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Sustainable agricultural practices and their adoption in sub-Saharan Africa

A selected review

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Abstract

Sub-Saharan Africa (SSA) currently produces about 10% of global agricultural output, while possessing 25% of the world's arable land. That said, there is probably less additional agricultural land available than generally assumed, given the trend in rural population density, which is in places comparable to Asian levels. Moreover, most soils are fragile, with low nutrients and concentration of organic matter. A 'great balancing act' is needed between growing and diverse requirements for food and nutrition security (FNS) and the resources available. More generally, there are both conventional challenges (demographics) and emerging challenges (climate change) to the achievement of FNS. The debate on the sustainability of agriculture requires translation into specific approaches and practices.

Through a literature review, we develop a qualitative assessment of the potential of a selection of sustainable agricultural practices within the SSA context, with an emphasis on factors for adoption, adaptation and innovation.

Most of the focus on sustainability tends to emphasise environmental or ecological dimensions. However, the question from a social science perspective is rather 'what is being sustained, for how long, for whose benefit and at whose cost, over what area and measured by what criteria'. According to this approach, sustainable agriculture is not only a goal but a learning process with no pre-defined technological, management or political path. However, the level of analysis of the land sharing or land sparing debate is that of the landscape, so the translation is neither direct nor complete at farm level; even less so at plot level. Although agricultural practices form the backbone of sustainable agriculture, they fall short of responding to such a challenge by themselves. Practices integrated into productive systems provide a first level of coherence. However, to be sustainable, agriculture also requires other elements such as local environmental management and other landscape-level management tools.

Farmers and rural households are changing; they are not static policy targets. Communities are rapidly changing as they become more aware of alternative agricultural practices, systems and crops, but at the same time they may be reducing their involvement, implication and investment in agriculture due to increasing off-farm employment opportunities, and hence not investing in yield- or soil-enhancing practices.

There are different cost structures for adopting off-the-shelf packages for conventional intensification than for knowledge-intensive alternatives. Knowledge-intensive practices may result in paradigmatic changes to day-to-day operation and reduce direct input costs, but they tend to be site-specific, instead raising the transaction costs associated with their adoption. To clarify the distinction, the costs of Green Revolution and technologically-based solutions (e.g. seed improvement through conventional hybrids or other means, more specific pest control substances, improved irrigation systems) almost exclusively comprise direct input costs.

Agriculture in Africa faces highly diverse challenges in terms of a sustainable approach to responding to the region's FNS needs. As such, there is no single solution ('silver bullet') allowing the sector to sustainably increase its contribution to food supply. Ultimately, opting for a coherent set of approaches, or more targeted agricultural practices, depends on the great diversity of local contexts (environmental, institutional, seasonal, etc.), as well as the characteristics and objectives of individual farmers and their communities. Collective action in the uptake of key practices has been recorded as producing more sustainable benefits.

When looking at each newly adapted practice as an innovation, it is essential to look towards more coherent, and more importantly effective, sustainable production systems. To be sustainable, any FNS intervention would benefit from adopting a landscape framework, so that the various objectives of sustainability can be coherently negotiated alongside pure FNS objectives.

Therefore, land sharing could be particularly relevant for areas with potential agricultural frontiers (e.g. Sahel countries, Democratic Republic of the Congo), but also for those where forest 'encroachment' is the only remaining frontier given the rising population density.

As is the case for input-based intensification of agriculture, the results from the different management-based approaches are not universal and absolute responses cannot be derived from the cases reviewed (including the meta-analyses). Careful targeting and local adaptation remain fundamental for both improved performance and the long-term adoption of any of the principles and associated practices. A general challenge for adoption is that of timing. Any new practice or approach promoted is expected to provide at least a perceptible contribution towards farmers' short-term objectives, to which they are generally most sensitive.

1 Introduction

Hunger is still the reality for more than 0.8 billion individuals. Although the number of food insecure people has decreased from about 1 billion over the last 30 years, there has been a rising trend since 2015 (FAO, IFAD et al. 2019), with a serious risk of further acceleration due to the Covid-19 pandemic (FAO 2020). The proportion of undernourished people is 9.2% of the total population (down from 18% 30 years ago) (FAO, IFAD et al. 2014, FAO, IFAD et al. 2019). The objective in the Millennium Development Goals (MDGs) to halve undernourishment by 2015 was therefore not met except in some regions of the world, notably some parts of Asia and of Latin America and the Caribbean (United Nations 2014). Sub-Saharan Africa experienced an increase in absolute terms, although it has significantly reduced the proportion of undernourished individuals from 33% to 23% of the population. Although chronic undernutrition among young children declined, one in four children is still suffering from it (United Nations 2014). Moreover, 2 billion individuals still suffer from iron deficiency or other micronutrient deficiencies (vitamins, minerals, etc.), highlighting the importance of food being not only available but also nutritious and healthy (WHO 2012, Kloos and Renaud 2014).

Evidence rejects simplistic appraisals reducing hunger to the lack of food, such as analyses by Sen (1981, Kloos and Renaud 2014) looking at the lack of access and entitlement to food. The success of more inclusive food security strategies and strengthened social protection policies in the Latin American context, such as the Zero Hunger programme in Brazil, is a confirmation of this key dimension (FAO, IFAD et al. 2014). Hunger remains not only because of a production gap, but also because of conflict, lack of job opportunities and access to land. It is also the result of the unsustainable use of natural resources, on which the rural poor are directly dependent for their livelihoods (Cavendish 2000, Kamanga, Vedeld et al. 2009).

The future evolution of this challenge towards 2050 (and beyond) will depend on how the world food system responds to a total population reaching around 9.7 billion, with sub-Saharan Africa set to experience a doubling of its population to about 2.2 billion individuals (UN DESA 2019). Even if all food resources were evenly distributed, at current production levels the calories available would not cover projected needs in 2050 for every individual; an estimated 65%[1] increase is required in food calories directly available for human consumption. This type of projection includes the expected changes in consumption dynamics and also patterns associated with the nutrition transition (Popkin, Adair et al. 2012). Growth in food demand is also expected to include marine resources, particularly in a context of urbanisation towards coastal areas, where most cities are located and where about 55% of the world population is concentrated – a proportion that is expected to increase to 68% by 2050 (UN 2019). Today, over 200 million people depend, directly or indirectly, on marine resources for their livelihoods[2], including the growing role of aquaculture. At world level, fish contributes to a sixth of all animal protein consumption, and is the main source of animal protein, key micronutrients and fatty acids for 3 billion people (FAO 2013). Finally, biofuels are placing additional demand on land and crops, as a contribution to climate change mitigation measures[3].

However, as expressed by the World Resource Institute, a 'great balancing act' is needed between the increasing and diversifying needs and the resources available (Searchinger, Hanson et al. 2014). More generally, the achievement of food security faces both conventional and emerging challenges. The Sahel is particularly challenged, as illustrated in Box 1 (Ceccarelli, Winograd et al. 2019).

Box 1. Long-term food balances

Long-term food balances in 11 Sahelian countries were modelled under climate change scenarios to 2050, to test whether biomass from agriculture and natural vegetation will cover future human needs. In 2012, about 15% of food biomass was already imported. Given the expected impact of climate change on crop yields, food self-sufficiency is not expected to be reached. By the year 2050, food biomass imports are expected to reach 40% of total food needs under the most productive agriculture scenario, and up to 65% under the less optimistic scenario (Ceccareli et al., 2019).

1 Up from previous estimate of 55% (Alexandratos, N. and J. Bruinsma (2012). "World agriculture towards 2030/2050: the 2012 revision." ESA Working Paper - FAO **03**.), which was based on an outdated population projection and did not account for weaker than needed production in sub-Saharan Africa.

2 Since 1950, fishing populations have grown by 400%, while agricultural populations have grown by only 35% over the same period. Some estimates indicate that up to 500 million people depend on marine resources (FAO, reported in World Bank, 2004).

3 Development of biofuels was rapid from 2000 onwards, particularly in developed countries and in Brazil. However, given the recent changes to both US and EU momentum in this area, the impact from these currently leading producers will probably be less significant. However, the importance of future industrialising nations is not so easy to grasp. China has now targeted cassava as a good option, given that this crop is not classified as a food crop in China, although it has consequences for trade (HLPE (2013). Biofuels and food security. Report 5. Rome, A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.

Based on the statistics available from the Food and Agriculture Organization of the United Nations (FAO)[4], there has been an improvement in African agricultural performance since the 1990s, and particularly since 2000, except in West Africa. On average, productivity has grown by 3.2% annually (1990-2011), slightly faster than demographic growth, which had not been deemed achievable at the beginning of the period (Platteau, 1990 in Wiggins 2014). However, this was half the target established in the 2003 Maputo Objectives (CAADP 2003). The composition of output changed little over the period, being focused on production of cereals, roots, pulses and vegetables, locally or regionally traded. Traditional export crops have generally not experienced such growth (Wiggins 2014). Growth was based on higher productivity of land and labour. Yield per hectare increased, and total growth was therefore only moderately dependent on expansion of the agricultural frontier. However, some of the countries and regions that met their MDGs (Jones and Gibbon 2011, United Nations 2014) also experienced large land use transformation; for example, Brazil or Indonesia, which were singly responsible for 34% and 17% respectively of all greenhouse gases (GHGs) from deforestation between 2000-2012.

Although Africa is estimated to possess 25% of the world's arable land, and have some of the most fertile land in the world (Jones, Breuning-Madsen et al. 2013), it is currently only producing about 10% of global agricultural output (Jayaram, J. Riese et al. 2010). That said, the estimated additional agricultural land available is probably less than generally assumed, given the trend in rising rural population density, which is in places comparable to Asian levels. Moreover, most soils are fragile, with low nutrients and concentration of organic matter. There are several challenges to the resilience of soils, such as desertification. The remaining areas are constituted of highly weathered and acidic soils, with high levels of iron and aluminium oxides, requiring 'careful management if used for agriculture' (Headey and Jayne 2014)(Jones, Breuning-Madsen et al. 2013). Patterns of resource use in Africa have resulted in soil degradation, partially jeopardising productive assets, but there is no consensus on the extent and severity of this (FAO and ITPS 2015).

[4] This is not devoid of significant potential biases (Jerven, M. (2014). "The Political Economy of Agricultural Statistics and Input Subsidies: Evidence from India, Nigeria and Malawi." Journal of Agrarian Change **14**(1): 129-145.

2 Objectives and scope

The general objective of this review is a qualitative assessment of the potential of sustainable agricultural practices within the institutional context of sub-Saharan Africa (SSA).

The emphasis is on the economic and institutional dimensions of such practices, rather than the agronomic one. To this end, the review looks at factors for adoption, adaptation and innovation of more sustainable agricultural practices.

As a rule, the geographical scope of the experiences reviewed in the analysis is within the Sahel and similar drylands in SSA. Other valuable experiences include examples from more humid areas where intensive agricultural practices are used, developed or tested.

3 Approach and methods

Notwithstanding the importance of the various dimensions of food security strategy beyond a quantitative increase in supply, the following report focuses on sustainable and more productive agricultural practices adapted to sub-Saharan countries, with special emphasis on the climate-challenged Sahel and Horn of Africa. As such, the options assessed in this work should be seen as contributing, along with other approaches, to achieving and maintaining food security in the face of current (identified) future global changes. In some cases, such options could also contribute to food sovereignty objectives[5], if they were to be mainstreamed into intervention and support goals.

3.1 Methods

The report gathers a conventional literature review of existing publications (peer-reviewed journals, major reports and relevant project documents). The material consulted was mostly in English, although some references are made to French documents, particularly for West and Central African experiences. The key databases consulted were Scopus and Google Scholar. The first part of the research focused on the question of agriculture and sustainability in general (keywords included 'sustainable agriculture', 'land sharing', 'land sparing', 'sustainable intensification' and 'ecological intensification').

This general overview was followed by searches on specific agricultural practices and approaches identified in the literature as sustainably contributing to improving the productivity of SSA agriculture.

Specific implications for drylands are highlighted from the more general review, particularly regarding institutional dimensions of uptake, adoption and adaptation of given practices and approaches.

3.2 Structure of the report

This introduction is quickly followed by a review of the challenges in achieving food security in the context of global changes, to frame from the supply side the potential contribution of a dynamic agricultural sector, particularly in SSA. The Green Revolution – i.e. intensification of conventional agricultural input – as the main response to the challenge is briefly assessed from the extended literature available, particularly with regard to its sustainability as a long-term strategy[6]. The balance of the Green Revolution is considered when looking for complementary production approaches to respond to the challenge.

The core of the report proceeds to explore, identify and assess relevant sustainable practices and approaches that offer complementary avenues to the Green Revolution in SSA, in particular the Sahel and other dryland sub-regions.

Conclusions are drawn from the whole exercise, accompanied by potential avenues for action formulated to inform intervention.

