



Deliverable 2.4

Potential building blocks for the research and innovation agenda of the future Europe – Africa strategic partnership on sustainable intensification of the African agri-food systems

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Abstract

D2.4 is the fourth and last deliverable of WP2. It presents a wide review of the potential building blocks on which a Europe/Africa partnership on research and innovation in Agro food systems can be constructed. The document comprises two sections:

Section I provides general considerations on intensification of agrifood systems, the options ProIntensAfrica has taken to understand the intensification dynamics, and the ways research and innovation can appropriately support this process.

Section II presents the themes of the expected agenda, analysing first megatrends and challenges, food systems, trade and access to market, natural resources. Then, the document explores different cropping systems in order to identify the needs of a large diversity of stakeholders, at different scales, in different ecological zones to support the decision-making process. Finally, a wide spectrum of cross cutting themes are explored (biosciences and technologies, genetic diversity, large scale land acquisitions, innovation in partnership, collective actions, multi-criteria evaluation, ecosystem services, foresight capabilities, critical technologies, urban and peri-urban agriculture). If relevant, all the items are analysed with the ProIntensAfrica option that different visions of agricultural intensification address diversified (and complementary) research agendas.

The content of the Agenda is mainly based on the PROIntensAfrica literature review. The full contributions of the authors, including lists of references, are available on an online platform, accessible on: <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMV2c>

These building blocks will be later in the project confronted (i) to the case studies conclusions, (ii) to the vision and criterion developed by the other WPs, and (iii) to a realistic future Europe / Africa partnership. From these confrontations, the final ProIntensAfrica R&I agenda will be defined.

Keywords:

Research, Innovation, Agriculture, Environment, Intensification, Pathways, Sustainability, Employment, Africa.

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1 Introduction

Enhancing food and nutrition security in Africa involves intensifying agricultural production per unit of labour or land, but it implies much more than that. Food and nutrition security is not only a matter of availability; it also includes diversity, quality and regular accessibility to food for consumers. Many challenges have to be simultaneously addressed before increased food production will result in higher food and nutrition security. Local collective actions, farmers' organisations, improved processing, development of the private sector, challenges and opportunities due to urbanization, improved chain performance for local, regional, and international market access, infrastructure, enabling institutional and policy environments, need to be considered to enhance the agriculture-driven economic growth of African countries.

The equation is even more complex as agricultural intensification usually results in higher labour productivity, but fewer employment opportunities in agriculture. Hence, part of rural population will have to find sources of income from other sectors than agriculture. This is particularly problematic for Sub-Saharan Africa (SSA) because agriculture should create more jobs to face the demographic challenges in SSA.

New approaches are required. In order to maintain productive capacity of natural resources, intensification should be adopted in a sustainable manner. Sustainable intensification is about prudent and efficient use of resources, ecosystem services, social and economic impacts, induced technological dependency, the limits of natural and energetic resources over different scales of time and space, and must take into account climate change and political instability. New exciting avenues are offered by agro-ecological approaches based on the understanding and mobilisation of agro-ecological processes such as the optimisation of available water and nutrients, and the control of pests with limited use of fertilisers, pesticides and energy. These avenues need to be analysed and compared, with the appropriate tools and metrics, in order to evaluate both their performance and their sustainability. Comparative research is needed to fully unlock the potential of this approach.

The PROIntensAfrica initiative undertakes an integrative, collaborative, world-leading research approach with a wide range of stakeholders in Africa and Europe. It addresses sustainable intensification pathways in agri-food systems to meet the major societal challenges which improved food and nutrition security and rural livelihoods represent.

Building a shared vision of the performance of different intensification pathways in different contexts is central for the successful implementation of sustainable intensification through the enhancement of existing practices or technical and organisational innovations. The diversity of climatic, edaphic, social, economic and political conditions results in a wide diversity of production systems. Furthermore, understanding the actual dynamics and drivers which led a farmer, a community or a government to take a decision towards the adoption of an intensification pathway is also important, and makes the difference between a Science Agenda, and a Science and Innovation Agenda. Finally, effective and comprehensive comparison between different pathways requires a multi-criteria assessment approach, identifying the relevant agronomic, social, ecological and economic knowledge, and later indicators to compare situations and performances.

D2.4 offers the preliminary identification of a Research and Innovation Agenda, exploring different cropping systems and different ecological zones, in order to identify the needs of a large diversity of stakeholders, at different scales, and to support the decision-making process.

The document comprises two sections: SECTION I provides an overview of PROIntensAfrica and general considerations alongside options for a Science and Innovation Agenda; SECTION II presents the themes of the Science and Innovation Agenda.

1.1 Methodological note

The draft PROIntensAfrica Science and Innovation Agenda deliverable (D2.4) has been assembled and written under the coordination of the WP2 team. The general framework of the document published in 2014 as “FARA Science Agenda for Agriculture in Africa (S3A)” has been utilized as a starting point when preparing D2.4. However, in order to fully cover the spectrum of agricultural intensification in Sub-Saharan in Africa, substantial development has been made in the content.

The content of the Agenda is mainly based on the PROIntensAfrica literature review (see D2.2). The WP2 team collected bibliographic synthesis on previously identified topics regarding agricultural intensification in Sub-Saharan Africa. Since some items were missing from the literature review, the WP2 team may have called for specific and external contributions and mobilized specialists to identify consistent and original research questions and their idea for future research interacting with agricultural intensification pathways in Africa.

In order to elaborate a consistent final document, text contributions have sometimes been reshaped, shortened or modified. Occasionally only paragraphs, phrases or ideas have been included. Some contributions will be elaborated in the forthcoming PROIntensAfrica project documents.

In order to have a homogenized text, the citations have not been kept in the document. However, with the agreement of the contributors, and under their responsibility their full contributions, including lists of references, are available on an online platform, accessible on this link: <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMV2c> ;

In addition, public documents, grey literature, official reports and other documents may have been consulted and are referenced in every item. Aspects or documents which may have been omitted in this report can be rectified in the official report to be published in March 2017.

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2 PROIntensAfrica options for a Science and Innovation Agenda

2.1 Definition of intensification: a review¹

The FAO's injunction to increase food production by 70% by 2050 in order to compensate for population growth, rapid urbanisation and dietary changes, is diversely appreciated and interpreted in the research community. Indeed, the response to this injunction crystallises controversies about how to address food and nutrition security. This questions the very nature of the food systems our diverse societies need and deserve, and has implications for the understanding of agriculture intensification. On the one hand, a part of the community focuses on quantitative and trade-concerned dimensions, on maximising physical yields and incomes, and on minimising production costs all along the value chains. Positions can then differ depending on the way environmental sustainability is addressed and on the acceptable thresholds defined in the artificialization of agriculture processes. On the other hand, some researchers do not recognise the urgency of the injunction and focus on enhancing the adaptation capacity and autonomy of food systems. They postulate that beside the necessity to (re)adapt agriculture to natural constraints and opportunities, the social sustainability of food systems is a condition for reaching food and nutrition security.

Therefore, while there may be global agreement on the importance of reducing agriculture's impacts on natural resources, the meaning of agricultural intensification comes in several forms: there are differences in the way it is defined, but also in the way it is measured. In a broad sense, intensification refers to a dynamic process of land use changes over time. More precisely, intensification refers to a situation where a production factor - generally the limiting one - is used more intensively, i.e. when for the same amount of this specific factor (land, labour, capital), more of other production factors are mobilised, resulting in a better performance and more output. Intensification can be considered, therefore, as the result of an action in which some aspect of a system has been intensified, a rearrangement of the combination of production factors.

In the early definitions of intensification, it is not a given model but a way of maximising productivity and increasing production per land unit or man-hour or capital unit, the aim being to increase the overall production level and to generate higher incomes. Today, besides production and income, new expectations are placed on agriculture regarding quality, equity and sustainability. The current debate around sustainable intensification illustrates the need to shift from a production paradigm to a sustainability paradigm. The challenge now is to find new intensification models, which integrate new goals beyond production and incomes. These goals include smart and reasonable natural resource management, food security and self-sufficiency, poverty reduction, and participatory mechanisms. Sustainable intensification marks the arrival of a new, but as yet barely tried, phase in development thinking. With regard to sustainable intensification, additional factors and assets are now taken into consideration as new inputs to be used more intensively: knowledge, innovations and complexity, ecosystem services and ecological processes, empowerment, human capital, workforce, labour rights, etc.

Besides production level and income, new outputs are also considered regarding quality and food security, equality and equity, environmental and social sustainability. For intensification to be sustainable it should promote positive economic impacts (including providing international and national markets), environmental impacts (including landscape and climate

¹ This section is based on elements from D2.1: "A literature review about experiences, research and innovation results obtained with a large spectrum of intensification pathways"

change concerns), and social impacts (including reducing inequalities and promoting political stability and food justice). Sustainable agricultural intensification is also more connected to the concept of food systems; it involves a diversity of practices, policies, norms and values together with a wide range of different actors, which reinforces the complexity of finding a common definition. Therefore, yields, income and performance are no longer adequate for measuring agricultural intensification. It now requires cross-analyses, multi-level, multidisciplinary and systemic evaluations.

2.2 Intensification pathways for PROIntensAfrica: an option²

2.2.1 Defining the pathways

While conducting the literature review and case studies, we slightly adapted the ProIntensAfrica rationale. The initial denomination and borders of intensification pathways have been fine-tuned, taking into account their diverse representations among the actors involved. The choices below may still be controversial. Indeed, it is difficult to escape the potential economic and political impacts of one vision of future agriculture versus another in general and in SSA in particular. In the literature and in the field, recurrent and sometimes incompatible references to ‘sustainability’ and ‘agro-ecology’ are made. We choose here to use the sharpest definitions possible, in order to identify contrasting pathways and intensification options, and to clarify future controversies.

