	•World Development •Structural change and economic dynamics •European Review of Agricultural Economics	464	
Agricultural innovation	agricultur* AND innovat* AND concept*	•Ecological economics •World development •Food policy •American journal of agricultural economics •Journal of agricultural Economics •Agricultural Economics •European review of agricultural economics...	68	10

Source: Authors elaboration

Table A3: Other sources

	Source	References
	From citation tracking and reference of references	Johnston and Mellor, (1961); Kuznets (1961); Gliessman (2016, 2018); HLPE report (2019); Guto et al, 2012; Corbeels et al, 2014; Vogel, 1994
	Internet Google search and library books	Christiaensen, Demery and Kuhl, 2011; Ligon and Sadoulet, 2018; Ivanic and Martin, 2018; Hazell (2009); Jayne et al (2019); Gliessman (2007); Altieri and Nicholls (2005); Start (2001); Stevens (2018,2019)

Source: Authors elaboration