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[5] Food sovereignty contrasts with the concept of food security in the sense that it highlights the dimension of power embedded in the international development of agribusinesses. Food sovereignty was defined as 'the right of peoples to define their own food and agriculture; to protect and regulate domestic agricultural production and trade in order to achieve sustainable development objectives; to determine the extent to which they want to be self-reliant; to restrict the dumping of products in their markets; and to provide local fisheries-.based communities the priority in managing the use of and the rights to aquatic resources. Food sovereignty does not negate trade, but rather, it promotes the formulation of trade policies and practices that serve the rights of peoples to safe, healthy and ecologically sustainable production'. Summarised contribution to FAO, The State of Food and Agriculture 2005 by Via Campesina. http://www.fao.org/docrep/008/a0050e/a0050e08.htm#TopOfPage

[6] The Green Revolution alone was conceived as temporary and as only part of the response to the challenge of hunger. In the words of its initiator, 'The green revolution has won a temporary success in man's war against hunger and deprivation; it has given man a breathing space. If fully implemented, the revolution can provide sufficient food for sustenance during the next three decades. But the frightening power of human reproduction must also be curbed; otherwise the success of the green revolution will be ephemeral only' (Borlaug, N. (1970). The Green Revolution, Peace, and Humanity. Nobel Lecture, Royal Swedish Academy of Sciences.

4 Agricultural practices and sustainability

In order to start reviewing and assessing sustainable agricultural systems in SSA, we need to define both the unit of analysis that makes up such agricultural systems, and what can make them more sustainable.

This section briefly reviews what makes up agricultural systems, from cropping techniques to production sequences and activities that shape the landscapes of entire farming regions. In turn, qualifying such systems as sustainable requires a definition of what is sustainable, first broadly attributed to development and then to the challenges specific to agriculture. We consider some of the implications of the interactions between agricultural practices restricted to the plot (or farm) and wider landscape management approaches for food security.

The review focuses on:

- a selection of practices and approaches (e.g. conservation agriculture);
- factors for adoption, rejection or dis-adoption, and implications for success (e.g. opportunity and transaction costs).

4.1 Approaching agricultural practices

The main agronomic approaches help to locate the present review of suitable practices as contributors to sustainable agricultural systems.

In their agronomy handbook, Doré et al. (2006) highlighted three complementary and contemporary research projects in agronomy. One focuses on modelling the functioning of constitutive elements of crops, such as plant growth or soil dynamics. A second approach starts from specific cropping techniques (tilling, fertilisation, sowing, etc.), so as to assess their performance and to benchmark such performance in different settings. A third approach understands farming as a coherent system (i.e. agrosystems). This comprehensive approach encompasses different traditions of systems research, which can for brevity be divided into Anglo-Saxon and French schools, although several others have developed, such as land use management analysis. There is the 'farming systems research' (FSR) programme, which focused on how intervention strategies (cropping techniques, broader practices, etc.) influence the evolution of agrosystems by 'capturing the tight interplay between the agrotechnical, economic, sociological, managerial, and cultural variables intrinsic to the farm unit' (Simmonds 1985). The programme underemphasised most of the context (economic, social and environmental) and its evolution by focusing on farm level, which became the centre of sociological analysis through agrarian and peasant studies. In turn, the French school of 'comparative agriculture' developed around the concept of agrarian systems[7]. This conceptually associates the research interests of FSR and those of peasant studies, by jointly analysing the transformation in agricultural practices and changes to social interactions, not just locally but more broadly, with nested levels of analysis (Cochet 2012).

Taking stock of such a brief overview, the systemic approach is deemed more relevant to our line of enquiry, given that agricultural systems are expected to respond to increasingly diverse emerging challenges, such as global change but also societal expectations (environmental, aesthetic, social, etc.) (Doré, Makowski et al. 2011). Moreover, farming approaches may affect and redraw the boundaries of farming systems themselves, by extending management of a single plot to that of entire farming regions, agrarian systems and landscapes. Therefore, the type of approach in responding to agricultural challenges has implications for defining the unit of study (Gliessman 1992). This highlights the need for a coherent approach to both agricultural practices and local environmental governance, as both shape agrarian systems in the region through landscape, natural resources and common goods institutional arrangements.

This brief review to identify the unit of analysis demonstrates that agricultural practices are an adaptable concept, particularly when scaling up analysis from a plot to a cropping system, to an agricultural system (i.e. farm), farming region and, for our purposes, to the level and depth of agrarian systems. The question of varying scale is particularly acute in the arid and semi-arid areas of SSA. The extensive nature of agriculture, particularly in integrating cropland and livestock, operates on a larger scale than crop-centred farming systems, by integrating resources of the landscape (Robinson, Ericksen et al. 2015).

[7] The adjective 'agrarian' is seldom used outside rural sociology in the English-speaking literature (de Bonneval, L. (1993). Systemes agraires, systemes de production: Vocabulaire français-anglais avec index anglais (Agricultural systems. Production systems. French-English Dictionary with English index). Paris, INRA. Hence the choice of the term here, where it retains its institutional depth, something that may not be the case with other terminology.

Although the framework could be seen as weakened by operational difficulties faced when attempting to define its social and geographical scope, in the context of the last 50 years of globalisation where systems are less stable than they used to appear (Cochet 2012), it is argued here that its relevance is legitimately reinstated by the need to respond to the current requirements for agriculture to sustainably contribute to food security. The approach also allows for a multi-level/multi-scale analysis and is well adapted to SSA and the tropics, given their great heterogeneity. The attention to change and evolution is also an asset in this review of practices, given the focus on factors for adoption (and rejection) within given institutional contexts. That said, and following the general methodological observation of Ostrom (2010), the stance is that, at this level, it is an approach that is selected and not a model. The agrarian system is seen here as a 'framework intended to contain the most general set of variables' relevant to examine a diversity of practices and institutional settings[8].

4.2 Defining the unit of research: agricultural practice in context

Following the classical French agronomic school, with a focus on farmers' decision-making and behaviour, the general definition of a practice is defined by distinguishing it from a technique. A technique is an operation (e.g. tilling) or a series of operations with an objective (e.g. production). In turn, a practice can be defined as the way in which an agent (i.e. farmer) implements a given technique within a given context (Teissier 1979, Milleville 1987). Unlike a technique, which can be defined independently from the agent, a practice is agent-dependent. It is also important to highlight that such practices are not only technological in nature, but also can be managerial, institutional, cultural, etc.

In reaching a more practical definition, we need to acknowledge that practices are also sequenced in time and space and that they also vary in scale. Finally, such practices also evolve and are adopted by groups of farmers sharing similar production challenges within a larger context, identified as agrarian systems (Mazoyer 1987). This larger unit of analysis is the outer reach of interaction of agricultural practices and was defined as a system 'which has evolved through time and is resilient, is adapted to the bio-climate of a given area and which is able to respond to the current social context and needs to harness the potential from the natural environment'[9] (Mazoyer 1987).

The analysis is based on a nested configuration of levels, with the building blocks of agriculture defined as management (or cropping) techniques[10], which are the sequences of various techniques involving specific tasks at given plot level (Sebillotte 1974). Taking the example of a generic annual crop (e.g. maize, sorghum), such sequences run from the previous harvest to the next, including soil preparation, seeding, weeding and fertilising until harvest, as shown in Figure **1**. Agricultural management, or cropping techniques developed in a planned sequence, form a management that can then in turn be associated with the entire decision-making sequence leading the production process (or protocol) and categorised as agricultural practice.

At a broader level, there is the cropping system, which gathers the type of crops, crop sequence and management techniques used on a particular plot or field over a period of growing seasons. The cropping systems, combined with other systems such as forestry, livestock and other enterprises, make up the farming system (i.e. farm). In turn, farming systems belong to an agrarian system. There are operational difficulties in setting the geographical scope of agrarian systems and defining whether they should be established at the level of a village, a cluster of villages or beyond (e.g. river basins) (Cochet, Devienne et al. 2007, Cochet 2012). For our purposes, we choose to define the agrarian system of reference as the area and landscape shaped by communities sharing the same rules and institutions, particularly with regard to the use of common resources that can influence rural activity, such as pasture, water and forest/bush. This choice has the advantage of facilitating connections between the analysis of agricultural practices and that of local environmental governance.

Figure 1 Illustrating different levels of decision-making for agriculture: nested scales of analysis

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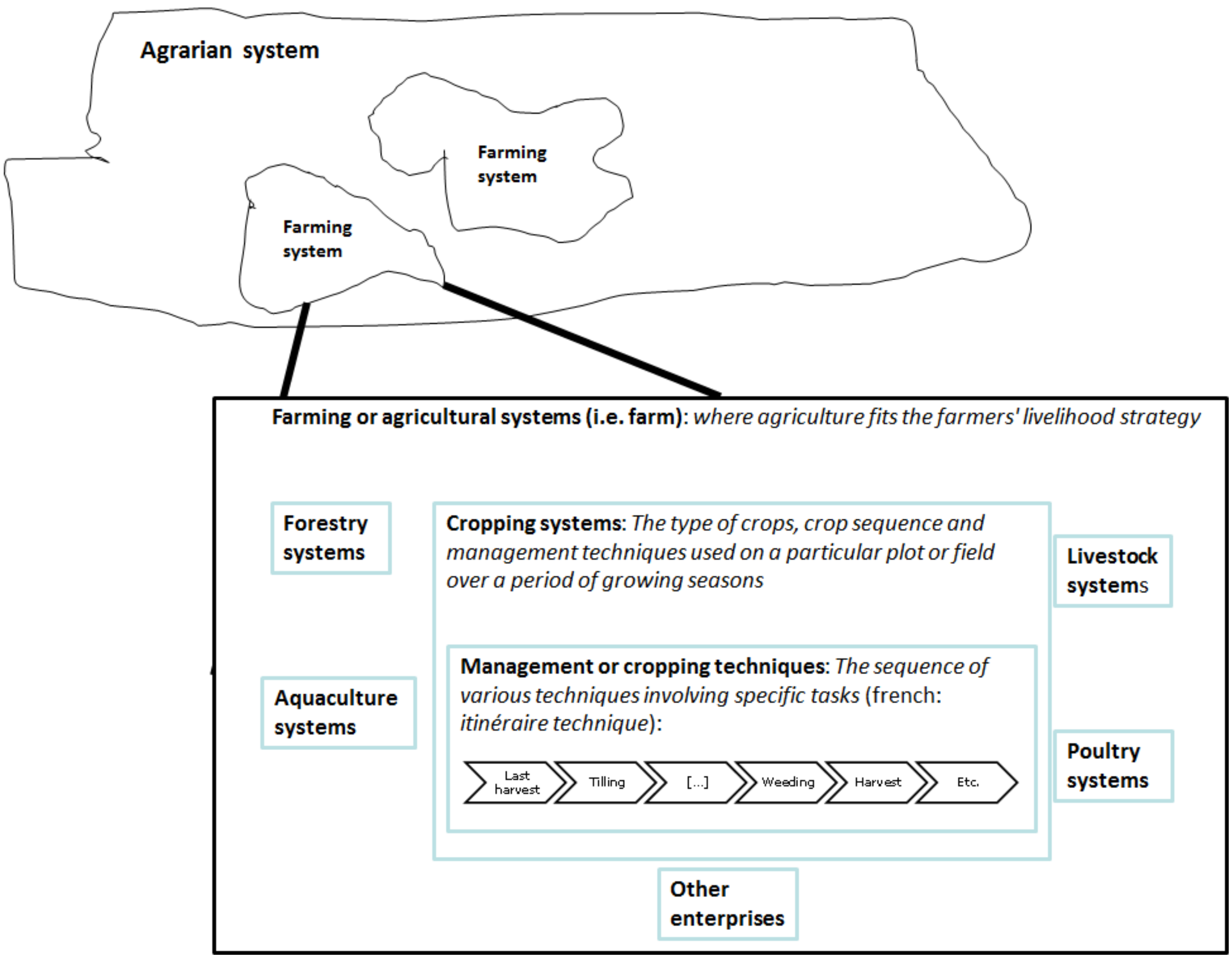
8 In turn, 'a specific theory is used by an analyst to specify which working parts of a framework are considered useful to explain diverse outcomes and how they relate to one another. [...]. Models make precise assumptions about a limited number of variables in a theory that scholars use to examine the formal consequences of these specific assumptions about the motivation of actors and the structure of the situation they face' (Ostrom, E. (2010). "Beyond Markets and States: Polycentric Governance of Complex Economic Systems." American Economic Review **100**(3): 641-672.

9 Translated by the author.

10 In French, *itinéraire technique*.



Source: Based on definitions by Gliessman (1992), Doré et al. (2006), Mazoyer (1987), Sebillotte (1974).

Following the description of possible practices, the choice of practices according to each cropping system, farming system, and larger farming or agrarian system is bound to be guided by the chosen objectives, both in the short and longer term. Such objectives could be simplified as being to produce as much as possible in a sustainable way.

4.3 General characteristics of sustainable agriculture

There are several visions of what makes an agricultural system sustainable (Koohafkan, Altieri et al. 2011, Cook, Silici et al. 2015) and there is still debate as to what extent a given agricultural practice is sustainable (Pretty 2008).

That said, characteristics are expected to be in line with the general definition of sustainable development in the Brundtland Commission (1987) report to the UN, as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. The concept has since evolved into a three-pillar model, where sustainable development is associated with a balance between environmental, economic and social dimensions.