Pathway 1: Conventional intensification

This pathway is dominated by high external inputs used, notably breeding (including GMO), pesticides and mineral fertilizers and the extensive use of irrigation and mechanization. We could name it “conventional intensification pathway”. It is also identified as the “neo - conventional green revolution” pathway for Africa, mostly supported by large agribusiness firms of agricultural supplies (mechanization, water management, chemicals, etc.). It targets all kind of farms but implicitly encourages large scale farming as a natural consequence of desired high productivity gains. The Green Revolution’s implementation includes natural resources management and environmental sustainability concerns, but it still dominantly refers to maximizing production as its goal in the short term, through an artificialization of the cropping conditions. This pathway, which refers also frequently to sustainability, is based on the conviction that physics, chemistry and biotechnologies can produce technologies which are able to substitute the natural processes, while increasing land productivity. The three pathways defined below refute this conviction.

Pathway 2: Ecological (sustainable) agricultural intensification

A pathway considering more explicitly local knowledge and ecological services while enhancing a rational use of biotechnology (including GMO), external inputs, irrigation and mechanization. It aims to increase land and labour productivity and income (therefore intensification is seen as a necessity) following a classical market oriented strategy. This pathway shares with the so-called “conventional” one the main objective of maximizing resources potential for increasing production’s volume, but while requesting dedicated research to correct its widely recognized externalities and mistakes, and with a focus on natural processes valorization. Environmental and social sustainability is a real concern as well as the need to avoid exceeding natural resources’ consumption thresholds. Private investments and public-private partnership are highly compatible with this pathway, which may lead to encouraging large-scale farms and their dependency to agro-supplies. The

² This section is based on elements from D2.1: “A literature review about experiences, research and innovation results obtained with a large spectrum of intensification pathways”

“Montpellier panel” has given a wide theoretical framework for the “Sustainable Agriculture Intensification (SAI) pathway”, based on three pillars: genetic intensification, ecological intensification and social intensification.

Pathway 3: Agro-ecology pathway

Another pathway to think and implement sustainable agriculture intensification is the “agro-ecology pathway”, understood as strictly combining social and technical movements all along the whole agri food chain and widely in food systems. Maximization of labour and/or land productivity is not the previous goal in this SAI incarnation, nor the increase of production’s volumes; labour and land intensification is requested only when needed, which is the case in most situations in SSA, and is subordinated to welfare and food justice’s maximization. Technical rationale and main goals are rather to maximize natural processes involved in cultivated process in order to diminish external inputs, and their related costs. Autonomy of the production systems from mineral inputs and autonomy of the farm from agro-furniture (including indebt-ness) are also key objectives. Therefore, its priority targets are small-scale farms and local, as well as national, markets are targeted; long value chain integration requiring specific conditions is involved.

Pathway 4: Organic agriculture pathway

The “organic agriculture pathway”, refrains from the use of pesticides and mineral fertilizers and emulates ecological systems and cycles. At its origin, very close to the agro-ecology movement, its main objective is not intensification, but a shift to better quality that should allow better prices. That’s why it is ruled by the definition of market conditions, certified in different ways. European markets and integrated commodity chains are strong drivers for this pathway. Intensification is a more recent concern; evidence demonstrates that the yield gap between conventional and organic practices could be reduced. Even if basically short circuits and local anchorage should be promoted, this pathway doesn’t exclude long distance input procurements as long as they are organic. It is emerging in SSA but involves, for now, few producers and productions on a wide diversity of certification processes. The references are much more to be found in developed countries. International movements, relayed by national and regional organizations are supporting the organic agriculture development in SSA.

These pathways (intensification options) have to be regarded in the specific situation of SSA. Agricultural challenges and issues have common traits all over the world, but SSA remains particular for at least four major reasons:

- It’s the only part of the world where demographic transition is not yet begun and the subcontinent’s population growth will explain two-thirds of the planet’s demographic trends over coming decades. It’s also the only part of the world where, despite rapid urbanisation, the rural population will continue to increase.
- The second reason, connected to the first, is the employment challenge these demographic trends present. Within the next 15 years, some 375 million of SSA’s youth will become of working age and because the subcontinent is experiencing an incipient economic diversification, agriculture will have to provide an important share of the jobs that will have to be created.
- A third reason is that in SSA there is a concentration of most of the world’s very poor and undernourished people. Therefore, food and nutrition security relies more than everywhere else on addressing simultaneously the four pillars: availability, access, utilisation and stability.
- A fourth reason is the specific agriculture in the SSA equation, where production has more or less succeeded in following past demographic growth, but without an overall significant increase in its performance per unit of land used. The yield gap is still in a global perspective higher than in other developing areas, but closing this gap will have to be achieved without mobilising the classic green revolution processes. Green revolution damage to natural resources should indeed be avoided, while public support for its implementation is increasingly less of an option for both governments and donors.

2.2.2 Discussion on pathways and farms organisation models

The link between PROIntensAfrica intensification pathways and farm organisation models offers another key to understanding the political basements of the place and role of agriculture and food systems in SSA's societies. As shown in the table below, agribusinesses and corporate farms are more likely to adopt the conventional or the ecological intensification pathways, but globally, all types of farm organisation can implement any of the pathways. Add the fact that a single farm can develop one, two, three or four pathways among its different plots, and it appears that our pathways are not limited to one form of labour (and capital) management.

Table 1: Farm organization model vs intensification pathway.

Farm type	PROIntensAfrica pathways			
	High input	Ecological Intensification	Agro Ecology	Organic
Agribusiness / corporate farms	X	X	x	X
Family-business agriculture	X	X	X	X
Family farmers (without permanent employee/s)	X	X	X	X

Note: The size of the "x" illustrates the relative importance of the issue.

From a political point of view, the table shows that agro-ecology (AE) is rather ill-suited to agribusiness/corporate farming. . Production systems yet existing in SSA's agroecology mostly concern small family farms; large-scale projects mainly refer to conventional pathways Its spread in Africa will come rather from political incentives in favour of family farms, including family businesses. While each pathway can be implemented by any organisational framework, the political choice to act in favour or against corporate farming model will impact the shares of the various pathways in the corresponding country. For instance, the positioning of organic agriculture would certainly be closer to those of agro-ecology in cases where family farms are targeted, whereas more contrasted representations will appear if family businesses or corporate farms are targeted (using, for example, imported organic fertilisers).

Apart from the agro-ecological pathway, all other PROIntensAfrica intensification pathways are compatible with very diverse food systems. High input, EI and even organic pathways can be part of standardised, normative, highly concentrated and industrialised up and downstream agricultural production food systems. But they can also be part of food systems relying on diversity, artisanal processes and proximity. While the high input pathway seems more favourable to corporate farms and to concentrated, mass agro-industrial food systems, it can be compatible also with the promotion of family farms and territory-based food systems.

Intensification options and sustainable production mainly depend on political orientations in the way food systems are managed, quite independently from technical concerns. Policy matters, trade laws and monitoring all along value chains and food systems will ultimately be the major influence on the social impact of intensification practices. Therefore, one has to take into account the whole food system, starting from providers of agricultural inputs through to consumers, to record the role and overall effects of intensification choices on societies.

2.3 The drivers for intensification: a review³

In order to contribute adequately to the design and implementation of suitable and desirable pathways, it is useful to describe different types of situations which may generate or boost an intensification process. Such an exercise calls for the identification of the possible combinations of drivers that together contribute to making intensification happen. These combinations rely on drivers that are active at different scales (global, national, local, household, field etc.) and that involve social, economic, ecological and technical dimensions. They can therefore be described with reference to the types of drivers.

As a process of improving the performance of a particular production factor, intensification of agriculture in Sub-Saharan Africa can take place in different situations: (i) when this factor is lacking, (ii) when it is in relative abundance or (iii) when, independently from its availability, the context is attractive for a shift in production patterns.

The first situation (i.e. the deficit of a particular production factor) usually results from demographic dynamics and its implications for production patterns. It refers to a Malthusian situation: productivity is increasing slowly while population is growing exponentially. The decreasing relative availability of land and/or fertility resources may result from both a degradation of renewable natural resources as a consequence of increasing pressure and a fragmentation of households from one generation to the next. It leads farmers to explore two options: moving and contributing to a pioneer process through encroachment of forest or extensively used areas, or increasing productivity. Choices are made according to the local specific configuration of drivers and the relative attractiveness of both options: they derive from opportunities and barriers such as the physical and juridical capacity to set up in new areas, the social networks and infrastructure that makes it possible or not, the incentives for intensification rather than dislocation (infrastructure, prices, access to inputs and markets etc.), the risks in terms of health and security etc. Pioneer processes are frequently observed in regard to cash crops and are, for example, usual for cocoa (See IDCS 3). Intensification processes take place both when there are strong limitations on the pioneer front and when drivers for intensification are in place. This might occur when the risk and cost of dislocation become too high and/or when the opportunity for intensification becomes more attractive. This might also occur when a particular and specific problem can be resolved, making dislocation unnecessary (soil erosion, soil alkalisation, water quality, pest control etc.).

The second situation, i.e. the relative abundance of a particular factor, usually results from an increasing investment capacity. This occurs, for example, when the emergence and structuring of a belt for cash crop turns into local accumulation processes (e.g. cotton belt in Burkina Faso and Southern Mali or pioneer cash crops such as palm oil, rubber or cocoa). This then impacts the whole farming system, and in particular the importance of livestock and the production patterns of food crops and not the only cash crop. This might also occur through remittances from migrants, both from urban centres and from international migration. Finally, it might also occur due to non-agricultural sources of income and capital accumulation, such as mines or tourism. The abundance of a particular factor might also result from an investment in infrastructure: being a hybrid of the second and third types of situations. This is the case for water and irrigation opportunities when an irrigation scheme is implemented (e.g. Senegal Valley and the Office du Niger in the mid-20th century).

The third situation, i.e. the attractiveness of a shift in production patterns, usually derives from public interventions, which makes increased productivity feasible and profitable. This happens when a whole set of measures are met, regarding the security of land tenure, pricing policy and regulation (including storage capacity), financial and technical support for

³ This section is based on an original contribution of Patrick Caron, “*Intensification drivers*” Chairman of the High Panel of Experts (HLPE) on Food Security and Nutrition, available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

production, public and private infrastructure for access to inputs and marketing facilities, and sanitary support and regulation. This not only requires public investment, but also the contribution of all stakeholders to the dynamic. This not only relies on global and national drivers; local configurations and dynamics are also important, as demonstrated in the case of peri-urban contexts or geographical and labelling institutional arrangements. In such cases, the structuring of the connectivity between production and consumption areas, between rural and urban centres in particular, are of fundamental importance.