According to the extensive review in the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), agriculture is sustainable when 'the productive resource base is maintained at a level that can sustain the benefits obtained from it. These benefits are physical, economic and social. Ecological sustainability thus needs to be defined in relation to the sustainable use of natural resources, i.e., maintaining the productive capacity of an ecosystem' (McIntyre, Herren et al. 2009).

The introduction of efficiency requires that sustainable agriculture makes the best use of resources (i.e. environmental goods and services) without damaging these assets (Pretty 2008). In operational terms, sustainable agriculture can be translated into key principles, such as summarised in the review by Pretty: 'i) integrating biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy[11], competition, predation and parasitism into food production processes; ii) minimising the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers; iii) making productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs; and iv) making productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest and credit management' (Pretty 2008).

Most of the focus tends to be on the environmental or ecological dimensions of sustainability. However, and as suggested by Pretty (2000), beyond the exercise of trying to define in absolute terms the concept of sustainability, the question from a social science perspective is rather 'what is being sustained, for how long, for whose benefit and at whose cost, over what area, and measured by what criteria'. According to this approach, sustainable agriculture is not only a goal but a learning process with no pre-defined technological, management or political path. For agricultural practices, this relative definition has four distinctive advantages. The first is that agricultural practices have a unique operational dimension (i.e. facilitation of sustainable agriculture) (Röling and Wagemakers 2000). It also more clearly acknowledges the different agendas of stakeholders, and makes trade-offs between the different pillars of sustainability more visible. Finally, it provides a specific space for the social dimension of sustainability (Martínez-Alier 2003)[12], which is more difficult to formulate under the absolute definition of the concept. The issues are the challenges of ecological distribution, understood as 'the social, spatial, and intertemporal patterns of access to the benefits obtainable from natural resources and from the environment as a life support system, including its "cleaning up" properties. The determinants of ecological distribution are in some respects natural (climate, topography, rainfall patterns, minerals, soil quality and so on). They are clearly, in other respects, social, cultural, political, and technological' (Martínez-Alier 2003).

The goal of agriculture is not only to 'maximize productivity, but to optimize it across a far more complex landscape of production, rural development, environmental, social justice and food consumption outcomes' (Pretty, Sutherland et al. 2010), echoing both the IAASTD (McIntyre, Herren et al. 2009) and Sachs et al. (2010). Sustainable agriculture is about best and equitable use of available resources. Operationally, the concept also recognises that there may be many pathways to agricultural sustainability, and that no single configuration of technologies, inputs and management is more likely to be more applicable (Pretty 2008). This broader reading of agriculture as a key link within a larger network of food security providers entails the development of a landscape approach to agriculture, if it is to answer the need for food security within a global change context.

One of the key resource bases on which agriculture depends is land, both as soil and extension (i.e. land which could be used for alternative land uses such as forest or other hosts of biodiversity).

Let us first focus on the land as extension. To respond to the challenge of developing agriculture while conserving biodiversity and other ecosystem features, the land use options span a continuum from 'land sharing', which integrates biodiversity within heterogeneous agricultural landscapes, to 'land sparing', which clearly segregates the functions between productive agricultural land and conservation/protected areas (Green, Cornell et al. 2005, Tscharntke, Clough et al. 2012). For some, the land sparing/land sharing debate encapsulates a paradigmatic choice over sustainability (Koohafkan, Altieri et al. 2011).

At first, 'best use of resources' may intuitively be associated with using as little as possible, so as to limit land-use change (biodiversity loss, GHG emissions, etc.), therefore favouring a 'land sparing' strategy. Improving production and sparing land from use change entails the development and adoption of intensification. At the level of agricultural practice[13], intensification refers to a process by which increased use of inputs and labour results in increased output per hectare (or other unit of land). Traditional definitions account for three main ways of intensifying agriculture; namely increasing yields (production per unit of land), increasing cropping intensity per unit of land or other inputs, and choosing higher market value crops in a given unit of land (Pretty, Toulmin et al. 2011). Productivity improvements, through yield growth (and livestock feed efficiency), are expected to reduce the need to expand the agricultural frontier, but it is crucial to assess their effect. The overview of the evidence by Hertel, Ramankutty et al. (2014) for Asia, Latin America, and the

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[11] 'The suppression of growth of one plant species by another due to the release of toxic substances'. Merriam-Webster (2015) http://www.merriam-webster.com/dictionary/allelopathy.

[12] The social dimension of sustainability tends to be more effectively highlighted by both the 'environmental justice' and 'environmentalism of the poor' approaches. Environmentalism of the poor relates to actions and concerns in situations where the environment is a source of livelihood. (Martínez-Alier, J. (2003). The Environmentalism of the Poor: A Study of Ecological Conflicts and Valuation, Edward Elgar Publishing, Incorporated.

[13] Broader, socio-economic understanding of intensification was formulated by Boserup (1965) as the process of relative changes in the availability of labour, land (cultivated or not) and capital because of population growth. At this stage, intensification is limited to its agronomic meaning. However, when looking at the drivers for adopting given practices, this definition is operational in analysing trends. Boserup, E. (1965). The Condition of Agricultural Growth: The Economics of Agrarian Change under Population Pressure. London, Allan and Urwin.

Middle East asserts that the original Green Revolution was land-sparing, compared to an alternative world without the adopted intensification of practices.

However, gains in productivity may also be associated with additional agricultural land, because of two reinforcing factors. First there is the 'rebound' or Jevons paradox[14] effect (Polimeni, Mayumi et al. 2009), which makes the use of an input more profitable thanks to productivity improvement, and therefore incentivitises its growing use. Here, agriculture is made more attractive than alternative land uses, and deforestation could be favoured by improved productivity in agriculture (Villoria, Byerlee et al. 2014). This effect is then exacerbated by expanding market opportunities, through progressively improved integration of African producers into global markets (Rudel, Schneider et al. 2009)[15], not to mention by the unfolding nutrition transition towards diets higher in energy, fats and refined sugar content (Popkin, Adair et al. 2012). As a mirror effect, the increase in land rents could make conservation efforts – such as payments for environmental services (PES) or reducing emissions from deforestation and forest degradation (REDD+) schemes – more expensive to maintain as competitive alternatives (Phelps, Carrasco et al. 2013). In terms of the evidence regarding effects of agricultural technological change on deforestation, the latest review on the matter (Villoria, Byerlee et al. 2014) stresses that technological progress[16] contributes (and is likely to contribute in the future) to both land-sparing effects and land use change. The effect depends on the institutional contexts (i.e. land rights and specific environmental policy), and the level of integration of the sector with global markets (i.e. elastic demand). Looking ahead, the interaction between local effects and global effects needs to be highlighted, as local and global total factor productivity growth is expected to spare land overall in regions such as Latin America and the Carribean, but to have mixed effects for Africa, which is likely to experience increased deforestation in the context of increasingly integrated global markets (Hertel, Ramankutty et al. 2014, Villoria, Byerlee et al. 2014).

It is expected that a sustained Green Revolution in Africa will have net land-sparing effects in the long-term (Hertel, Ramankutty et al. 2014). The argument that the land-sparing strategy (Phalan, Onial et al. 2011) is more appropriate than land-sharing, in responding to the imperative of sustainable food security, is however open to discussion and remains a matter for debate, particularly for Africa. Key questions arise as to how suited it is to the challenges in developing countries, when many lack effective means which may compromise the protection of conservation areas ('nature islands'). Not only do many tropical developing countries have a proven record of land-sharing practices, they also have shallow soils and other characteristics (e.g. low and/or unpredictable precipitation) exacerbated by the non-responsiveness to synthetic fertilisers, making them unsuitable for intensive use as required under the land-sparing strategy. Moreover, as pointed out by Fischer et al. (2011), ironically the closer we come to minimising the use of non-renewable inputs, the closer we get to 'land sharing — namely, knowledge-intensive agroecological systems with multiple crops and a complex structure'.

This general debate over sustainable agriculture puts forward three broad strategies contributing to sustainability. On the one hand, there is intensification, which focuses on keeping and improving productivity levels in a given area. Input intensification by itself, even if land-sparing, is also linked to environmental costs (Conway and Barbier 1990, Pingali 2012) and associated human health costs (Udeigwe, Teboh et al. 2015); hence the need to formulate the concept of sustainable intensification (SI)[17] (The Royal Society 2009). In certain cases, no sustainable intensification is possible, and the needs of wider sustainability may require lesser intensification in given areas (Garnett, Appleby et al. 2013). Moreover, improvements may not be related to input intensification, but rather to institutional intensification through upgrade of common rangeland management or the availability of risk management mechanisms (Robinson, Ericksen et al. 2015). On the other hand, other practices are looking to integrate agriculture into wider ecosystems (formerly simply understood as surrounding it), by exploiting the possibilities of wildlife-friendly forms of agricultural extension into new agricultural land through land sharing (Fischer, Abson et al. 2014). In turn, practices at plot and farm level also allow for an additional dimension of intervention: diversification. Diversification is understood as the 'enrichment of the production system related to species and varieties, land use types, and management practices' (Liniger, Studer et al. 2011). Diversification also goes beyond agricultural production, and encompasses new processing and other farm-based

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14 W. Stanley Jevons, in The Coal Question (1865), noted a paradox regarding coal consumption and efficiency improvements in steam engines: 'It is a confusion of ideas to suppose that economical use of fuel is equivalent to diminished consumption. The very contrary is the truth.'

15 'Even when agricultural commodities declined as much as 15% to 35% in price over a decade, intensification-associated declines in cultivated areas only occurred when market integration drove smallholder farmers and inefficient forms of cultivation out of agriculture (e.g., Mexico) or when merchants increased their imports of foodstuffs and governments provided incentives for farmers to conserve land' (Rudel et al., 2009).

16 Here, a disambiguation is needed with regards to what is defined as technological progress, intensification and yield growth. Yield growth has generally been associated with technological progress. However, intensification can result from both factor substitution (i.e. land surface and inputs such as fertilisers) and technological progress (i.e. same output with same land but fewer other inputs). In the case of the Green Revolution, both factor substitution and technological progress were introduced (Villoria et al., 2014).

17 Sustainable intensification is a central element for key development actors; see FAO (2015). The Director-General's Medium Term Plan 2014-17 (Reviewed) and Programme of Work and Budget 2016-17. Rome, FAO, FAO (2017). The Director-General's Medium Term Plan 2018-21 (Reviewed) and Programme of Work and Budget 2018-19. Rome, FAO.CGIAR (2015). CGIAR's Strategy and Results Framework 2016–2030. Montpellier, CGIAR.

and income generating activities (Dixon, Gibbon et al. 2001). Again, within each option, diversification of crops and farms may directly contribute to the overall sustainability of agriculture.

The sustainability strategies for agriculture are translated into practices, but these are not defined *a priori*. The value of approaches and specific agricultural practices requires assessment, accounting for their contexts (physical, institutional, social, etc.). This was clearly formulated in the case of sustainable intensification by Garnett, Appleby et al. (2013), when insisting that 'building the social and natural science evidence base to allow formulation of context-dependent SI [Sustainable Intensification] strategies is a research priority'.

When revisiting the starting point over the land sharing or land sparing debate, the level of analysis is that of the landscape. Hence the translation of a strategy for sustainability is neither direct nor complete if it is limited to plot- or farm-level practices. Although agricultural practices form the backbone of sustainable agriculture, they fall short of responding to such a challenge by themselves. Practices integrated into productive systems provide a first level of coherence. However, to be sustainable, agriculture also requires other elements such as local environmental management and other landscape-level management tools (Sayer, Sunderland et al. 2013, Scherr, Shames et al. 2013, Sunderland, Baudron et al. 2015).

4.4 Translating objectives into approaches and practices

Sustainable agricultural practices can be associated with various existing classifications, including the Good Agricultural Practices (GAPs) and World Overview of Conservation Approaches and Technologies (WOCAT) consortiums, to which FAO is also associated.

GAPs were defined as addressing ' environmental, economic and social sustainability for on-farm production and post-production processes resulting in safe and healthy food and non-food agricultural products' (FAO 2003). GAPs encompass levels that go beyond the scope of the present analysis, although remaining fully compatible with the directly production-related stages of agriculture.

In turn, WOCAT focuses on best sustainable land management 'technologies and approaches', including water use (Liniger, Studer et al. 2011). The assessment of the technologies and measures is guided by four land productivity principles, namely: a) improved water productivity on both rainfed and irrigated land; b) improved soil fertility; c) improved plant management (i.e. pest and weeds); and d) improved microclimate (i.e. protect from wind, keep moist). It is based on a repository of standardised data shared by practitioners. In turn, four main types of technologies or measures are used for the classification: i) agronomic (i.e. soil surface treatment), ii) vegetative (i.e. live fences, perennials), iii) structural (i.e. terraces, ditches) and iv) management (i.e. crop composition).

The IAASTD report (McIntyre, Herren et al. 2009) did not advocate specific policies or practices, but assessed a range of options for action that meet development and sustainability goals while addressing the multiple functions of agriculture. For SSA, a 'basket' of agricultural technology options is one that is more flexibly adapted to farmers and their context specificities, contrasting with a conventional approach associated with a small number of technologies. This is an approach that is better suited to the highly diversified existing agricultural production systems.

As part of the UK Government Foresight project, The Future of Food and Farming: Challenges and choices for global sustainability, Pretty et al. (2014) highlighted the potential for sustainable intensification in Africa through a variety of technologies and practices that can help to improve land health while sustaining or improving yields. These include agroforestry, use of fertiliser trees, soil and water conservation, conservation agriculture, making the most of patches, integrated pest management (IPM), techniques for improved horticulture, and improvements to crop varieties and cultivation techniques.

In a more recent effort, the World Bank (Walker, Hash et al. 2016) systematised the technological prospects for improving crop productivity in Africa's drylands, focusing on three areas: i) genetic improvement, ii) crop management, and iii) land management opportunities.

Based on these, we selected a few approaches that could shed light on current significance, potential and adoption requirements. Further reviews could be carried out to cover other relevant practices and approaches[18].

[18] Other approaches to investigate include:

i) Integrated pest management (IPM), including push-pull. About 55,000 farmers have been identified as having adopted push-pull throughout East Africa (Khan, Z. R., C. A. O. Midega, J. O. Pittchar, A. W. Murage, M. A. Birkett, T. J. A. Bruce and J. A. Pickett (2014). "Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020." Philosophical Transactions of the Royal Society B: Biological Sciences **369**(1639).

ii) Integrated crop-livestock management practices (ICLMPs) (or crop-livestock integration): In SSA, mixed crop-livestock systems provide 40-85% of maize, rice, sorghum and millet, and around 80% of milk and meat (Herrero, M., P. K. Thornton, A. M. Notenbaert, S. Wood, S.

Here, we focus on the following, detailed in Table 1:

- Agroforestry, including Farmer-Managed Natural Regeneration (FMNR)/ Assisted Natural Regeneration (ANR),
- Conservation Agriculture (CA),
- Integrated Soil Fertility Management, including micro-dosing,
- Organic agriculture (OA) or organic farming,
- Stand-alone soil management techniques (zaï, cross-slope barriers, bunds, etc.).

Msangi, H. Freeman, D. Bossio, J. Dixon, M. Peters and J. van de Steeg (2010). "Smart investments in sustainable food production: revisiting mixed crop-livestock systems." Science **327**(5967): 822-825, Herrero, M., P. Havlík, H. Valin, A. Notenbaert, M. C. Rufino, P. K. Thornton, M. Blümmel, F. Weiss, D. Grace and M. Obersteiner (2013). "Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems." Proceedings of the National Academy of Sciences **110**(52): 20888-20893.Livestock systems (grazing only, and more diversified and integrated systems) are relevant to 60% of the population in the Sahel. More precisely, in West Africa, crop-livestock systems cover 2.7 million km^2 and account for 75-80% of all cattle, sheep or goats (Ly, C., A. Fall and I. Okike (2010). "The Livestock Sector in Need of Regional Strategies." Livestock in a changing landscape: Experiences and regional perspectives: 27.The current importance of mixed crop-livestock systems in the region provides a scale for the potential adoption of integrated management and practices. Moreover, millions of hectares of land not cultivable given their fragility are however suitable for livestock production (Pell, A. N. (1999). "Integrated crop-livestock management systems in Sub-Saharan Africa." Environment, Development and Sustainability **1**(3-4): 337-348. Small ruminant (sheep and goat) systems having adopted ICLMPs in central Ghana out-perform non-integrated systems, both in terms of productivity and efficiency (Asante, B. O., R. A. Villano and G. E. Battese (2017). "Integrated crop-livestock management practices, technical efficiency and technology ratios in extensive small-ruminant systems in Ghana." Livestock Science **201**: 58-69. The use of pigeon pea, ash/neem, improved pasture and storage of crop residues statistically improved the value of output among the 510 farmers surveyed. Regarding inefficiency, it is the storage of crop residues that systematically reduced it throughout the three districts surveyed. Another key determinant of inefficiency was the (non)use of tetracycline (ibid.
iii) Agroecological intensification, which is currently being reviewed by various DG DEVCO initiatives.

Table 1 Approaches and associated practices reviewed

Approaches	Main characteristics	Associated practices	Main coverage as per meta-analyses and reviews[19].
Agroforestry, including FMNR/ANR	Also known in French as *Régénération naturelle assistée*, it integrates the use of woody perennials with agricultural crops and/or animals to improve soil and water resource use and supply of fuel, fodder and food products, as well as providing habitat for associated species.	1. Trees on farmland 2. Parkland (scattered trees) 3. Alley cropping 4. Windbreak and shelter belts 5. Homegardens 6. Silvopastoral systems	Agroforestry: Nigeria, Ethiopia, South Africa, Ghana and Benin FMNR: drylands (mainly Niger but also Burkina Faso, Ethiopia, Ghana, Mali and Senegal)
Conservation Agriculture	Approach to improve agronomic performance, as well as to protect and enhance the resource base and the environment of agro-ecosystems.	1. Continuous minimum mechanical soil disturbance (i.e. minimal tilling) 2. Permanent organic soil cover 3. Diversification of crop species grown in sequences and/or associations (i.e. ensuring rotation and/or intercropping with, for example, legumes)	Most examples from Eastern and Southern Africa, including Madagascar, with additional lessons from Sahel/West Africa (e.g. Cameroon).
Integrated Soil Fertility Management, including micro-dosing	Set of soil fertility management practices following sound agronomic practices (timing, soil suitability, etc.)	1. Use of (mineral) fertiliser 2. Organic input 3. Improved germplasm (improved seeds) 4. Combined with knowledge of how to adapt these practices to local conditions	Examples from across SSA. East Africa, West Africa and Central Africa (Burundi, eastern Democratic Republic of the Congo, and Rwanda)
Organic agriculture or organic farming	A food production system 'that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects' (IFOAM 2008). It is applicable to crop and animal production, as well as wild harvest systems.	1. Organic agriculture combines tradition, innovation and science 2. Rejects or strictly limits artificial pesticides, fertilisers, plant growth regulators, antibiotics, genetically modified organisms (GMOs) and other artificial additives	More limited recorded examples (e.g. Benin, Ethiopia, Ghana, Kenya, Uganda, Nigeria). More relevant existing literature focuses on potential in SSA or actual in Latin America and the Caribbean, and in developed countries.

[19] There is an inherent bias as to what is analysed and recorded in the literature. Other examples exist but may not have had the same exposure to systematisation.

		3. Crop rotation 4. Mechanical weed control, including ploughing 5. Nitrogen fixation from leguminous crops, green manure crops 6. Use of compost or manure fertilisation 7. Biological pest control 8. Marketing practice (optional): Certification	
Stand-alone soil management techniques (cross-slope barriers, bunds, etc.)	Measures for reducing runoff velocity and soil erosion, and aggradation measures to re-build soil	1. Contour stone bunds 2. Improved planting pits (zaï, tassa)	Burkina Faso, Ethiopia, Ghana, Kenya, Niger.

4.5 From agriculture to sustainable agriculture through given practices

The important progresses made in agriculture since the mid-20th century were defined as the Green Revolution (Borlaug 1970). The basis of modern agriculture developed through intensification, understood as increased yield per hectare through the introduction of new varieties, inputs (fertilisers, pesticides and irrigation water), mechanisation, and rural infrastructure in general. Over the period 1961-2007, agricultural output tripled while agricultural land only expanded by 11% overall (in FAO, 2009; Pretty, Toulmin et al. 2011) and by 30% for cereals (Pingali 2012). Intensification appears to have 'spared' land currently dedicated to other uses (i.e. forest, wetlands, savannah, and ecosystems in general) and therefore to have contributed to reduced biodiversity loss overall.

However, the expansion of agricultural land was concentrated in tropical forested areas over the period 1980-2000, as agricultural land surface receded in the developed North (Gibbs, Ruesch et al. 2010). Modern agriculture, as now practised, has significant negative environmental impacts, both as a user of inputs and as a generator of pollution (Conway and Barbier 1990). That said, some analyses highlight that short-term productivist policies – favouring inappropriate implementation of the techniques developed by the Green Revolution – are to blame, rather than reducing the linkage to inherent unsustainability of intensification practices (McIntyre, Herren et al. 2009, Pingali 2012).

The proposed response to Africa's food security needs 'invokes successes associated with the Green Revolution strategy in South Asia' (Feldman and Biggs 2012). Even setting aside the environmental and social weaknesses of the approach, the current context and institutional settings for bringing about such a revolution in Africa are very different from what they were 40 or so years ago in Asia and in Latin America and the Caribbean. Not to mention the regional and local differences, the rollout of this strategy was based on public-sector leadership, research and investments, and capacity building for agencies and national research institutions (Pingali and Raney 2005). By contrast, the current context is defined by a market-led global production system with an expansion of the role of the transnational private sector, particularly with regards to life sciences research (Feldman and Biggs 2012). The main difference being that the research responds to commercial interests that 'build on, and alter, public-sector R&D capabilities and resources' (Feldman and Biggs 2012). The change in the leadership of agriculture research is likely to generate another bias[20] to the approach ultimately researched and developed in the field (Vanloqueren and Baret 2009).

The Green Revolution illustrates an input-intensive solution to productivity challenges, without specific requirements to coordinate agricultural activities with broader ecosystems. In contrast, alternative options which look to manage interaction between agriculture and broader ecosystems tend to be characterised by:

- system management-like options,
- potentially higher transaction costs, with associated needs for appropriate governance structure to manage them.

These differences do not exclude significant contributions of a purely technological nature, but these are not at the heart of the approach, unlike the Green Revolution.

Some, like Evans (2009) within the framework of a Chatham House report, define the alternatives to the Green Revolution as 'knowledge-intensive', in contrast to input-intensive conventional agricultural intensification. However, this is misleading, for two reasons. The first is that both approaches are knowledge-intensive, particularly with regard to resources invested in R&D since the onset of the Green Revolution – Tittonell (2013) put forward an educated 'guestimate' of a 90-95% research gap between conventional agricultural intensification and its alternatives. The two approaches differ in the focus given to knowledge construction. In addition, lower input, gene revolution-based alternatives tend to remain top-down (and narrow) plant science-based agricultural technologies, rather than a contribution to broader agricultural and rural management. If we were to really push the point, less input-intensive gene alternatives could be qualified as technological 'quick fixes' to a complex challenge: achieving food security in a globalised food market vulnerable to climate and other global changes.

Thus, we argue that a more operational distinction (and one more relevant to policy) lies in the fact that the Green Revolution approach (and its heirs in technological single-objective solutions) is fundamentally based upon technological/engineering solutions. Their uptake implies low uncertainty in terms of outcome, and low specific

[20] If today's leaders in agricultural technology research were to lock out low-input (i.e. knowledge-intensive) but efficient options that tend to benefit farmers and society in general, because such practices do not expand their opportunities and markets, then an reenergised role is needed for public research bodies to actually respond to the objectives of sustainable agriculture. This approach should also be strengthened by participatory research with direct involvement of farming communities, so that their combined efforts 'create business opportunities for small-scale farmers but not necessarily for agribusiness' (Aprodev (2012). Agricultural research for sustainable agriculture and global food security. Aprodev Policy Brief: EU Horizon 2020.

investments (in the sense of potentially being taken hostage in the transaction by other producers/ other holders of rights over the common resources on which the farm system depends)[21].

Through deeper integration of agriculture with its base, dependent and surrounding ecosystems, alternative practices entail transactions that go beyond direct transfers from one actor to another. Given their required level of interaction, alternative practices in agricultural intensification both depend on and generate transfers that may be 'indirect, have a spatial dimension, involve time lags, be complicated to reproduce or even be hidden. They may be intended or unintended, targeted or non-targeted, predictable or unpredictable' (Hagedorn 2008). Moreover, Hagedorn (2008) highlights that actors in such transactions may not know each other and may be difficult to identify. These alternatives could not differ more from 'quick fixes'.

Therefore, the alternatives tend to be associated with more localised/specific knowledge (e.g. botanical knowledge beyond conventional crops), highly specific investments (mechanical weeding or other transaction-specific) and complex interactions (e.g. integration of cultivated crops with managed and natural landscape ecosystems).

This interpretation is adapted from a reading of outcomes and recorded uptakes of agri-environmental schemes under the European Common Agricultural Policy by Ducros (2007, in Van Huylenbroeck, Buylsteke, et al., (2009). She highlighted how uncertainty, asymmetric information, and highly specific investments can hinder the uptake of more complex (although more rewarding) agro-environmental contracts. Farmers tended to prefer simple options, such as buffer strips and field margins.

To clarify the distinction, the costs of Green Revolution and technologically-based solutions (e.g. seed improvement through conventional hybrids or GMOs, more specific pest control substances, improved irrigation systems) almost exclusively comprise direct production costs, with marginal transaction costs for the user. In contrast, the development of management-focused practices gives rise to non-trivial transaction costs (Gómez, Delacámara et al. 2013, Marshall 2013). On the one hand, alternative practices may be less input-intensive, but on the other, the cost share of input costs may also be lower.