2.4 Existing initiatives for Science and Innovation Agendas in Africa: a review

Strategies and research programmes are blossoming in Africa. The PROIntensAfrica Research and Innovation Agenda acknowledges the efforts and strategies towards agricultural development in Africa and aims to contribute to this constructive dynamic. After being on the sidelines of development strategies for decades, agriculture is increasingly considered as a strategic field to enhance overall development. Several reports, such as the *World Bank 2007* and the *IAASTD Agriculture at a Crossroads* report, have emphasised its importance on overall development and underlined the need to invest in the agricultural sector in order to build sustainable food systems that will produce enough to feed the growing population while preserving natural resources.

International, regional and national institutions have defined their position and strategies to support agriculture in Africa following their development goals and objectives. In 2011, the World Bank published *Africa's Future and the World Bank Support to it*, a 10-year strategy built on the lessons learned from the Africa Action Plan (2005). In order to make African agriculture more competitive and enable farmers to scale up, several programmes have been implemented, such as the Enabling Business of Agriculture which targets five fields (seed, fertiliser, machinery, finance, markets and transport) to modernise agriculture

FAO has published several reports regarding agriculture in Africa. However, its main strategic document *Building a common vision for sustainable food and agriculture* (2014) explores agriculture worldwide and defines the key principles for sustainability in food and agriculture such as improving resource use efficiency, preserving natural resources etc.

The FAO OECD Agricultural Outlook 2016-2025 focuses on the challenges in Sub-Saharan African agriculture, while other reports focus on specific topics (i.e. the FAO, IFAS, WFP 2015 report *Achieving Zero Hunger: The critical role of investments in social protection and agriculture*).

The IFAD Strategic Framework for 2016-2025 doesn't focus on Sub-Saharan Africa but defines strategic objectives to achieve the SDGs by 2030. For example, these objectives are market inclusiveness, access to technologies and climate resilience.

In order to encourage and facilitate the implementation of national agricultural strategies and investment programmes, within NEPAD, the African Union launched the Comprehensive Africa Agriculture Development Programme in 2003. In June 2006, the African Union Special Summit of the Heads of State and Government adopted the *Abuja Declaration on Fertilizer for the African Green Revolution* and, in 2010, the Executive Council of the AU endorsed the *African Agribusiness and Agro-Industries Development Initiative (3ADI)*. These initiatives aimed to promote the industrialisation of African agriculture in order to make it more productive and profitable.

A very important document about Africa's development strategy is the NEPAD Agenda 2063 (2013), whose goal is to plan the structural transformation of Africa over the next 50 years. In

line with the agenda, several documents regarding agriculture have been published such as *Ending Hunger in Africa. The elimination of hunger and food insecurity on the African continent by 2025*. The report recommends increasing access to fertilisers and seeds as well as improving irrigation infrastructure in order to make Africa food secure and self-sufficient. In the report *Agriculture in Africa: Transformation and Outlook* (AU, 2014), agriculture is considered as “a driver of economic transformation in Africa”. These documents promote an intensification model based on technologies and external inputs.

In favour of reaching their goals, international, regional and national organisations all underline the importance of research and innovation to develop adapted strategies and address the major challenges African countries are currently facing.

The fourth pillar of the CAADP is to promote agricultural research and technology dissemination and adoption. The research themes defined as continental priorities by CAADP are *Integrated Natural Resource Management* and *adaptive management of biotechnologies*. A major part of the activities being conducted within this pillar consist of capacity building in the continental/regional/national agricultural innovation system as a whole. FARA is in charge of pillar four, through the implementation of the *Framework for African Agricultural Productivity* (FAAP). This is a reference document for implementing the CAADP and aims to enhance investment in research, science and technology to enable farmers to increase their productivity.

The FARA *Science Agenda for Agriculture in Africa* (S3A) is a major document regarding research in Africa and a reference for the PROIntensAfrica Research and Innovation Agenda. It identifies key strategic issues that will impact on science and agriculture and presents options for future research in order to deepen the contribution of science to agricultural development at all levels. The *Science Agenda for Agriculture in Africa* is a long-term strategic framework that consists mainly of the range of science and technology opportunities available to bring about agricultural transformation in Africa. The S3A provides guidelines towards ecological intensification in African agriculture.

As is explained in the document, S3A has been designed to benefit from and add value to CAADP and other AUC-NEPAD strategic documents, such the *AU Agenda 2063*, NEPAD's *Science and Technology Consolidated Plan of Action* (CPA 2003; 2005) and the *Technology and Innovation Strategy for Africa 2024* (STISA2024 2014).

The PROIntensAfrica Research and Innovation Agenda also aims to benefit from the experiences of African regional research centres, which have mostly developed strategic plans towards ecological agricultural intensification.

CCARDESA: The Agricultural Productivity Programme for Southern Africa (APPSA 2014) aims to improve the generation and dissemination of technology within participating countries by, for example, identifying or developing promising technologies.

CORAF/WE CARD: The 2007-2016 strategic plan has been reinforced and extended with the research and development priorities for agricultural transformation in WCA (2014-2018). It explores three main themes: food, health and nutrition security, market and trade, and sustainable agriculture. The key research programmes are technical research including biotechnology, policy research and capacity strengthening.

ASARECA: The ASARECA Strategic Plan 2007-2016, Agricultural Research for Development in Eastern and Central Africa, was produced to support the MDG. It aims to enhance agricultural research to promote economic growth, food security and the sustainable use of resources.

Countries and national research institutions often have a strategic plan for agricultural research. Among the Sub-Saharan countries, we randomly chose to explore three countries (Senegal, Madagascar and Cameroon) to understand the articulation of national strategies with regional and international ones. The ISRA Strategic Plan 2016-2020 (2020) claims to align with existing research agendas but underlines the fact that its strategic plan is based on specific demands (from NGOs, farmer organisations, national authorities etc.) that have been collected on the ground. In Madagascar, the strategic plan for national research institutions is the national strategic plan implemented by the State in line with its general policy. In Cameroon, the Strategic Plan 2013-2021 has been implemented in order to respond to the needs of development actors, including ministers in charge of rural development, agro-industries, producer organisations etc. Although national research centres' strategies align with the regional and international agenda, they might favour local actors' preferences.

Several studies have also attempted to build an agenda and outline the priorities for science and research in Africa with a different vision. The ProIntensAfrica Research and Innovation Agenda is not claimed to be exhaustive but it acknowledges the efforts made regarding research in Africa.

The Inter Academy Council (IAC, 2004), The International Assessment of Agricultural Knowledge, Science and Technology for Development Report Agriculture at a Crossroads (IAASTD, 2009) recommends a change of paradigm towards a sustainable food system. It documents the agro-ecological and ecological intensification pathways.

The CGIAR research programmes are organised to address specific themes, for example, agriculture for nutrition and health, dryland cereals, and integrated systems for the humid tropics). The CGIAR research is mostly oriented towards the ProIntensAfrica ecological agricultural intensification option as it has been advocated by the Montpellier Panel.

The High Level Panel of Experts on Food Security published a series of reports cross-cutting different themes such as social protection (2012) and food losses and waste (2014) with food security and expressing specific recommendations.

3 Themes of the Science and Innovation agenda

3.1 Introduction

As expressed above, the rationale of PROIntensAfrica is that a variety of intensification options are required to ensure sustainable intensification of the diverse food systems across Sub-Saharan Africa and to deal with the variability within increasingly complex food systems.

Therefore, the science agenda we suggest adopts a global point of view and aims to articulate the sectorial visions of the usual research on agriculture intensification. Specific, disciplinary, highly specialised research is needed to address the large variety of topics involved in sustainable intensification. Based on PROIntensAfrica's key observations, we have reached the conviction that highly specialised research must be completed by more global approaches and, above all, that each of them should contribute to:

- An integrated vision of actual trends and challenges in food systems.
- The definition of credible alternatives to build sustainable combinations of options to ensure sustainable systems.

From the gene to the market and the plate, from soil fertility and seed management to adapted public policies, research should nourish this great ambition to state the role and

functions agriculture should play in SSA and the kind of intensification required to reflect its diversity.

The proposed agenda advocates connected research to reach global targets, not necessary all together but bearing all of them in mind. The following list is not exhaustive, but offers items and goals for research: adapting to and mitigating climate change, ensuring decent work opportunities for the growing number of urban and rural workers, increasing farmers' incomes and welfare, ensuring food and nutrition security and justice for producers and consumers, protecting natural resource use from irreversible thresholds while respecting community regulations, contributing to the security of people through enhanced political stability, etc.

The agenda presented tries to facilitate this ambition, connecting and articulating the different issues identified, and declining them within the PROIntensAfrica pathways with the following framework:

- First, three items concern major issues and the global environment. These items have to be scientifically stated in order to better set the scene of agricultural intensification. The agenda suggests that we document: the global challenges of SSA's agriculture in economic transition; the food systems and their value chains related to these major issues; environmental and natural resources seen as opportunities or pressures to intensification.
- Then come our propositions around production sustainability issues at the plant, field and household scale, including the upstream problematic and particular attention to multicriteria evaluation of sustainable intensification.
- Research should address downstream issues, exploring the other segments of food systems and their various crucial questions regarding sustainability.
- Finally, cross-cutting research themes are presented, linking up the previous issues and enhancing the connection between researchers and politics: biosciences and technologies, intellectual property, land issues, NTIC and big data management, innovation in partnership and collective action, public policies and foresight and, finally, multicriteria and comparative evaluation of entire food systems and of their various combinations.

3.2 Megatrends and challenges for agriculture in Africa

African agriculture is evolving in a rapidly changing global context which bring new challenges and opportunities for future development strategies. Sub-Saharan Africa countries' economies are also changing fast. Population growth and demographic movements will require fast implementations of institutional strategies in order to benefit from it and to meet the increasing demands for food, employment and decent livelihoods elsewhere. In this section, 5 megatrends and challenges have been explored in order to underline the opportunities and identify the research needs following a "pathway perspective" to do so.