As the Green Revolution and its human-made capital-intensive options reach their environmental limits, practices that are intensive in agro-ecology management, human capital and natural capital conservation need to be considered .

The debate about the conventional 'Green Revolution' through agricultural inputs, and technological intensification (e.g. seed improving strategies through biotechnologies), moves on to conservation through changing from annual to perennial crop varieties. Previous studies of perennial grasslands from which aboveground biomass has been removed for long periods of time indicate their potential to serve as a model for highly sustainable agricultural systems (Glover, Culman et al. 2010).

4.6 Current scale, recorded and potential impact of approaches reviewed

Before engaging with the elements that shape adoption of given practices and approaches, it is important to recall the orders of magnitude of the extent of their adoption by farmers across the region. Some practices have been adopted by a sizeable share of farmers in other regions, such as North and South America (e.g. conservation agriculture: ~10% of cropland), but have very low adoption levels in most SSA countries, except for South Africa (~2% of cropland). Others remain as low but have experienced a significant progression (e.g. modern organic agriculture). Finally, others tend to be more location-specific, and given their properties have only just started to be adopted beyond their area of origin (e.g. zaï).

Table 2 presents a wealth of details on the scale of current adoption of the approaches selected in our review.

Table 2 Scale of adoption or partial adoption of approaches and associated practices

Approaches	**Scale of adoption (and potential adoption), especially in sub-Saharan Africa**
Agroforestry, including FMNR/ANR	In terms of land surface, almost half the world's agricultural land has at least 10% tree cover, suggesting widespread use of the approach (FAO 2013). This is probably the most widely adopted set of approaches, with an estimated 1.2 billion individuals relying on them (Meijer, Catacutan et al. 2015). Hundreds of thousands of farmers across the Sudano-Sahelian zone and into East and Southern Africa grow trees along with cereal crops, to boost productivity on

21 This understanding is akin to that of Transaction Cost Economics (Williamson, O. E. (1985). Yhe Economic Institutions of Capitalism: Firms, markets, relational Contracting, Free Press.

	more than 5 million hectares of cropland. The trees improve soils and provide firewood and livestock fodder, for example (Glover, Reganold et al. 2012). For some, agroforestry systems have prevailed despite relatively unsuccessful efforts to introduce monoculture of annual crops in Africa (King and Chandler, 1978; in Mbow, Van Noordwijk et al. 2014). However, it is also widely acknowledged that data on the extent and type of practices is limited by the conventional[22] forest/agriculture classification in national statistics and forest surveys, including remote sensing (Mbow, van Noordwijk et al. 2014, Zomer, Trabucco et al. 2014, Sloan and Sayer 2015). For SSA, the distinction between forest and forested agricultural landscapes is generally difficult to establish, but estimates point to a 2% increase in the area with >10% tree cover, with an associated 0.6% decrease in areas with >30% tree cover (Zomer, Trabucco et al. 2014). Parkland systems are ubiquitous in the Sahel and FMNR can be found in most countries, with its practice only differing in degree. In an analysis of a sample of 1,080 households from Burkina Faso, Mali, Niger and Senegal, about 30% had low tree densities (<25 trees/ha), 36% oscillated between 25 and 55 trees/ha, while the remaining plots were more dense (Binam, Place et al. 2015). FMNR in Niger had enhanced at least 4.8 million hectares by 2008, since its (re)introduction in the 1980s (Reij, Tappan et al. 2009, Tougiani, Guero et al. 2009), through increase in tree densities and cover in the Zinger region. Moreover, the highest tree densities were found near the more densely populated areas (Reij, Tappan et al. 2009).
Conservation Agriculture	9% of the world's cropland is under conservation agriculture (CA), mostly in North and South America (Pannell, Llewellyn et al. 2014). Worldwide, about 15 million ha are under CA (Friedrich, Derpsch et al. 2012, FAO 2015). However, these numbers are mostly expert estimates and may not reflect data. In SSA, Ghana would be the exception as CA is recorded in statistics. Other estimates indicate South Africa (2% of arable area), Zambia (0.8%), Kenya (0.3%), Mozambique (0.2%) and Madagascar (0.1%). It is also applied in Benin, Botswana, Burkina Faso, Cameroon, Ivory Coast, Ethiopia, Eritrea, Ghana, Lesotho, Malawi, Mali, Namibia, Niger, Nigeria, Sudan, Swaziland, Tanzania, Uganda and Zimbabwe (Liniger, Studer et al. 2011). Even if adoption is weak (<1% of land under CA (FAO 2015)), Dugué et al. (2015) highlight that innovation dynamics are at play in these tropical regions, either autonomously developed or fostered through support projects. Agricultural innovation systems closely related to CA are developing, even integrating field trees into the equation (Dugué, Djamen Nana et al. 2015).
Integrated Soil Fertility Management, including micro-dosing	There are no specific statistics on the extent of adoption of this approach. The ISFM framework provides farming strategies for a large range of soil fertility conditions and cropping systems. Certain ISFM interventions have seen large-scale adoption across SSA: i) micro-dosing of fertiliser in combination with manure management and water harvesting, for cereal-legume systems in dry savannahs such as the West African Sahel, and ii) targeted fertiliser application in combination with organic inputs, for maize-legume intercropping and rotational systems in moist savannahs, which cover about 615,000 km^2 across SSA. Recently, ISFM systems have been developed for intensification of cassava (Vanlauwe et al., 2012), rice (Oikeh et al., 2010) and banana cropping in tropical agroecosystems (Wairegi et al., 2014). In slash-and-burn systems such as the Congo Basin, ISFM has great potential to address soil nutrient depletion and forest encroachment. Moreover, although the ISFM framework focuses on African smallholder farming, its practices also offer solutions for other agricultural systems.
Organic agriculture	Only about 1% of the world's farmland is under certified organic agriculture (OA), mostly in Australia. About 75.1 million ha are under OA, up from 11 million ha in 1999. Adoption in Africa remains marginal (about 0.18% of agricultural land is under OA, when excluding certified wild collection areas). However, it is emphasised that the transition to more intensive modern

[22] The FAO Global Forest Survey defines forests as land use. 'This definition excludes lands predominantly dedicated to other land uses, such as agriculture, even where these have appreciable forest cover. Similarly, it includes lands dedicated to forest production or conservation even where these are temporarily destocked. This definition is therefore distinct from one of forest as a land *cover*, that is, the simple presence of tree cover above a certain density (Sloan, S. and J. A. Sayer (2015). "Forest Resources Assessment of 2015 shows positive global trends but forest loss and degradation persist in poor tropical countries." Forest Ecology and Management **352**: 134-145.

	organic agriculture from low-input traditional agriculture can be seen as an opportunity in terms of the adoption of given practices. Moreover, although less than 1% of agricultural land is under certification, a large number of farmers are now involved in this in the region (FiBL and IFOAM 2020). The simple ratio of land per farmer in SSA indicates that ecological agriculture is currently undertaken by large groups of smallholders. The latest estimates indicate that south of the Sahara, the leading countries accounting for both most land and most producers are Uganda (210,000 farmers), Ethiopia (204,000 farmers) and Tanzania (150,000 farmers) (FiBL and IFOAM 2020).
Stand-alone soil management techniques (contour bunding technology, zaï, etc.)	Zaï has allowed the rehabilitation of 200,000-300,000 hectares since the 1970s in the Central Plateau of Burkina Faso (Reij, Tappan et al. 2009). Farmers in Mali and Niger have also been supported to adopt this technique, along with other contour bunding technologies (Birhanu, Tabo et al. 2014).

The actual effects of adoption of an approach or practice are a fundamental key to adoption itself. Some have proven effectiveness at farm level through assessments looking at farmers' performance (e.g. conservation agriculture). However, for others, evidence of effectiveness is only available through field experiments. Table 2 expands on the specific effects recorded for each of the five approaches revisited here.

Table 3 Potential and recorded effects

Approaches	**Potential and recorded effects**
Agroforestry, including FMNR/ANR	FMNR is expected to increase income through improved crop yields, tree product sales and livestock production (more fodder). Carbon credits are also now offering potential new income streams. Woodfuel/firewood is made available, along with non-timber forest products (NTFPs) for self-consumption. The approach improves local environmental governance and strengthens resource (i.e. tree) and land ownership/user rights, and offers the opportunity to build community capacities to interact with other levels of governance (local, regional, national). Environmentally, FMNR is expected to reduce erosion, rebuild lost soils, increase water availability (improved infiltration, less soil-moisture evaporation), reduce winds and temperature, and offer carbon sequestration potential (Birch, Weston et al. 2016). Although there has been no systematic quantification of the economic impact of FMNR, simple estimates for Niger point to an annual production value of USD 280 million (40 extra trees per ha, each tree contributing USD 1.40/year, over 5 million ha) (Larwanou and Adam, 2008; in Garrity, Akinnifesi et al., 2010). Wide practice of FMNR in the Maradi region of Niger was confirmed (Haglund, Ndjeunga et al. 2011). More recent structured attempts to look at impacts of FMNR on livelihoods, yield and related food security (production, food shortages and crop diversity) point to increases in income. In Niger (Maradi), farmers intensively engaged in FMNR were recorded to earn about 10 times more than the average household in 1998 (XOF 150,000 vs XOF 17,450) (Evans, 1999 in Cunningham and Abasse 2005). Firewood sales could reach USD 46-92 per capita/year, a sizeable contribution for households of FMNR practitioners when average annual revenue was around USD 200 (Tougiani, Guero et al. 2009). In subsequent analyses, household income was recorded to increase by 18-24% (USD 46-56/year) for adopting households. However, cereal production per capita in each household only increased marginally (40 kg/per capita/year) and no significant effect on food crises was identified from the sample (Haglund, Ndjeunga et al. 2011). Similar results were found by Binam et al. (2015) for rural households increasing their practice of FMNR from low to young active and more continuously established. There was an increase in gross household income of on average USD 72 for Sahel countries (Burkina Faso, Mali, Niger and Senegal). Small improvements in yields, of 70 kg/ha/year (around 10-15%

	increase), could be identified at Sahelian level, although not always significant at country level. However, an increase in the diversity of household diet was captured at around 12% for the group of countries. Beyond the direct income factor, FMNR adoption is understood to have social and environmental benefits (see list in Birch et al.(2016). Tougiani et al. (2009) assert that farmers from the Aguie Desert in Niger weathered the 2005 famine, induced by drought and locusts, thanks to their investments in FMNR. In northern Ghana, although improved income and yields were also recorded three years after FMNR project implementation, the most valued benefits related to the increased value of stocks (i.e. trees and livestock) and their role in buffering households and the community against shocks; access to more wild products; and construction of social capital. From USD 150 per household/year in direct income and productivity benefits, assets and non-market values reached USD 1,000 per household/year (in 2013). Overall values including externalities and effects on neighbouring communities were also estimated (Weston, Hong et al. 2015). In Senegal, field trials have shown that millet yields in low input fields double after two years of FMNR implementation, from 296 kg to 767 kg (ISRA, 2010 in Birch, Weston et al. 2016).
Conservation Agriculture	In their worldwide review, Pittelkow et al. (2015) confirmed the trend found in previous reviews that no-till yield losses tend to diminish over time, although they do not outperform conventional till even after 10 years of adoption. However, yield responses differ, depending on i) the agroecological context (including soil type) and ii) the seasonal context (Giller, Andersson et al. 2015). In general, significant short-term yield losses were recorded for SSA in annual crops: maize, rice, cowpea and sorghum (Brouder and Gomez-Macpherson 2014). That said, CA is recorded to have increased yields in dry climates (Rusinamhodzi, Corbeels et al. 2011) when combined with appropriate agronomic management.
Integrated Soil Fertility Management, including micro-dosing	A better *ex ante* understanding of the potential impacts of new technology packages, or new policies, on the performance of smallholder farms of different configurations will allow better targeting of resources and a better understanding of the likely impacts of development initiatives (van Wijk, Tittonell et al. 2009). Looking at the existing literature, most systematically recorded effects of micro-dosing originate from station or field experiments.
Organic agriculture	In semi-arid environments (Tigray province, Ethiopia), cereal yields were improved by the adoption of compost (5-15 t/ha) over synthetic fertilisers (mean 40 kg/ha). On average, fertilisers yielded 4.5 t/ha of wheat, compared to 5.5 t/ha for compost. Similar results were registered for teff and barley (3.5 to 4.9 t/ha and 5 to 6.5 t/ha, respectively) (Kassie, Zikhali et al. 2008). OA is not a perfect synonym for sustainable agriculture, but it has proven to be better performing on most sustainability metrics than conventional agriculture (Ponisio, M'Gonigle et al. 2015). Highlighted benefits are associated with richness and abundance of species, soil fertility, nitrogen uptake, water infiltration and holding capacity, as well as energy efficiency. However, for temperate areas, this balance is not straightforward (Tuomisto, Hodge et al. 2012). Critiques of the approach define OA as a low-external-input / low-output system associated with low agricultural productivity, which cannot respond to the growing food needs of the SSA population (Connor 2008, Connor 2013, Kirchmann, Kätterer et al. 2016). Its limits in terms of environmental sustainability are mainly linked to land use efficiency and its reliance on external inputs (Connor 2008), mainly sourced from conventional farming (Nowak, Nesme et al. 2013, Kirchmann, Kätterer et al. 2016). The reliance on external organic output thus increases its land-use footprint (effectively reducing its per ha yield) and means that it may rely on conventional agriculture (although this is debatable if OA is seen as one response among many, including conventional input intensification). The adoption of more intensive organic agriculture is associated with higher yields than low-input traditional agriculture, but lower than high-input conventional practices (Badgley, Moghtader et al. 2007). Yield gaps between the different potential approaches (OA and high-

	input conventional) have been subject to intense debate, particularly when discarding OA as part of the response to sustainable food security as an 'unjustified luxury' (Halberg, Peramaiyan et al. 2009). More importantly, with regard to specific practices, Ponisio et al. (2015) identified a key role for agronomy in defining the traditional gap between the approaches. The review demonstrates that, in single plot comparison exercises, two management practices that diversify crop fields in space or over time – multi-cropping and crop rotation – improve yields in OA systems (Ponisio, M'Gonigle et al. 2015). Moreover, this approach of not limiting to a single crop but introducing hints of crop systems allows for a more comprehensive understanding from the point of view of the farmer, whose financial security and livelihood depends on profits from various crops grown over several seasons (Crowder and Reganold 2015). However, when looking at the database of 1,000 comparisons reviewed, only 6% informed on crops in subtropical or tropical areas, limiting the generalisation of these otherwise illustrative meta-analyses to SSA. Looking beyond the yield gap, the energy efficiency of OA compared to conventional agriculture has some advantages in the developed world (Smith, Williams et al. 2015). Although soils may play a more important role in energy efficiency, farming systems do make a difference, with most grazing systems (intercropping and local forage) having better energy efficiency, and crop systems compensating yield loss with absence of mineral fertilisers. However, for poultry, pigs and potatoes, the energy requirements per product are higher in OA than in conventional agriculture. Mechanisation of activities is comparable in terms of efficiency, and the higher labour intensity of OA makes more use of 'human energy' (Smith, Williams et al. 2015). However, advocates of this strategy claim that the system is actually a low-external-input / high-output system. In SSA, higher yields are recorded compared to current performance (Badgley, Moghtader et al. 2007) and OA is one of the few options for intensification in resource-poor environments (Walaga and Hauser 2005). Higher prices for organic commodities than conventional ones are part of the answer, but a strategy that only focuses on certified, mainly external, markets may make households too vulnerable to fluctuating market conditions. (Walaga and Hauser 2005, Halberg, Peramaiyan et al. 2009). OA has to be understood as multifunctional and not only focused on conventional yield maximisation. OA can increase productivity, and also incomes, with limited environmental impact, as well as 'build up natural resources [i.e. soil], strengthen communities and improve human capacity, thus improving food security by addressing many different causal factors simultaneously' (UNEP-UNCTAD 2008). OA has shown that it can 'increase access to food in a variety of ways' (UNEP-UNCTAD 2008).
Stand-alone soil management techniques (cross-slope barriers, bunds, zaï or tassa, etc.)	Soil management techniques are expected to preserve, and in some cases improve, soil productivity and soil quality in general (e.g. health, chemical composition, biological processes, stability). The detailed review of zaï by Nyantakyi-Frimpong (2020) also recorded benefits that included improved soil fertility and restoration (Burkina Faso, Niger and Kenya), enhanced seed germination (Burkina Faso and Kenya) and improved vegetation cover and plant diversity (Burkina Faso, Ghana and Kenya). However, controlled experiments on zaï (Roose, Kaboré et al. 1999) have suggested that only soil productivity restoration is achieved, rather than overall soil restoration. Zaï addresses runoff management, seed and manure conservation, fertility and water concentration (in areas with at least 300 mm/year of precipitation) in the seed holes. Recent evidence confirms the early records of productivity improvements, with welfare implications for households (Reij, Tappan et al. 2009). From the experiences recorded in Ghana (Ehiakpor, Danso-Abbeam et al. 2019), zaï adopters have a higher household consumption expenditure (+22-35%), per capita consumption expenditure (+23-34%) and total household income (+8-9%) than their non-adopting counterparts. For Burkina Faso, yield productivity was improved by 61% for sorghum in the Ouahigouya area (from 528 to 850 kg/ha), following early local estimates showing that households using zaï moved from annual cereal deficits of 644 kg (or 6.5 months of food shortage) to a surplus of 153 kg/year (Reij 1996). Although contributing to improved food security, zaï did not improve cash farm income for the farmers studied, as most of the production was self-consumed and not traded.

4.7 Factors for uptake of agricultural practices

There is very rich literature covering the factors and reasons behind farmers' and communities' choices regarding practices. The question of uptake has been approached from a variety of angles, particularly that of innovation systems (Triomphe, Floquet et al. 2016)(Triomphe, Floquet et al. 2016).

Starting with research and technology development, the IAASTD (McIntyre, Herren et al. 2009) unambiguously highlighted that participatory and community-driven approaches can increase both the relevance of agricultural knowledge, science and technology (AKST) and the likelihood of new technologies and practices being adopted by small-scale producers. In turn, the review also insisted that both research and extension efforts can improve rates of adoption by addressing its current limitations regarding language and gender – only 17% of extension agents were female (McIntyre, Herren et al. 2009) whereas women represent about 65% of agricultural workers (ILO 2016) .

The key to success is to avoid blanket approaches in fostering a given approach, as demonstrated by the historical record of conservation agriculture in Zimbabwe documented in Box 2.

Box 2. Conservation agriculture in Zimbabwe: limits of blanket policies

The first thing to highlight is that CA was originally identified as a response to energy availability constraints faced by large-scale farming when the white minority regime faced international sanctions and embargo over the period 1965-1969. The root of the response lay with neither soil conservation nor smallholder producers.

The current development in the promotion of CA in Zimbabwe, according to Andersson et al. (2012), is that there is now a move away from trial stations/farms which used to be the core of the strategy, to the recent and current political and faith-based development (Giller, Andersson et al. 2015). Inspired by successes recorded in Zambia, CA has overtaken policy.

The adoption of planting basins has been introduced as a prerequisite for resource-poor smallholders to access inputs from supporting agencies. Although a variety of CA packages are currently promoted, in reality the diversity of farms and situations makes successful uptake of the practice limited. Only a limited share of smallholders possesses the conditions appropriate to this package.

Although the focus on smallholdings tended to narrow the strategy of rural development in SSA, this remains the most effective way to benefit most rural poor in the region, as no change in the dominance of the smallholding structure is expected within this generation (Larson, Otsuka et al. 2014, Holden 2020, Riesgo, Louhichi et al. 2020).

This debate over small vs large holdings highlights the need to avoid an approach that could be too narrow (Collier and Dercon 2014, Larson, Otsuka et al. 2014) and highlights the opportunities offered by medium- to large-scale farms in contributing to poverty reduction and food security in the region.

Moreover, the comprehensive overview by Garzón Delvaux, Riesgo and Gomez y Paloma (2020) shows that, whereas small farms tend to be more performant than larger ones when using gross output indicators (i.e. yields or total value of production), the more global productivity indicators (i.e. profitability or efficiency) point in the other direction, and larger farms tend to be more performant than smaller farms in the respective contexts.

This dimension matters for two reasons. The first is that the 'solutions' or improved/alternative agricultural practices to be fostered could be more easily associated with a certain type of structure and capacity.

The second is that there are questions about the long-term environmental sustainability (and increasingly so) of smallholdings. However, this specific dimension lacks evidence and requires further research.

Another defining aspect is that of the low level of adoption of standards by agriculture in the region. There is an important debate, however, as to whether conventional certification and associated standardisation of agricultural products marginalises the poorest farmers (Maertens and Swinnen 2009), although the experience of certified Organic Agriculture is an illustrative example to foster adoption (Box 3).

Box 3. Practice and beyond: adoption of certified organic commodity production for export

Recorded organic certification experiences indicate enhanced market access and competitiveness with positive, although modest, implications for income and poverty alleviation. Schemes for pineapples in Ghana (Kleemann and Abdulai 2013, Kleemann, Abdulai et al. 2014), tea in Kenya (increase of 40%) (UNEP-UNCTAD 2008) or cotton in Benin (Kloos and Renaud 2014, Sodjinou, Glin et al. 2015) point in such a direction.

Such instruments are also expected to improve management practices, from organic by default (or rather low to no-input by default) to modern OA, and to improve yield performance.

The opportunities for certified organic production also have gender-sensitive dimensions. A case in point is that of organic cotton production in Benin, which is beyond the small-scale pilot stage and is mainstreamed into agricultural policy (Sodjinou, Glin et al. 2015). The production chain is conventionally organised around the acquisition of synthetic inputs. Not having to depend upon this system, women have entered cotton production as farmers and labourers, with the (reproductive) health advantage of not being exposed to pesticides and gaining financial independence. Even access to land is eased, as more marginal areas can be used or in safe combination with food crops (Kloos and Renaud 2014, Sodjinou, Glin et al. 2015).

However, positive effects on income and livelihoods do not seem to be the results of organic certification alone. For example, certified organic and Fairtrade coffee producers in Nicaragua may have been faring relatively well during a coffee price crisis but remained among the poorest during more favourable cycles, whereas conventional farmers followed the general development of the country (Beuchelt and Zeller 2011). No statistically significant differences in poverty level were found between organic/Fairtrade certified and conventional coffee farmers in poorly structured cooperatives in Ethiopia (Jena, Chichaibelu et al. 2012).

Nominal higher prices for certified organic produce do not systematically equate with better conditions. The livelihood and poverty alleviation potential of organic certification depends on determining factors. The details of the organic certification scheme, especially the internal incentive structure towards quality or technical improvements, was identified as key for cocoa in Uganda (Jones and Gibbon 2011). In turn, the existence and form of collective structures and cooperatives was also identified as improving access (lower individual costs, mediated knowledge, bargaining position, etc.). Poorly functioning structures could mean impoverishment for farmers (coffee in Ethiopia – (Jena, Chichaibelu et al. 2012), but functioning ones would make the scheme pro-poor (pineapples in Ghana (Kleemann, Abdulai et al. 2014)). The level of added value of the produce, and the interaction with Fairtrade certification providing price guarantees and support to organisations, was more profitable than alternatives for coffee producers in Uganda (Chiputwa, Spielman et al. 2015, Garzón Delvaux and Gomez y Paloma 2018). Whether sales are on the spot or through contract farming has also been identified as influencing the success of the schemes for cocoa and coffee in Uganda (Bolwig, Gibbon et al. 2009, Jones and Gibbon 2011), but may also be limiting depending on the context, as is the case for producers in Uganda (Chiputwa, Spielman et al. 2015).

Following what emerges from the review, the key factors for adoption were identified and classified as enabling environments, conditions and barriers in Table 4.

Table 4 Key factors for adoption: enabling environments, conditions and barriers

Approaches	**Enabling environment**	**Conditions**	**Barriers to adaptation/adoption**
Agroforestry, including FMNR	FMNR is fostered in an environment where a surviving underground rootstock is available (Danthu, Hane et al. 2002), making tree growth very fast. This tree growth based on existing rootstocks refuted the belief about slow growth of native species, which plagued most past reforestation initiatives in the region (Tougiani, Guero et al. 2009). This aspect is key, as for FMNR to be adopted (or rather to be practised in a more intense way), tangible and quick benefits are needed (firewood/woodfuel, fodder, mulch, windbreaks and habitats for predators of pests) (Tougiani, Guero et al. 2009). Benefits of FMNR are understood to be obtainable at minimal cost, contributing to its expansion. The labour needed to practice FMNR places its annual cost-benefit ratio between 2.5 and 3, beyond the rule of thumb of 2 identified by the International Maize and Wheat Improvement Center (CIMMYT) for a farmer to adopt an innovative practice (CIMMYT, 1988 in Haglund, Ndjeunga et al. 2011). In Niger, level of education was identified as a statistically significant factor for the probability of adoption, as the probability increases by 3% per additional year of schooling. Living up to 15 km from a market tends to increase adoption, whereas beyond this point, it decreases with distance (Haglund, Ndjeunga et al. 2011).	FMNR is especially suitable for, but not limited to, dryland tropics. In addition to returning degraded land to productivity, it can be used to maintain fragile but yet not degraded areas (Maisharou, Chirwa et al. 2015). A distinctive feature of FMNR is that, in principle, it does not require planting or seeds, as what is promoted is support for surviving rootstocks of previous vegetation in an agricultural landscape, i.e. improved clearing (Joet et. al, 1998; in Haglund, Ndjeunga et al. 2011)). Other related concepts (e.g. ANR) may be more associated with less selective regeneration of forests. However, specific analyses in Niger have identified farmers with non-arenosol soils as more likely to practice FMNR than those in more sandy areas (Haglund, Ndjeunga et al. 2011). The type of species selected is expected to play a determinant role, as some species are more likely to act as fertiliser trees than others (e.g. Faidherbia albida). FNMR / parklands in drier areas of the Sahel tend to be more diverse than in less dry areas, possibly revealing an interest for farmers in diversifying to manage risk (as they do for crops in the face of uncertainty) (Faye, Weber et al. 2011).	Resource endowments (i.e. land scarcity) have acted as incentives for adopting improved fallows in Zambia, but the more intensive systems in Kenya tend to avoid planting fertiliser trees (Franzel 1999). With regard to land tenure, meta-analysis conducted for West Africa by Fenske (2011) offers a more nuanced relationship between tenure security and investment. Length and frequency of fallows are negatively affected by weak tenure. However, tree planting may enhance rights to future uses of the land, depending on the nature of the insecurity in tenure (e.g. titling, gender-biased inheritance systems) (Fenske 2011), something echoed by Lovo (2013) for Malawi, as well as previous work in Ethiopia (Deininger and Jin 2006). FNMR development is hindered by restrictive forest laws (*code forestier*) regarding tree felling (in this case, 'improved clearing'). Although Niger and other Sahel countries (Mali, Senegal, Ethiopia) have gradually lifted this barrier, regulation coherence remains an issue (Garrity, Akinnifesi et al. 2010, Birch, Weston et al. 2016). Contradictions between rural and forestry codes are still a source of disincentive to FMNR in Niger with regard to tenure and use of on-farm trees (Mikulčak 2011). Too strict but weakly enforced tree cutting regulation is also a disincentive to plant or manage existing trees, because of the risk of illegal cutting by free-riders, both as a loss of the asset and the risk of fine by officials (Tougiani, Guero et al. 2009). Extension services