3.2.1 Climate change as a megatrend for Agriculture⁴

Climate models anticipate that Africa will experience a median temperature rise of up to 4°C in the 21st century, with diverse amplitudes among sub regions. Africa has been plagued by climate variability, with persistent droughts occasionally alternated by flooding. Global research on climate issues and rainfall distribution has revealed that the Sahel in West Africa experienced an unusually wet period from 1950 until 1970. Thereafter, it was followed by extremely dry years from 1970-1990. Presently, increasingly unpredictable weather events as well as changing patterns of diseases in crops and livestock are observed.

⁴ This section is partly based on the following documents: FAO, 2016. The agriculture sectors in the intended nationally determined contributions: Analysis. Working paper, Climate and Environment Division (NRC) Publications. Rome, FAO: 80 pp., and Torquebiau, E. (ed) 2016. Climate Change and Agriculture Worldwide. Springer, 348 pp.

Human activities, including unsustainable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, overgrazing, improper crop rotation and poor irrigation practices, dwindling resource base, all contribute significantly to land degradation. This land degradation is aggravated by climate change and leads to a significant reduction of the land productive capacity. This has a significant implication for Africa in terms of ability to produce enough food.

The combination of several climate change induced phenomena and the on-going population increase result in an acute demand for land, creating new challenges which require Africa to have greater foresight and a science strategy for managing the anticipated global changes in agriculture and food systems. As a matter of fact, future increases in agricultural production will have to come from both intensification of existing practices in the form of yield increases and higher cropping intensities as well as from expansion into new lands (in limited areas of the world). In this case, the contribution of science will be critical to assess how to raise yields sustainably, to identify domains and technologies for sustainable expansion, and to address the related social equity issues. While confronting the challenge of climate change, Africa also needs to target broader development objectives. This requires political commitment to invest in science and technology, to prioritize climate resilience and adaptation, and to increase agricultural productivity.

While climate change will strongly impact African agriculture, calling for urgent adaptation actions, the mitigation of climate change is also an issue of concern which can be addressed in Africa as anywhere else. Agriculture globally contributes to about 24% of greenhouse gas emissions. Approximately half of these emissions come from land-use changes (deforestation) while the rest originates directly from agricultural activities, such as emissions from mineral fertilization of soils and fertilizer manufacture, enteric fermentation of ruminants or anaerobic decomposition of organic matter from flooded crops. The combination of adaptation to climate change and mitigation of climate change can actually be seen as an asset for agriculture. It makes it possible to describe agriculture as one of the solutions to climate change (mitigation) through soil carbon sequestration, while giving it the possibility of better production (adaptation) and hence improved food security. This makes a lot of sense when viewed from the perspective of developing countries. Indeed, these countries are not (or very little) responsible for anthropogenic emissions of greenhouse gases, past or present. Making them bear the burden of mitigation is therefore unanimously considered unacceptable. On the other hand, the majority of these countries are calling for the international community to help them adapt to the climate change they are experiencing.

In preparation for COP 21 in Paris in 2015, all countries were asked to draft a document presenting their "nationally determined contribution" in terms of mitigation of climate change (reduction of emissions and / or carbon sequestration). Interestingly, 95% of developing countries decided to include in this document a need to adapt to climate change, which is perceived by them as the main climate challenge. This rate reaches 100% in sub-Saharan Africa and South-East Asia, while none of the contributions submitted by developed countries includes a section on adaptation. It is the land sector that is most frequently cited as a priority for adaptation, and among the 130 countries (out of 188 that submitted a contribution in March 2016) that cite adaptation, 95% refer to crops and livestock and 83% and 46% to forests and aquaculture respectively (FAO, 2016). In order to address those expectations from developing countries, it is required to design agricultural and forestry solutions which promote synergy between adaptation and mitigation.

Achieving adaptation and mitigation simultaneously is at the heart of the concept of climate-smart agriculture which also aims to attain sustainable food security. Agricultural intensification pathways do not influence adaptation and mitigation similarly. The conventional intensification pathway can perform on mitigation, especially if it achieves high yields, but it will be questioned about how it achieves sustainable food security and

adaptation. The ecological intensification pathway would probably be more efficient in terms of contributing simultaneously to adaptation and mitigation while the agroecology and organic agriculture pathways would probably do better on adaptation. This categorization, however, is not clear cut and the different pathways respond differently to the climate change varied challenges. It is thus required to investigate, with multicriteria evaluation tools, how different practices contribute to the synergy between adaptation and mitigation and in the end whether this is possible while at the same time improving food security. Interestingly, the two options (adaptation and mitigation) can reinforce each other without this being a declared objective. A farmer who designs a practice extremely well adapted to the local environment will probably produce a lot of biomass above and below ground and will hence contribute to mitigation. Conversely, a farm where mitigation is the main target will probably not be able to reach its objective sustainably unless a well-adapted cropping system is in place. Which intensification pathway will be able to best achieve adaptation and mitigation simultaneously, and in which geographic or social context, remains an open question.

3.2.2 Demography, urbanisation, employment and their cross-cutting challenges⁵

With an increase of 1.3 billion people over the next four decades, UN population latest population prospects anticipate that SSA will represent 50% of the world's population growth. By 2050, the number of workers in SSA is expected to increase by nearly 800 million. SSA is the only region in the world which hasn't achieved demographic transition, and the most recent population foresight study suggests that when occurring, this transition will remain slow. Over the same period of time, the continent will continue its densification, both in rural and urban areas, with constant changes in land sharing and land use. Another exception in SSA is the rural population growth, which is expected to continue until at least 2050. In conjunction with this, urbanisation is expanding rapidly and will continue to do so. This expansion results in the emergence of a few megacities, sometimes organised in networks of cities, with a tipping point expected in 2040.

With regards to the expansion of domestic markets and growing demand for food and fibres, these megatrends are opportunities for intensification. The densification of rural areas classically encourages land and labour productivity through the adoption of agricultural innovations. The subcontinent should also prepare for the so-called demographic divide, a period of a decrease in births with fewer older people, during which the ratio of active to non-active people is exceptionally high. Historically this period is favourable to economic emergence.

These trends are challenging for achieving agricultural intensification while ensuring sustainable economic and social development. First, rural densification without innovation results in an expansion of the cultivated area, with major constraints on access to natural resources and its management. Second, the specific urban context in SSA, with the development of megacities which leave behind intermediary cities that therefore can't offer the economic conditions and sufficient public goods and assets for supporting local development and agriculture intensification. Third, the massive arrival of new workers on the labour market questions the capacity of national economies to create enough decent jobs, both in agriculture and in other sectors.

The job equation in SSA is complex because agricultural intensification usually results in higher labour productivity and therefore fewer employment opportunities in agriculture. This

⁵ This section is partly based on Bruno Losch, ILO report "Structural transformation to boost youth labour demand in sub-Saharan Africa: The role of agriculture, rural areas and territorial development", Working Paper n°204, and on AFD-Cirad-Nepad Atlas "A new emerging rural world, An Overview of Rural Change in Africa", Spread 2 "Youth Employment: a Challenge for the Continent".

is problematic because it remains obvious that due to demographic trends and to the poor dynamics of the secondary and tertiary sectors over past decades, agriculture will have to create more jobs. Besides, the equation has to take into account that agriculture is increasingly unattractive to young people, and that its modernisation is necessary to reduce the drudgery in agricultural labour and increase incomes. Finally, agricultural transformation through intensification has to combine diverse ambitions and goals regarding demographic and urbanisation trends and employment challenges.

Research priorities to address these challenges:

- First, data on job creation perspectives and potential in the different models/pathways of intensification are lacking. The measurement is complex because of pluriactivity and the diverse functions of agriculture for households and more broadly for communities, but the job equation needs methodological investments. It is important to reflect the possible contribution of agriculture, depending on different scenarios for evolution in other sectors. It is also important to compare job creation performances between pathways and between combinations of pathways, distinguishing self-employment and wage labour.
- Second, research should provide technical alternatives for labour-intensive agricultural models. Productivity gains require the integration employment. Intensification evolutions and innovations should better integrate the inclusion of labour, which is generally poorly considered.
- Third, territorial approaches count in addressing the job equation. The divide between urban and rural areas is fading due to SSA's overall densification. In order to analyse and to anticipate labour problematics and dynamics, and with a special interest in the demographic divide, fine-tuned demographic research, including the very nature of people's mobility at different scales (from the local to the international) should be implemented.

3.2.3 Institutional shifts and economic diversification⁶

Regional integration may seem far removed from agricultural intensification, but with the challenges and issues in SSA, there are great opportunities for the inclusive development of the sub-continent and its agriculture. African regional organisations have a key role to play in dynamics for change. This role is related to market access, and the perspectives for national agriculture to provide regional markets under certain conditions and norms. The idea is to take advantage of the current urban and rural transformation and densification to create or gain market share in specific segments. Research should be more proactive in evaluating integration (or disintegration) processes and suggesting ways to achieve it.

Regional organisations, together with national institutions, should tackle political instability in the subcontinent and, very specifically, terrorism issues. Research has a role to play in clarifying the history and dynamics of conflicts, the key actors involved and also the economic, environmental and social impact of this recent issue on development be it rural or urban. But research should also better document the impact on agricultural development (including intensification pathways) of political instabilities and rising insecurity (which may be political or more classical delinquency). Conversely, we lack evidence about the concrete impact of agricultural development and policies on instability and insecurity. Labour force mobility, market disorganisation and opportunities, land access, agricultural supports or access to inputs are some of the items that could be studied regarding the insecurity of people and assets.

In SSA, among the global challenges of institutional and governance shifts, decentralisation is a key element in past decades. But the process is slow and structural change is mostly underwhelming, or only just beginning to materialise in terms of the financial and budgetary

⁶ This section is partly based on AFD-Cirad-Nepad Atlas "A new emerging rural world, An Overview of Rural Change in Africa", Spread 4 "Economic Transition and New Territorial Model" and spread 7 "Decentralization in Africa: an Opportunity for Rural Areas?".

autonomy of local authorities. Nevertheless, given our previous comments on the difficulties in thinking about intensification and agricultural policies more generally, decentralisation remains promising for rural areas to reinvest, in adapted ways, in development strategies. The potential starts from agriculture and the possibility to promote and support local intensification pathways. Decentralisation is, indeed, crucial for rebalancing investments, ensuring regional equity and managing tension and crises linked to resources, in the service of alternative agricultural policies.