	Ownership of trees on cropland was identified as key by early observers (Tougiani, Guero et al. 2009). A good grasp of the variance between statutory law and customary principles emerges as a cornerstone for enabling development of FMNR. In practical terms, this means that locally empowered farmers engage in flexible organisational approaches to agroforestry, gathering all user groups, including conflicting or marginalised groups such as herders and women (Tougiani, Guero et al. 2009, Mikulčak 2011). An example is the management committees in 170 villages around the Aguie Desert Community Initiative, which are now promoted around Niger by extension services (Tougiani, Guero et al. 2009). Their financing is relatively autonomous, through revenue and fines, and they cover both agricultural and forestry issues. FMNR that accounts for farmers' preferences about tree functions (human food, fuel, animal feed, fertility and general soil improvement, product revenue) is more likely to succeed. In the West African Sahel, direct human needs are favoured over fertility improvement. Revenue generation was not identified as a priority in the villages visited (Faye, Weber et al. 2011).		consider that a good crop field is one which is kept free from regrowth shoots and trees, to facilitate ploughing (Cunningham and Abasse 2005, Tougiani, Guero et al. 2009). Remaining conflicts between herders (nomad and sedentary) and farmers are a limiting factor to significant engagement in FMNR (Tougiani, Guero et al. 2009, Faye 2013). A marginalised view of younger farmers may also be preventing more proactive adoption of FMNR (Mikulčak 2011). A likely drop in availability of firewood/woodfuel over two to three years is a matter of concern (Birch, Weston et al. 2016).
Conservation Agriculture	CA has to be seen as a knowledge-intensive technology, but its promotion has coincided with the significant withdrawal of public extension services, which were not replaced by private providers deterred by high transaction costs, marginal/dispersed clientele and improbable profits. This also implied fewer	Suitable for all climates, particularly semi-arid zones: 'it is most effective where low or uneven rainfall limits crop production'. 'CA is also suitable for sub-humid and humid climates: such as the moist savannah of West Africa and part of the East African highlands. The technology has specific challenges in arid climates, however, it still performs better than tillage-based alternatives, given adequate mulch' (Liniger, Studer et al. 2011).	Key aspects highlighted in the literature on why uptake is disappointing despite its theoretical prospects include: (1) opportunity costs of crop residues for animal feed rather than for mulch, (2) short-term reduction in yields under the zero tillage-mulching combination when facing high discount rates for farmers, (3) farmers averse to uncertainty, (4) constraints in the availability

	opportunities for CA uptake. (Erenstein, Sayre et al. 2012).	In Southern Africa, CA has also provided higher yields in drier and well drained areas, in the context of general agronomic improvements (e.g. nitrogen inputs) (Rusinamhodzi, Corbeels et al. 2011). The variety of cases reviewed (tropics or temperate regions, in both developing and developed economies) demonstrates the wide adaptability of CA systems (Erenstein, Sayre et al. 2012, Pittelkow, Liang et al. 2015). Although mulching in semi-arid zones improves rainwater use efficiency (i.e. higher infiltration and lower evaporation losses), no-till by itself may lead to higher run-off and lower yields, therefore leading to lower yields (Giller, Witter et al. 2009). Early planting and weeding are recognised as key to management. CA systems have been used by large-scale commercial farms in South Africa and Zimbabwe, less so by smallholders (Erenstein, Sayre et al. 2012). (This supports the hypothesis of CA as cost-reducing rather than yield enhancing.) CA has widespread adaptability but this requires specific efforts in its adaptation to account for the characteristics and socioeconomic conditions of each place (Erenstein, Sayre et al. 2012). However, the analysis of Giller et al. (2009, Giller, Andersson et al. 2015) points to the probable inappropriateness of CA for generally poorer smallholders (capital, access to services, etc.). In their latest review, Giller and other scholars have called for strategic adoption of CA (Giller, Andersson et al. 2015).	of resources at key moments of the year, such as capital, labour or even land. CA as a package is challenged around the need for crop residues for mulching in areas where it competes with alternative uses, mainly as animal fodder (Valbuena, Erenstein et al. 2012, Baudron, Jaleta et al. 2014, Pannell, Llewellyn et al. 2014). This competition is stronger in areas where total biomass available is low overall. Issues include: 1) residues considered as common resources by community with common grazing rights (Wall, 2007, in Pannel et al., (2014); 2) in cases were residues are private, farmers may use it for animal feed, as fuel for weed and pest control (Giller, Witter et al. 2009), or harvested for sale (Valbuena, Erenstein et al. 2012). All this is exacerbated if fodder has a high value in the area. The benefits of CA may require 5 to 10 years to materialise (Erenstein, Sayre et al. 2012), directly challenging the needs of smallholders with higher discount rates. CA as a package is complex (Baudron, 2007, in Giller et al., (2009) and it can be considered a knowledge-intensive practice: it requires various practices to be changed simultaneously. As such, it requires reliable extension services. Lack of equipment/tools/machinery adapted to CA has also been identified as a barrier to uptake (Erenstein, Sayre et al. 2012). Access to adapted (small-scale) and CA-compatible machinery and tools, in addition to the important herbicides, is key to any viable adoption (Dugué, Djamen Nana et al. 2015). That said, this implies additional efforts to

			understand, and control for the effects of, widespread use of herbicides in the region by small-scale farmers (Dugué, Djamen Nana et al. 2015).
Integrated Soil Fertility Management, including micro-dosing	There is a great need for high-resolution information on soil fertility, to tailor practices and maximise the benefits of the approach.	The approach was developed for the dry savannah of West Africa (micro-dosing with manure) and is now being adapted to more humid environments for cassava, banana and rice (Vanlauwe, Pypers et al. 2012, Wairegi, van Asten et al. 2014). Homesteads and close-to-home fields are more like to be engaged in ISFM (Nkamleu 2007).	The adoption of part or all the practices of ISFM is confronted with limited access to farming inputs, with high transaction costs (Alene, Manyong et al. 2008) . Lack of awareness of the approach is also a barrier (Lambrecht, Vanlauwe et al. 2016). In addition, there is traditional lack of access to financial services and aversion to risks associated with production and markets. Other input market imperfections, linked to labour and land, have been identified. Finally, limited availability of organic residues and competition from livestock have also been highlighted. Adoption of part or all the practices of ISFM faces a series of non-exclusive challenges.
Organic agriculture	Poverty is a constraining factor in the adoption of given practices in the semi-arid region of Tigray (Ethiopia). The general policy context, and efforts to alleviate poverty in particular, can act as a catalyst for adoption. Public policy, through approach to information for farmers, was also identified as relevant. Labour policies also directly impact the adoption of a given practice, given their variable labour intensity. In addition, the specific issue of gender and age of decision-maker (i.e. affecting levels of aversion to risk) remains key in policy intervention (Kassie, Zikhali et al. 2008). Membership of farmers' organisations increases the likelihood of adopting certain practices (e.g. conservation tillage, and its combination with compost) (Kassie, Zikhali et al. 2008).	OA is a set of principles and can be adapted to any conditions in principle.	Adoption of compost is viewed as knowledge-intensive (related to education) in semi-arid Ethiopia (Kassie, Zikhali et al. 2008). Poorly functioning or weak farmers' organisations affect particularly the development and livelihood-enhancing potential of OA under certification. In Mali, the main organic cotton producers' group had to be replaced in 2016, when farmers were abandoning the scheme following mismanagement and delays in payments, but it is currently recovering (Textile Exchange 2016). Coffee producers belonging to poorly functioning organisations were worse off under organic certification than alternatives in Ethiopia (Jena, Chichaibelu et al. 2012). Access to inputs is likely to remain a challenge in input-poor contexts.

	Adoption is spatially clustered: farmers are more likely to adopt OA if their neighbours embrace this type of change (or at least approve of it). This was established for Honduras (Wollni and Andersson 2014) and temperate areas in Europe and the US (Parker and Munroe 2007, Schmidtner, Lippert et al. 2012). An additional aspect to highlight is that spatial proximity entails lower fixed individual learning costs for farmers (Lewis, Barham et al. 2011), and that farmers who more readily engage in OA tend to concentrate in areas where conventional intensification and mechanisation is less profitable: where there are lower opportunity costs associated with forgoing conventional intensification in favour of OA. (Schmidtner, Lippert et al. 2012). An example is organic cotton developed on marginal land in Benin (Kloos and Renaud 2014). Agro-ecological conditions less favourable to conventional intensification (hilly and steep slopes) may be an encouragement to adopt OA instead. OA certification involves costs but also clear advantages, as it creates a clear set of adoption incentives for farmers. (Kleemann and Abdulai 2013). When benefiting from functioning farmers' organisations (farmers' group, cooperatives, etc.), certified OA is more pro-poor, as some educational and generational barriers are not individually borne and are overcome (Kleemann, Abdulai et al. 2014). Disaffection from conventional systems in crisis is identified as a key factor for embracing OA among heavily indebted cotton producers in Benin (Sodjinou, Glin et al. 2015).		

Stand-alone soil management techniques (cross-slope barriers, bunds, zaï, etc.)	Adoption and the intensity of adoption (quantities or level of adoption) in the Upper East region of Ghana is favoured by male-headed farms, availability of larger land surface, and access to non-farm income and financial services (Danso-Abbeam, Dagunga et al. 2019). Likewise, access to extension and membership of farmers' organisations significantly favours adoption (but not intensity of adoption) (Danso-Abbeam, Dagunga et al. 2019). Availability of affordable labour has been identified as an important enabler of the adoption of this labour-intensive technique, particularly in its set up, as a fixed cost (Schuler, Voss et al. 2016). The impact of termites on soil improvements in the development of zaï depends on the particular species and ecological requirements, as pointed by Kaiser et al. (2017) for northern Burkina Faso. Access to mechanisation through animal-drawn tools could increase uptake of zaï (Schuler, Voss et al. 2016). Access to non-farm income allows the purchase of productive farm inputs.	Water-holding capacity is limited and the structures respond negatively to excessive rains, in areas with precipitation of more than 700-800 mm (Roose, Kaboré et al. 1999, Kiepe, de Ridder et al. 2001). Zaï is especially suited to degraded land in dry tropics, such as crusted soils, although it can also be used to allow the cultivation of previously marginal land (Schuler, Voss et al. 2016). However it is not suited to sandy soils or inland valleys (*bas fonds*), as they are vulnerable to waterlogging.	Rising opportunity costs of labour, because of migration, have been identified as a barrier to wider adoption of zaï by farmers in Burkina Faso. Most farmers adopt it but only for a fraction of their land, given such increasing labour costs (Schuler, Voss et al. 2016). The threat of expropriation has been identified as a dis-incentive to the adoption of climate change adaptation measures such as zaï in northern Ghana. Such tenure uncertainty is considered a social barrier to farmer innovation (Nyantakyi-Frimpong 2020), highlighting the link between institutions and the adoption of agricultural practices. Lack of availability and access to both organic manure and fertilisers has been identified as a barrier to wider uptake of zaï (Schuler, Voss et al. 2016).

5 Lessons emerging from practice-specific adoption experiences

The review shed light on the selected approaches and practices, and shared lessons learned in fostering their adoption and diffusion. This section presents key recommendations extracted from the literature that could inform specific interventions.

Agroforestry, including Farmer-Managed Natural Regeneration (FMNR)

- Policies that institutionally segregate forest from agriculture miss opportunities for synergy at landscape scale (Mbow, Van Noordwijk et al. 2014).
- More active and productive agroforestry practices (e.g. FMNR) would benefit from systematic harmonisation of regulations under existing forestry and rural codes (Tougiani, Guero et al. 2009, Binam, Place et al. 2015).
- In the Sahel, FMNR is ubiquitous and its promotion is about improving the degree to which it is practised (Binam, Place et al. 2015).
- The promotion of FMNR should be directly associated with other climate change adaptation strategies, as it is also a recognised mechanism for diversifying the portfolio of livelihoods (beyond income) (Haglund, Ndjeunga et al. 2011).
- Tree domestication programmes should work on priority species that respond to the functional needs of specific regions, rather than focus on a few species across all potential beneficiary regions – primarily directed at raising income at the expense of diversifying its source – as favoured by farmers in the drier areas (Faye, Weber et al. 2011).
- FMNR has been introduced on the grounds of improving arable soils, but crop yield gain may be secondary to livelihood gains from natural assets, consumables becoming once more available from landscapes, and greater resilience to climate change (Weston, Hong et al. 2015).

Conservation agriculture

- The complex interaction between soils, climatic conditions and tillage demands pragmatism in implementing CA.
- CA may not provide much contrast to current practice consisting of limited tilling with hand hoes.
- Tillage and ploughing should be seen as alternatives rather than competition.
- More attention should be paid to the pathways of experience, fine interaction at soil-chemical and weather level (between average precipitation and dry/wet spells), geo-referencing, and the socio-economics of farms involved in studies and monitoring of CA in SSA.
- The latest reviews point to reducing the emphasis on no/reduced tillage as a first uptake when favouring CA adoption, when mulching and crop rotation are not present. The introduction of CA should therefore focus on implementing no-till systems where the two other principles are present (Pittelkow, Liang et al. 2015). However, the quantity of mulching needed in each case remains unclear (Paul, Vanlauwe et al. 2013).
- Farmers should be exposed to multiple options to test and choose from. Testing is key to allowing for nuanced and context-specific recommendations.

Integrated Soil Fertility Management, including micro-dosing

- At plot level, organic inputs can only address part of the nutrient needs. Other plot-level interactions are recommended to enhance the agronomic efficiency of the practice (e.g. tillage, moisture, other nutrients besides nitrogen). At farm level, improved understanding is needed of the interactions between soil fertility, crop and land management practices, and yields (Vanlauwe, Descheemaeker et al. 2015).

Organic agriculture

- The most active local research on organic agriculture is taking place in Nigeria, Uganda, Kenya, Ghana and Mauritius, but this remains marginal, also reflecting what is happening in developed economies where research in the field remains underfunded (Vanloqueren and Baret 2009, Niggli 2014). In Africa, the current focus of research is on crops and far less on livestock (Ssekyewa, George et al. 2012). This bias against training in organic animal production and aquaculture also pervades the skillsets of instructors, as shown for Nigeria by Aiyelaagbe et al. (2016) or highlighted in Uganda by Nalubwama et al. (2011).

- Transition from low input, traditional or degraded practices (e.g. no fallow) to modern OA tends to result in higher yields (in contrast to developed contexts, where lower yields are the resulting effect).
- From agronomic perspectives, certification standards tend to be biased towards the realities of development from Green Revolution to OA, unnecessarily raising the transition costs (Walaga and Hauser 2005).
- Training, extension, and demonstration are more critical in OA than in conventional agriculture, because it is a managerial method (Schoonbeek, Azadi et al. 2013).

Stand-alone soil management techniques (e.g. zaï)

- Availability of affordable labour has been identified as an important enabler of the adoption of this labour-intensive technique, particularly in its set up, as a fixed cost (Schuler, Voss et al. 2016). Access to mechanisation through animal-drawn tools could increase uptake of zaï (Schuler, Voss et al. 2016).
- Access to non-farm income allows the purchase of productive farm inputs (Danso-Abbeam, Dagunga et al. 2019).
- Tenure uncertainty remains a social barrier to farmer innovation (Nyantakyi-Frimpong 2020), highlighting the link between institutions and the adoption of agricultural practices.

6 Conclusions and possible avenues

The debate on the sustainability of agriculture needs to be translated into practices. However, the level of analysis of the land sharing or land sparing debate is that of the landscape, so the translation is neither direct nor complete at farm level; even less so at plot level. Although agricultural practices form the backbone of sustainable agriculture, they fall short of responding to such a challenge by themselves. Practices integrated into productive systems provide a first level of coherence. However, to be sustainable, agriculture also requires other elements such as local environmental management and other landscape-level management tools.

— To be sustainable, food and nutrition security (FNS) interventions would benefit from adopting a landscape framework, so that the various objectives of sustainability can be coherently negotiated alongside pure FNS objectives. Operationally, this could mean including opportunities to strengthen land use planning in rural projects, and ensuring that a given agricultural project also contributes to, and is coherent with, a landscape perspective.

Looking at the landscape-level strategies, it is important to question simple assumptions such as whether land sparing is the only way forward to be sustainable. Regions vary widely in their capacity to conserve given areas in the 'conservationist' sense, excluding users. Implementing this approach is also very costly (i.e. opportunity costs), with few local benefits (and documented negative local effects).

— Land sharing could be particularly relevant to consider for areas with potentially expandable agricultural frontiers (e.g. Sahel countries, Democratic Republic of Congo), but also those where forest 'encroachment' is the only remaining frontier, given a rising population density (e.g. Burundi, Kenya, Rwanda, and to a lesser extent Uganda, Nigeria and the highlands of Ethiopia). At project level, this could involve identifying i) the actual interactions of farmers, and more broadly communities, within the farm-forest/pasture continuum in each intervention area, and ii) whether the area is actually suitable for intensification, as many shallow soils and other characteristics (e.g. low and/or unpredictable precipitation) make them unsuitable for intensive use.

Certain inherent characteristics of African soils require special attention when assessing potential sustainable agricultural practices. Not all African soils react to inorganic nitrogen application. In fact, many soils are going from being (i) responsive to fertiliser use, to (ii) non-responsive but still productive, and increasingly becoming (iii) non-responsive and degraded.

— Management approaches that could improve soils emerge as a prerequisite for conventional intensification. Operationally, this would require i) more systematic pre-assessments of soil responsiveness to fertilisation, and ii) promoting soil-building (aggradation) strategies before engaging in narrowly defined external input intensification.

In addition, the availability of assets to farmers remains key in venturing into new practices. Tenure security has been identified as key to engagement in investing, particularly in soil-enhancing practices (2011). At a larger scale (larger holdings and landscapes, rather than plot level), where important interactions occur with other users (e.g. water users, pastoralists), rigid or non-adaptable property rights (even if tradable) may exacerbate conflict and hence lower investment.

— The issue of land tenure policy remains a dynamic field with two main avenues: i) Clarification of ownership or user rights is important. However, this does not simply equate to privatisation of land, but to establishing clear rules for its use. Investment incentives vary according to the practice (agroforestry vs soil conservation), but also according to the context (gender, previously existing user rights) and ultimate objective of farmers. ii) More generally, this is a very delicate subject, as it can accelerate the transfer of land out of customary systems and effectively foreclose on smallholders' development options, without clear-cut evidence as to the advantages to FNS, poverty reduction or rural development of such a (mostly irreversible) process. Land tenure security is important but it should not be limited to individual tradable property rights, instead including collective rights and efforts to make the various existing systems (de jure, customary, private, public or collective) more compatible instead of exclusive.

Farmers and rural households are changing; they are not static policy targets. Rapidly changing communities may be more aware of alternative agricultural practices, systems and crops, but at the same time they may be reducing their involvement, implication and investment in agriculture, hence not investing in yield improvements or adoption of soil conservation practices.

— This calls for recognising the evolution of communities towards more complex local economies, before focusing on supporting agriculture as a static activity or sector. Projects would benefit from explicitly accounting for the diversification of actors in rural areas, which now include communities of smallholders, medium-sized farmers, wealthier urban dwellers re-investing in land, the State, and more recently national and international investors looking for cheap quality land.

Recalling the Malabo Declaration commitments, member states are expected 'to promote utilization of cost-effective & quality agricultural inputs, irrigation, mechanization and agrochemicals for crops, fisheries and aquaculture to boost agricultural productivity'. To achieve this, subsidies will be part of the package favouring their introduction but with implications for the public budget of the poorest of states.

— This problem calls for diversification and innovation in the introduction of subsidies, or at least partial relief of them. One possible way is to support extension services in diversifying their offer, with special emphasis on knowledge-intensive agronomic approaches. This clearly points to a very careful assessment of the costs and benefits of investing in technical support, versus the simpler message of more affordable input through subsidies. However, this does not necessarily mean the absence of subsidies, but a change in or combination of how they may be targeted (e.g. temporal output support to make up for the slower materialisation of benefits from alternative agricultural practices, and/or subsidised inputs).

Focusing on specific practices, improvement of input management is a common thread among all approaches and strategies.

However, there is a relative deficit of research and experimentation opportunities for alternatives to conventional intensification based on improved seeds and inorganic fertilisation.

— Future public support or incentives would benefit from diversifying their focus away from 'silver bullet' research (e.g. a certain seed, a single package) towards other management approaches to agriculture. Any supported approach requires rigorous records of its agronomic performance and its economic relevance to a given context.

Conventional intensification practices have an advantage over knowledge-intensive alternatives, as conventional intensification may be shaped as ready-to-use/off-the-shelf packages. Knowledge-intensive practices may result in paradigmatic changes in day-to-day operation, but they tend to be site-specific, raising the transaction costs associated with their adoption. To clarify the distinction, the costs of Green Revolution and technologically-based solutions (e.g. seed improvement through hybrids or other means, more specific pest control substances, improved irrigation systems) almost exclusively comprise direct production costs.

— When designing support to agricultural extension services, it is crucial to account for the differences between practices: knowledge-intensive practices at user level are different from the product/technique-based options. Projects promoting the adoption and adaptation of knowledge-intensive practices require special emphasis on the type and length of support provided to farmers. Limiting support to enhanced access to technology or inputs falls short in responding to the interaction needs for adaptation and appropriation of the approaches, if identified as suitable by farmers.

— Extension services would benefit from avoiding a single approach or input (e.g. a given fertiliser), so that farmers are effectively introduced to a larger variety of options in terms of practices, so they can experiment and truly adapt/adopt the most suitable practices.

The ready-to-use/off-the-shelf package is associated with the risk of not understanding what farmers are looking for from new practices (e.g. yield increase or stability in harvests).

— Agricultural policies and large programmes could look beyond simple support for yield enhancement, as this is not the only pressing need. A more nuanced reflection on the actual needs of farmers, and particularly of smallholders, emerges. There should be a special effort in agricultural projects to focus more on needs regarding production risks, net income stability and efficiency.

Advocacy may overestimate the actual net benefits of a given practice. Practices will perform as adapted and suited to the implementation context.

— It is preferable for interventions to avoid any blanket approach regarding the promotion of agricultural practices. This entails a somewhat conservative approach when presenting what a single practice can deliver, by accounting for the costs to the user associated with transition and adaptation (e.g. transaction costs).

A general challenge for adoption is that of timing. Any new practice or approach promoted is expected to provide at least a perceptible contribution towards farmers' short-term objectives, to which they are generally most sensitive.

— An intervention favouring a given set of practices probably stands a better chance of success if it is part of a larger set of interventions allowing for direct or associated short-term benefits to participants.

As a key contributor in responding to regional FNS needs, Africa's agriculture faces very diverse challenges in terms of a sustainable approach. As such, there is no single solution ('silver bullet') allowing the sector to sustainably increase its contribution to food supply. Ultimately, opting for a coherent set of approaches or more targeted agricultural practices depends on the great diversity of local contexts (environmental, institutional, seasonal, etc.), as well as on the characteristics and motivation of individual farmers and their communities. Collective action in the uptake of key practices has been recorded as producing more sustainable benefits.

As is the case for input-based intensification of agriculture, the results from the different management-based approaches are not universal and absolute responses cannot be derived from the cases reviewed (including the meta-analyses). Careful targeting and local adaptation remain fundamental ingredients for both improved performance and the long-term adoption of any of the principles and associated practices.

When looking at each newly adapted practice as an innovation, it is essential to look towards more coherent, and more importantly effective, sustainable production systems.

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List of abbreviations and definitions

ANR	Assisted Natural Regeneration
CA	Conservation Agriculture
CAAPD	Comprehensive Africa Agriculture Development Programme
DG DEVCO	Directorate-General Development and Cooperation
FAO	Food and Agriculture Organization of the United Nations
FMNR	Agroforestry, including Farmer Managed Natural Regeneration
FNS	Food and Nutrition Security
FSR	Farm System Research
GAPs	Good Agricultural Practices
GHG	Greenhouse Gas
GMO	Genetically Modified Organisms
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IFPRI	International Food Policy Research Institute
IPM	Integrated Pest Management
ISFM	Integrated Soil Fertility Management
JRC	Joint Research Centre
NEPAD	New Partnership for Africa's Development
OA	Organic Agriculture
SI	Sustainable Intensification
SSA	Sub-Saharan Africa
WOCAT	World Overview of Conservation Approaches and Technologies

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