Research should focus on evaluating and documenting the institutional process of decentralisation, on modelling and conceptualising its success and constraints, using economic, sociological, geographical and political science approaches. Research on decentralisation usually targets the sub-national level, aiming to reinforce local collectives. We suggest also paying attention to the organisation of decentralisation at the national level; constraints due to sectorial management of national policies do indeed influence the strategic capacities of local collectives. Research programmes should also imagine alternative cooperation policies enhancing decentralisation and its potential benefit for agricultural policies, which may be multilateral, bilateral, and national or, more usually, at the sub-national level.

These broad issues of institutional and political changes are necessary for understanding intensification processes in national and regional development. More specifically, a major reinvestment in national and local strategies for agriculture is needed. While sectorial policies have shown their limits, the role of agriculture in the structural transformation of national and rural economies has to be investigated. The classical development pathway results in modernisation of agriculture, mostly along pathway 1 or possibly pathway 2, with a rapid and high increase in labour productivity in agriculture, and a shift of most of the labour force towards inclusive and more dynamic sectors, first industry and then services. The replication of this classical trajectory is highly questionable given the current demographic, social and economic conditions in SSA and worldwide (see below), and there has to be a reinvestment in the role and functions of agriculture in global economic transition.

In particular, the consequences of intensification choices and policies on the enhancement or constraints of inter-sectorial connections, global household wellbeing, territorial dynamics (including the evolution of rural markets and infrastructures), should be more explicitly and specifically studied. Research has a great role to play in supporting alternative macro and mesoeconomic development models. For most SSA countries, solutions should come from endogenous strategies and dynamics, combined with specific forms of integration in global transformations.

3.2.4 Livelihood and rural communities⁷

The transformations occurring in agricultural structures and their environment (including their community) raise questions in the academic and political worlds. The questions being asked span the history of agricultural representations over the past century. The ways of perceiving and representing the different forms of agriculture relate to these transformations. Researchers are now invited to broaden their vision in order to address today's challenges and the different forms of intensification, as well as to understand their emergence at farm and community scales and to measure the impacts of the implementation of different pathways on farms, households and communities.

⁷ This section is partly based on the proceedings of international encounters Family Farming and Research, especially workshop 3 "In-house issues within family farming", and on 2013 HLPE report "Investing in smallholder agriculture for food security".

Research requires the integration of household overall strategies such as multiactivity, decision concerning workforce allocation both in agriculture and in other activities, commercial or social value-creation of the product, propensity and capacity to invest and in which sector, and inter-individual arrangements. This is especially true in SSA where family farming is the norm, and where changes are driven by the multifunctionality of agricultural and food systems. Research is needed to better understand the dynamics, and also to nourish potential shifts in public policies, with the emergence of multisectorial strategies to address intensification.

The sustainable rural livelihood framework, now frequently used and promoted by international institutions, invites us to tackle not only agriculture performance, but also households' entire practices and organisation beyond the farm. It should drive most of the research documenting and analysing livelihood dynamics and, more widely, agriculture transformation at household and community scales. It relies on the individualism postulate, but allows for the integration of individual and collective capabilities, actions and strategies. Thinking about 'livelihood' means considering first the environment of households, that is to say the conditions in which they operate. This environment includes the assets and capital related to the territory or the community. Households have their own set of private assets that they can use, that is to say their livelihood platform. But this platform differs from public assets and households have to pass through collective actions: the social relations, institutions and organisations of their community. Therefore, with this mix of assets, they can develop activities through specific strategies. These activities, depending on their social, economic and environmental performances, then have impacts on households' sustainability.

If statistical indicators evolve towards more livelihood approaches, which seems to be the case, research should participate in improving statistics and upgrading investigative methods:

- How can adequate statistics on agricultural households' structures, multiactivity, mobility, labour distribution among them, reciprocity and solidarity, internal tension/power relations be secured? The World Bank Living Standards Measurement Surveys tackles this ambitious but diverse set of household conditions and realities, and invites the investment in methodological improvements.
- Research must have a role in the definition of farms, by leveraging its understanding of the internal functioning of households involved in agriculture. It should therefore work with all relevant partners (NGOs, policy makers, farmers' organisations, as well as institutions responsible for producing statistics at national and international scales) and acknowledge the roles of institutions in the process of intensification.
- Given the complexity and dynamics of the inner workings of rural families and farms, research must adopt systemic and dynamic approaches. The idea is to economically and econometrically model farmer household practices and performance, their systems of activity, their relation to the natural and institutional environment, their inclusion and anchorage in their communities.
- Research on livelihoods should not neglect concomitant research on the community where agriculture plays a role. Territorial assets and resources, whether social, historical, natural, political, etc., complement household's assets and are necessary for understanding the opportunities and constraints in implementing intensification pathways in food systems.

3.2.5 Gender and youth issues⁸

Gender and more recently youth issues are at the heart of many agricultural development strategies. The question is about individual status and role in family farming (which is the

⁸ This section is partly based on the SOFA report (2011) "Women in agriculture, Closing the gender gap for development", on the proceedings of international encounters Family Farming and Research, especially workshop 3 "In-house issues within family farming", on the HLPE report (2013) "Investing in smallholder agriculture for food security", and on the book: Guétat Bernard H. (ed) (2014), *Féminin/Masculin, genre et agricultures familiales*. Montpellier, Quae, coll. Nature et Société, 247p.

main form of farming in SSA), but also refers to employment in large-scale farming and women and youth access to these jobs. The issue of gender equality is about males and females both having equal opportunities to participate and to contribute to different activities and to decision-making.

Since rural women constitute half of the players in smallholder food production, it is necessary to support them by specific policy and development interventions to realise the potential of African agriculture.

It is widely recognised that women play a key role in agricultural productivity through production and innovation, as stated by the FAO in 2011. However, social norms and unequal social power relations made women agricultural work almost invisible and explain unequal access to and control of productive resources. The idea then is to enhance women access to those resources, which might represent potential intensification factors, in order to increase feminine agricultural productivity. This calls for specific research on women social status in agriculture, on their access to production factors and on their ability to intensify their agricultural activities, whatever the intensification pathway may be.

Reflexion on youth in SSA's agriculture emerged jointly with the demographic and employment challenges, combined with evidence of the weak attraction of farming for younger generations. Today the choice between employment in the farming sector versus the sector of services in towns relates directly to intensification practises, work drudgery, expected income and social status from agriculture. Another question is the attractiveness of agriculture in terms of job ambition, especially for young workers, both in family and in corporates' agriculture.

Further research could be conducted to understand gender tasks' distribution within agricultural households and the gendered repartition of power in order to improve women social and economic status in the family and in the society. Similar questions could be addressed regarding young involvement in agriculture.

- Understand women and young workers' access conditions to productive resources (inputs, technologies, information...). What limits women and young workers' strategies and practices? What strengths and opportunities they take hold of?
- Explore gendered and generational power distribution and identify the right drivers of action to improve women and young workers' access to productive resources. What are the cultural values and power relations that impact women and youth status?
- Measure progress through households' livelihoods changes, produce knowledge and evidence on the compared performances of individuals and family farming. The major strength of family farming is the involvement of the whole family work force in a collective global farm's strategy, the gain for society of an individualistic view of agriculture must be questioned.
- As it is known that extension services have neglected specific needs of women, how gender-sensitive training and extension service provision could look like.

The different pathways identified in PROIntenAfrica reflect different visions and options for African agriculture. Introducing gender issues to think the pathways requires to understand women and young workers' positions in different productive systems.

- What are the roles and positions of individuals in the productive systems? How do their position and empowerment contribute to the performance of agriculture?
- Are there production lines (such as producing fruits and vegetables in the garden) which promotion would be particularly important for women and you workers' empowerment?

A gender question specific for agro ecology and ecological intensification is related to the concept of care. Indeed, women tend to take better stock of the "care" dimension of work.

The concept of care associated with women is an entry point to explore social dimensions of agricultural questions, and in particular human relations to nature and to natural processes in agriculture. The social status of women in charge of care (at the family level), leads to a specific apprehension of the environment and its social and cultural values. The gender division of labour is clearly an expression of these values, but it also could be seen to constrain intensification. Women's sensibility to the care dimension of work can potentially impulse and enhance the development and the adoption of specific agricultural practices, which are not only considered for their productive values but also for their social and environmental roles. Further research reconsidering women's role in agricultural intensification is required.

Finally, gender and youth studies need to explore the options to include women and young workers in the definition of agricultural policies in order to recognize and legitimate their knowledge, skills, practices and expectations. Deepen gender and youth thinking in agricultural research will open the door to reflexions on the social, environmental and cultural values of agricultural production. Collective action and the capacity of women and young workers to express themselves in the arenas where agriculture's future is discussed is key to that end.

- What are the levers of action to promote women and young workers' agricultural practices?
- Consider the social organization/dimension into the pathways and evaluate their potential for changes.

3.3 Food, food systems pathways, and value chains

Integrated analysis is required to simultaneously consider all the dimensions of food security. It means that research should not only focus on production and agricultural practices but consider the whole food system, i.e. all the processes involved in feeding a population, including input needed and output produced at each step. Research questions requiring diverse disciplines have been identified regarding 5 themes relevant for food system analysis: food and nutritional security, food systems dynamics, post-harvest handling, value chains and markets.

3.3.1 Food and nutritional security

Food security *“exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”* (World Food Summit 1996).

Four dimensions can be identified to define the concept of food security (FARA, 2014):

- Physical availability, often linked with the questions of production and productivity
- Access to food, for example market access.
- Better use of food i.e. reducing losses among the production scheme and improved nutritional quality
- Stability of production, access and use over time

Those dimensions mobilize a wide range of interrelated economic, social and political factors. The definition of food security not only refers to the amount of food required to fulfil people's basic needs. It also, and primarily, encompasses the access to - and the effective consumption of - various kinds of food products which cover nutritional requirements of individuals, and which are acceptable in social and cultural terms (“preferences” of the definition).

At the scope of research on food security has long been production and productivity, mainly of cereals. In this Malthusian perspective population growth justified yield increasing policies such as the Green Revolution. However, since production level and food availability is only one of the components of food and nutritional security, other attributes need to be considered to tackle the issues of hunger and malnutrition.

Food and nutrition security requires considering simultaneously food security, health and care. This is why a new definition has been published in 2012 by the World Committee of Food and nutrition Security: *“Food and nutrition security exists when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life.”* (CFS 2012)

The quality of food in terms of sanitary and nutritional characteristics has to be addressed to reach food safety. Intensification strategies need to consider the nutritional value of food as targeted outputs. One of the challenge for future research on intensification and its impact on food security would be to identify nutrition sensitive intensification pathways and evaluate the nutritional value of the food produced by different production systems.

Besides, food security requires to address the efficiency of the food distribution system to tackle the issue of food access at the households' but also individuals' levels. The fact is that even when food is available in sufficient quantities, poor and vulnerable households may be unable to access food sufficiently and adequately has contributed to this change of focus.

At the households' level, poverty and income may have significant impacts on the changes induced by population growth on the demand for food. Since food security is not only an issue of food supplies, it is also necessary to consider changes to improve the efficiency of food distribution systems and market access for rural households and poor urban households. The recent trends in urban areas often showed an excess consumption of calories leading to overweight and other related health problems. Research need to address food and nutritional security beyond agriculture to tackle these issues and explore food practices and human behavior.

It appears now clear that food access and distribution within the households play a key role in food security. For example, women appear to play a key role in the households' food security. Social variables such as time, power and income distribution need to be further explored regarding their impact on food security.

Food and nutrition security is not a question of production systems in terms agricultural practices but requires to adopt wider scale and observe the whole food system: from production to individual's consumption. In order to address food and nutrition security, intensification thoughts require to consider other inputs than production and productivity. Since availability is one aspect of food security it has to be considered but in order to understand food security issues, social, economic and political aspects of food systems need to be considered at different the following scales: society, households, individuals.

In order to address food security, the pathways should be considered as causal systems i.e. regarding their impact on the organization of the food system and on the social organization of the actors at the different levels above.

The pathways tend to insist on different components of food security and build different strategies. The high-input intensification pathway for example insist on the nutritional side on food and nutritional security and consider that genetic improvements will allow nutritional and

productivity improvements in food production. While the agroecology pathway mainly focus on food systems dynamics and the issue of access to food and/or to production resources.

3.3.2 Food systems dynamics⁹

Currently, among the diversity of agri-food systems in SSA, three major types can be identified: mass agro-industrial food systems, subsistence food systems and territorially-based food systems¹⁰. This simplified representation provides a connection to PROIntensAfrica intensification pathways. In SSA, mass agro-industrial systems' main focus is on pathways 1 (high input)¹¹ and 2 (ecological intensification), subsistence systems refer mainly to pathways 3 (agroecology) and 4 (organic) (and to pathway 2 in specific conditions), and territorially-based systems refer mainly to pathways 2, 3 and 4. This rough correspondence can be significantly improved and the research agenda indeed aims at characterising food systems regarding the field and farm structures involved in them, the diversity of products and people, and the agronomic practices concerned. Such a characterisation should benefit from the methodological efforts suggested below.

Currently, among the diversity of agri-food systems in SSA, three major types can be identified: "agro-industrial mass food production systems, subsistence food systems and territorially-based food systems. This simplified representation provides a connection to PROIntensAfrica intensification pathways. Mass agro-industrial systems main focus is on "high input" and ecological intensification, subsistence systems refer mainly to agroecology and organic intensification (and to ecological intensification in specific conditions), and territorially-based systems refer mainly to ecological, agroecology and organic intensification pathways. This rough correspondence can be significantly improved and the research agenda indeed aims at characterising food systems regarding the field and farm structures involved in them, the diversity of products and people, and the agronomic practices concerned. Such a characterisation should benefit from the methodological efforts suggested below.

Beyond this characterisation, performance in terms of economic competitiveness, income, employment, quality, health, wellbeing, social and natural resource management, all through the food system have to be measured more precisely. This means that intensification and its very nature matters both at the farm scale and also for many other stakeholders in many dimensions and functionalities. This also means that the performance of each food system and the performance of possible combinations of food systems of different kinds have to be considered. Special attention should be given to food justice and the right of everyone to food security. Only recently tackled by research programmes and institutions, these social dimensions require specific methodologies, at the crossroads of different disciplines, which has to be improved and more clearly implemented.

In addition, food system governance requires attention. Public and private frameworks govern the production, marketing and distribution of food. This is connected to the question of public policy choices, formulation and evaluation, which has to consider the diversity of farming models and food systems. Research echoes the alternative visions of value chains and their performance, as elaborate below.

⁹ This section is partly based on the proceedings of international encounters Family Farming and Research, especially workshop 6 "Contribution of family farming to food systems".

¹⁰ Territorially-based food systems herald a new form of food production and consumption based on close linkages between: family farms, micro, small- and medium-sized agri-food companies, alternative marketing channels and consumers. They are rooted in territories and thus have a marked impact on local development and employment on account of their social and solidarity-based economic organizational.

¹¹ Commercially oriented organic farms referring to this food system are today very rare in SSA.

At the global level, a research agenda targeting food systems is a way to understand how intensification process are driven by food marketing and consumption, and therefore to give indications for orienting agricultural models and intensification pathways. The drivers are conditioned by innovations and knowledge capacities, but they are also conditioned by education and training. Information and data are needed to document these dynamics and research has to set relevant indicators to establish adapted observatories at the local, national and regional scales. Innovations should also be produced in order to create information and incentive tools for promoting healthier and more eco-friendly products and systems.

At the production level, innovations should target selected products according to their nutritional qualities and sensory properties. The idea is to think of the product as a part of a food system and not just a commodity. The same rationale should be applied to subsequent technology research, which should take into account the whole chain and should guarantee access to them from all intensification pathways. Technology should fit the diversity of production systems and practices.

Research on norms and legal frameworks should also be encouraged. Innovative instruments to enhance quality and safety from a food system perspective have to be promoted. This concerns norms and labels, which have to be evaluated and improved.

3.3.3 Post harvest handling, food processing, safety and storage¹²

Ensuring food security for all, particularly the world's most vulnerable people, means guaranteeing the capacity to produce or buy enough food (access), the capacity to cover food requirements (availability), as well as consistency of supply, and food quality in the broadest sense of the term. Urbanization, changing lifestyles, changing standards and increasing globalization are modifying food systems. Growing instability and vulnerability are prompting a re-think of their sustainability.

Regarding SSA, different issues can be highlighted:

On the one hand, post-harvest losses (i.e. products lost after leaving the field and during transport or storage) in Africa range from 20 to 60%, across countries and for various commodities. Post-harvest processing, handling and storage systems are a consistent way to explore in order to improve agri-food systems functioning and impact food access elsewhere. This issue was a priority in the international research agenda in the 1970s and 1980s, and is now again at the heart of the debates.

On the other hand, the growing urbanization in most SSA countries creates increased need for food in cities, which means that larger quantities of food will have to be moved from rural areas to towns and cities. This requires to improve the existing handling, processing and storage of food systems and reveals a need for science and innovation. Reducing losses amounts require optimizing the different links of the agri-chain, while taking into account the local technical, social, economic, organizational, and political aspects. The idea is to reinforce and encourage interactions between agricultural practices, the efficiency and sustainability of food processes, and the organization of actors and value chains in order to reduce losses and wastage of food.

Addressing these issues can be organized along the following items:

Innovating to support the shift towards sustainable food systems

¹² This section is based on an article by Nadine Zakhia-Rozis et al, “*Un pas vers la sécurité alimentaire*”, in Biénabe E., Rival A., Loeillet D. (éd), *Développement durable et filières tropicales*, éditions QUAE, 2016 (english version in press), available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMV2c>

- Knowing the desirable and undesirable aspects of quality and their variability, from the choice of species, varieties or races, through production methods, to processing techniques which preserve and improve product quality and quantity.
- Analysing pollution chains to quantify fluxes and minimize the risks linked to the presence of biological and chemical contaminants, either emerging or neoformed at any point of the chain.
- Developing low-pollutant-input production and preservation techniques, processing techniques that avoid creating neoformed contaminants, and procedures that guarantee traceability.
- Avoiding wastage, notably of fresh products, by improving their adaptation to market and consumption conditions.
- Minimizing water, energy and waste losses during processing and transport operations, promotion of co-products.

Promoting local food resources within value chains

- Identifying in detail the quality characteristics of raw materials so as to make optimum use of them by combining differentiation and assembly strategies.
- Developing procedures integrating traditional and technological know-how, to ensure a diverse food supply tailored to local resources and habits.
- Boosting the performance and competitiveness of local farming systems (specific quality, origin, environmental and social footprint, etc.).

Supporting the governance of food systems

- Understanding the conditions in which producers access markets and consumers access food, in association with the different ways in which food is distributed.
- Studying the role of short chains in this trend (local production, fair trade, etc).
- Studying the strategies adopted by agro-industry in its relations with family farms.
- Supporting players' moves to boost food security in the face of volatile staple product prices and unequal access to markets: market regulation, building or strengthening niche markets (quality standards, certification, etc), supporting diversification into non-agrifood activities, etc.

Beyond these research issues, improving food storage can prevent much of the loss in quantity and quality of the harvest. Food quality and safety is also strongly related to storage practices. High-quality storage and processing technologies and facilities are also important to improve export capacities and enhance markets opportunities.

Considering national food production systems, it is recommended that food safety should be considered using a food safety management systems approach, for example hazard analysis and critical control point (HACCP) and as part of this, Good Agricultural Practice and Good Manufacturing Practice. It is important to identify the main food safety hazards, where they occur in the food production and marketing chain and their potential risk to consumer health. A multi-disciplinary approach to hazard identification, based on risk assessment, is necessary. This should include collection of data on occurrence of food hazards (for example, pathogens), and the conditions and handling practices that lead to their presence in food systems.

3.3.4 Value chains' organizations and regulations, where goes the value?

Globalization and deregulation of agricultural markets are long and non-linear processes. Indeed, commercial and financial exchanges' extension at global level raises new stakes around diet evolution, nutrition or health, affecting also SSA. But foresights anticipating a wide-open world for commodities are highly questionable today. Diversification and differentiation become keywords to think agriculture value chains today. One must take into account that commodities' markets are not the only way to valorise agricultural productions. Other ways exist for supplying national or international markets despite different productivity

performances: short circuit, certifications, new segments, ecosystems' services and other immaterial cost and profit have potentially new perspectives to rethink value chain's issues.

The sustainable development goals recent adoption insists, in line with the millennium development goals, on the need to introduce social and environmental sustainability in the global reflection on value chains organization and implementation. Value chains are therefore more than just organizations in charge of selling at the higher price possible. Value chains can participate in territorial development and can potentially enhance livelihoods' dynamics. They can spread out in diverse dimensions and directions depending on the products and actors involved, from agro furniture actors to the farmers and to all the wheelworks between them and the last consumers.

Catching value chains' diversity and diversity of pathways requires huge means and research. Most of research needs regarding environmental and social, are already discussed in others sections of the present document. The research agenda proposed here focuses on the value's repartition along the chains and among the actors.

News research questions are emerging and echoing with value chain's traditional research. Regarding cost-benefit analyses, who gains in case of better profitability? How much? What could be the consequences for consumers? What new types of remuneration could be imagined in case of lower profitability? Which organization settle to make these value added visible and to pay for them? Regarding value chains' governance, whose actors and coordination's each PROIntensAfrica pathway enhance and valorise? Agroecology and organic agriculture, at first glance, promote new coordination's all along the value chains, and for the second is mostly driven by downstream factors. Conventional agriculture relays on vertical integration, with most of the time a greater dependence from external trends and services.

What could be the impact on concentration or de-concentration of public policies and of governance structure of the value-chain? Regarding the diversity of intensification pathways and their interrelations, which improvement would be needed in value chains' analyses to catch this complexity?

When taking into account other parameters than value distribution, agroecological practises are they, in the long run, more resilient than conventional intensification pathway facing international market's constraints? If they are less profitable in first steps, value chain has to pay for this sustainability. How to settle organizations (quality, traceability) that can play this role?

3.4 Trade and access to market along the food systems¹³

During the past ten years, "food crises", the effects of market and trade issues on food security and social issues have been discussed widely. Questions regarding market access, prices competitiveness, added value redistribution or prices' volatility remain, but new ones also emerge. For example, the development and implementation of standards as well as other issues to escape from global and concentrated markets' competition are now explored. In return, they question the interest for agricultural intensification and the PROIntensAfrica pathways.

Market access refers to the possibilities to bring goods and services to the markets and to conditions related to potential delivery. Market access can be facilitated or constrained by factors such as financial, physical, climatic and natural conditions affecting the delivery,

¹³ This section is based on an original contribution of Jarkko Niemi, available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

logistics infrastructures, legal and contractual issues, competitiveness of markets and tariff (such as tolls and taxes) and non-tariff (such as quality standards) measures. Market access is relevant at the local, regional and international level. Improved market access is economically important for the suppliers as well as to their customers as it helps to allocate resources efficiently in an economy. In the international context, free trade agreements and standards have been negotiated to clear the rules for how to operate. Although globalisation may result in the smallholder farmers competing with their international peers, it may also help to improve allocation of tasks globally and offers other possibilities for economic activity. Freeing trade is said to benefit the poor especially, because developing countries can ill-afford the large implicit subsidies, often channelled to narrow privileged interests, that trade protection provides. Opposite arguments have also been presented.

Market access can be difficult because of financial or physical constraints and transaction costs that they cause. The costs of production and logistics of small-scale farmers may be so high that they are unable to sell the product at a competitive price or the price they receive may be insufficient to provide them with livelihood. Physical barriers which prevent access to the markets may exist: For instance, transportation of goods to the market may require long travelling with roads of poor conditions. An IFPRI map illustrates that in most parts of SSA, the travel time for farmers to reach a market place (town) with more than 20,000 population is between 2 and 8 hours, or even more. Another example is that the transportation of goods to the market may require costly investments in cold chains (e.g. in the case of meat and dairy products).

It matters how well competition operates. In a competitive market there are large number of buyers and sellers and none of them can control the price level alone. In a competitive market buyers and sellers have good access to information. At the local level, the buyer and seller power, access to information and poor infrastructure and logistics may thus challenge market access. In a broader context, small-scale farmers may face thresholds related to quantity and quality that they must deliver in order to access the markets.

The performance of local markets plays a decisive role in promoting economic growth and reducing poverty in Africa. Improved market access has been shown to increase GDP per worker and it plays an important role in improving food and nutrition security. Ensuring that farmers enjoy access to dynamic markets at all levels will foster investments and boost the livelihoods of the poor. Improvements in infrastructures and market performance are important when providing small-scale farm households with better opportunities to gain income.

An important aspect is farmers' fair access to markets, which includes the process of finding buyers to the products, finding price information and negotiating prices. Because market situation changes constantly, it is particularly important to have up-to-date information on the markets. More efficient market information systems can reduce agricultural marketing margins and price volatility and increase prices that farmers are able to receive upon selling their products. For instance, mobile communication may create opportunities to reduce the cost of linking buyers and sellers, thus developing opportunities to reduce poverty and gain benefits to smallholder farmers.

Market access can be considered to be particularly important for conventional and ecological intensification pathways especially when they focus on mass production, as well as for organic production which attempts to extract a quality price premium from the market. Farmers' capacity to meet various standards and norms is also a market access issue. The standards can deal with hygienic, safety and other quality characteristics or homogeneity of products. Standards are relevant in the local scale, national and international scale. In the national scale, standards are defined to protect people, animals, plants and the environment from adverse effect of products with unacceptable quality. Although standards exist to

improve food security and safety, they are a challenge to producers and countries which are facing hygienic and health challenges.

Non-tariff measures, i.e. technical barriers for trade, are an important constraint for farmers in SSA to access other African countries and especially high-income countries' markets where higher price premiums would be available. In agriculture and food, the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS), which is part of the trade rules of the World Trade Organization, is an important document. It provides countries a right to prohibit the import of agricultural goods from countries or regions which pose a risk for plants, animals or humans in the importing country. This is a challenge to SSA because several highly contagious animal diseases, plant diseases and pests are prevalent in SSA and they may be transmitted to importing countries. SPS issues can be a challenge especially for export-oriented mass-production systems as well as for agro-ecological or organic systems when they rely on extracting price premiums from the markets or when they don't have good means to control diseases or pests. Other hazards that are relevant in this context include for instance toxic or otherwise harmful substances in food, such as mycotoxins or chemical residues. For instance, the IMF has estimated that European food safety regulations save lives in Europe but also cost substantial amount of money for African agriculture which it is unable to trade with Europe due to more stringent regulations.

Price volatility is an important risk in developing countries. Three factors contribute to the strong link between food price volatility and risk for poor African households: the variation in staple food prices tends to be higher in Africa than elsewhere, poor households allocate a large share of their budgets to food, and larger share of population is dependent on agriculture in Africa than elsewhere. There may be a trade-off between lowering the food price and price volatility. The evidence on whether free trade increases price volatility in SSA is somewhat conflicting, as many studies say it does, while others say it doesn't. On one hand, improved market access to and from Africa may make SSA more sensitive to price shocks arising from the rest of the world. On the other hand, it may smooth out the price peaks due to weather shocks in Africa. Hence, international trade could both increase price volatility and stabilize food prices in SSA.

Price volatility is about variation, i.e. it includes both positive (rising prices) and negative (decreasing) price shocks. Rising prices send signals to exporters and provide farmers with incentives to increase production and improve their livelihood. However, importers and consumers face a rise in their food bill and thus economic challenges. In import-dependent countries this may increase malnutrition and poverty. Decreasing prices will have the opposite effects. Risk is a cost. So if price volatility increases substantially, it increases the costs of farmers and thus may reduce their willingness to produce. Since price volatility is relevant for both inputs and outputs, and covariation of input and output prices also matters, the role of price volatility can vary by intensification pathway.

Diseases and pests can be important also because they can add price volatility. In some cases, a large-scale disease or pest outbreak may reduce supply so that prices rise, and in some cases a small-scale outbreak which reduces exports may result in lowering prices.

From the policy point of view, it would be important that different countries have similar standards. This would help international trade as farmers meeting the standards in one country would do the same in another country. It is also important that the procedures ("bureaucracy", → transaction costs) related to initiating trade would be low.

Research is needed on

- Efficiency of market information systems and how to provide the buyers and sellers efficiently market information and what kind of information is needed? How to reduce the transaction costs?

- What are the roles of quality characteristics (including biosecurity) in trade locally and internationally, and how sanitary and phytosanitary risks can be managed to improve market access of farmers in SSA?
- What are the roles of institutions and infrastructures in facilitating access to the markets and how to strengthen the proper functioning of institutions?
- How to control adverse effects of price volatility and variations in supply on food and nutrition security and farmer incomes in SSA?
- How to create incentives for co-operation as asset mobility?

3.5 Agricultural biodiversity, landscape and natural resource management

Understanding and enhancing the role of biodiversity, of genetic resources and of ecosystem functions is essential. Biodiversity underpins to food security, sustainable livelihoods, ecosystem resilience, coping strategies for climate change, adequate nutritional requirements, insurance for the future and the management of biological processes needed for sustainable agricultural production. Natural resource management deals with managing the way in which people and natural landscapes interact. It also brings together land use planning, water management, and the sustainability of activities like agriculture, mining, tourism, fisheries and forestry. It recognises that people and their livelihoods rely on the health and productivity of the landscapes, and their actions as stewards of the land play a critical role in maintaining this health and productivity. This chapter deals with this issues and focuses on tropical production operations (family farming and cash crops) on a plot, farm and small-scale processing firm scale.

3.5.1 Tropical biodiversity research in support of sustainable development¹⁴

It is now recognized that a major crisis is developing in biodiversity on Earth, following different studies and analyses including those carried out by the CBD (*Convention on Biological Diversity*), IUCN (*The World Conservation*), and the fourth Millennium Ecosystems Assessment. Increasing population, over-exploitation of natural resources and un-controlled economic development in a globalising world are key-factors responsible for current global changes.

The consequences of the global warming and its impacts on the societies are priorities on development and political agendas, thanks to the mobilisation and the in-depth scientific, economic and political analysis made by the IPCC (*Intergovernmental Panel on Climate Change*). The major current biodiversity crisis is much more complex to understand and does not benefit from the relatively consensual work from such a panel.

Tropical regions are exceptional in terms of biodiversity with most known hotspots. Tropical regions are still among the richest reservoirs of plants and animals in the world. They have a huge amount of biodiversity carrying a high number of different species and ecosystems.

But their environments are most exposed to the climate change impact, natural hazards (including cyclones, volcanic activity and earthquakes) and pressures of human activities. Most have several factors in common: high population growth rates, high rates of migration, high demands imposed by tourism, increased urbanisation, land use changes, inappropriate or deficient waste management, public health issues, over-exploitation of marine and terrestrial resources. This biodiversity is a fundamental asset for economic development of

¹⁴ This section is based on an article from Philippe Feldmann “*Tropical biodiversity research in support of sustainable development*”, *Journal of Animal Science and Technology*, Special Volume, 3 : 29-91, available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

these regions. The different changes not only affect biodiversity but also have a major impact on the development of local economies as they highly depend on the quality of biodiversity.

Major efforts to reconcile biodiversity conservation and economic development are therefore essential to maintain the future economic viability of these areas.

Understanding these interactions between ecosystem functions and human activities is essential to ensure sustainable development in these areas. It is therefore necessary to assess the dynamics of the biodiversity as it will affect the resilience of ecosystems and the livelihoods (agriculture, forestry, fisheries, tourism) of local populations.

For this we require research on biodiversity in support of sustainable development with co-operation and synergies between teams and through disciplines:

- A better knowledge of biodiversity and of the drivers of its evolution;
- Tools and methods to achieve sustainable biodiversity management (including preservation and rehabilitation; how to maintain the diversity of natural resources? How to manage agrobiodiversity
- To enhance the biodiversity value of human controlled ecosystems.

Results will be for use by researchers, teachers, and stakeholders including decision makers, to ensure the sustainable management of biodiversity in tropical regions.

In order to illustrate topics of research on tropical biodiversity for development, examples of research actions are briefly provided in the following areas from knowledge and characterization to management, from valorisation to preservation and restoration:

Characterizing the state of biodiversity:

- To understand the threats on biodiversity, we have first to be able to describe it through inventories (list of species), to classify it with the help of collections, to characterize it by the mapping of their distribution and to evaluate their status (endemism, frequency, extinction risk by IUCN redlisting,...).
- The development of user-friendly multimedia identification software (IDAO), the analysis of genetic diversity of many crops, plants, or of animal wild and domestic biodiversity in Africa

Understanding the factors of evolution and their impacts is necessary to propose adequate actions to the different stakeholders:

- The first step is to analyse the origin of the biodiversity situation (impact of global changes, bioclimatic constraints and human activities impacts like agriculture and breeding, urbanization and landscape use). The analysis of the situations of conflicts between ecosystems and stakeholders will be most helpful.
- The second step is to foresee evolution with monitoring facilities, foreseeing evolution, by identifying the drivers, resilience, gene flows, invasive species and then to develop modelling of the functioning of these factors of evolution.

It will be therefore possible to propose tools and methods of sustainable management together with the actors:

- By developing sustainable use of biological resources (including development of biotechnologies), economic outputs like ecotourism
- and eventually developing research for integrating biodiversity into actors 'strategies (in their development and policy schemes, by implementing the Convention on Biological Diversity, ...)
- To ensure a sustainable use of the resources in a growing world, a new challenge after the green revolution is in the ecological intensification of the agriculture.

Preserving and restoring biodiversity:

- The research on conservation biology must be developed: population dynamics and genetics, conservatories: in situ in protected areas and ex situ by the development of collections centers

(samples, Biological Resources Centers) and methodological tools that will help to define the necessary priorities and for assessment of practices impacts.

The development of research and tropical biodiversity has to be motivated by the sustainable development of the living populations. The efforts will be considerable and, to avoid being submerged by the needs, would benefit to be co-ordinated by the mobilisation of all the competences through networking throughout the tropics.

3.5.2 Landscape issues¹⁵

Landscape management in Africa

Landscapes are important research objects because they carry a function, i.e., they convey a meaning of cause-effect relationship on the land. This relationship can take many different forms, like a land transformation due to a given practice (e.g., farming) or changes in vegetation because of a natural phenomenon (e.g., ecological succession). A main criterion is often the fact that the resulting 'land area' is not uniform.

Thinking at the landscape scale means thinking in terms of heterogeneity of land characteristics. This is the very essence of landscape ecology, which is *de facto* the ecology of land heterogeneity and has strongly contributed to the emergence of landscape approaches in land-use related sciences. Structural heterogeneity feature of landscapes has two major consequences. The first one is that 'areas of land' considered under the landscape approach are composite, i.e., they are made of identifiable, different units (or 'patches') which often exist within a 'matrix'. The second consequence of the heterogeneity feature of landscapes lies in the nurturing of biodiversity. Structural diversity, equals more habitats for flora and fauna and higher resilience of the area to external perturbations, including climate change.

The list of different land-use units which can support biodiversity and agrobiodiversity in a heterogeneous landscape is virtually endless, e.g., fields, forests, woodlots, tree plantations, fallows, field borders, riparian areas, shelterbelts, grazing land, wetlands, rivers, ponds, reservoirs, constructions, dwellings and associated land, gardens, heritage sites, protected areas, natural (non-protected) areas, etc. Structural heterogeneity can also be managed following a temporal approach, with different crops in different years or seasons, fallows, relay planting, rotational harvesting in forests, etc. This heterogeneity feature of landscapes may also leads to unexpected additional benefits, as for example improved livelihoods through a diversity of commodities and farm enterprises, or new development outcomes boosted by collective, landscape-level action and governance.

Landscape interactions

For a heterogeneous landscape to function, linkages and interactions should exist between landscape components, leading to functional heterogeneity. These interactions are absolutely necessary for a landscape approach. Without them, landscapes are simple made of contiguous, independent areas, or large areas as opposed to small areas. These linkages and interactions have been widely studied by landscape ecologists through a series of landscape units' categories. Common parameters used by landscape ecologists are spatial diversity (different units), heterogeneity and mosaic (organization of spatial units), complexity

¹⁵ This section is based on an article from Emmanuel Torquebiau, "Whither landscapes? Compiling requirements of the landscape approach", in Minang P.A., van Noordwijk M., Freeman O.E., Mbow C., de Leeuw J. & Catacutan D. (eds), (2015) *Climate-Smart Landscapes: Multifunctionality in Practice*. Nairobi, Kenya, World Agroforestry Centre (ICRAF), the full version of which is also available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMyV2c>

(number and type of interactions between spatial units) and connectivity (relations between units). This linkage of pattern, process and scale has become an important approach for plant ecology, used, for example, to analyze the functioning of tropical rainforests in terms of ecological units' dynamics and widely cited in plant ecology as the 'ecology of natural disturbance'. The same approach has been used to show that heterogeneity in savanna vegetation varies depending on the scale considered: at the microscale, plant-plant interactions are the main factor; at the local scale, disturbance-related plant recruitment mechanisms are important; and at larger scales, a shifting mosaic of patches undergoing asynchronous transitions between e.g. grassland, wooded and intermediate phases appear relevant. Taking into account this spatial-temporal patterning of patches is essential to design landscapes which mimic 'natural' ecosystems. Although people do not make a landscape to mimic a natural one, similarity with natural processes at the landscape scale are known to lead to improved sustainability and resilience. The analysis of patch interactions, including human influence, helps understanding whether adjacent land-use units share resources or rather compete for the same resources; whether a given unit can experience changes and transform into another unit; and whether what is happening in one unit has positive or negative consequences in another one. The study of these interactions can help decision-making in identifying how to best combine different units and where to locate them in a production-oriented landscape. Typical positive interaction examples include tree-planted units harboring bees next to annual crops which need to be pollinated, fields of pest-resistant varieties scattered within non-resistant varieties to decrease pest spreading, a wildlife corridor (or 'stepping stones') linking isolated habitat patches across a cultivated zone or the push-pull agricultural pest management where companion plants are used with crops to repel and attract pests hence reducing reliance on insecticides.

Negative interaction examples comprise cases such as erosion-prone tree plantation (e.g., teak) on top of a slope, the fragmentation of a wildlife area to a level where useful auxiliary fauna cannot successfully breed, or genetically modified crops planted nearby conventional crops (or wild relatives of the same species) so that crossbreeding occurs. Competition can also occur when plants or animals from neighbouring units share the same resources, e.g., tree roots from a woodlot invading a field. Such negative interactions also happen in natural environments, but may become problematic when they affect yields of cultivated species. The objective of the landscape approach should be to maximize positive interactions and minimize negative ones through the best possible arrangement of patches. It is also important that some form of integration (i.e., positive interactions) exists between components. For example, isolated fragments of natural vegetation surrounded by industrial farms may not lead to efficient biodiversity conservation. An essential component fostering patch interaction is made of all the ecological infrastructures which maintain a 'network' in-between patches, such as hedges, drainage ditches, windbreaks, live fences, paths and roads, streams and rivers (and associated riparian 'forest'), isolated rocks, varied tree and shrub lines, grass strips, dikes, rock alignments, terraces and all sort of irregular topographies. Combined with the patches identified earlier, they contribute to resource flows and make the landscape mosaic an incredibly rich patchwork of habitats and microclimatic conditions, essential at all scales. To 'kill' landscape heterogeneity, the fastest route is probably to use a big tractor to do away with these topographies and level the land before planting, a method often observed in industrial agriculture.

Landscapes, agrarian structures and intensification pathways

Structural and functional landscape heterogeneity can hardly be a feature of industrial agriculture based on economies of scale and of large, uniform fields managed with big machinery and limited labour. It is mostly a feature of small-scale family farming as it exists in SSAs. Exceptions exist on both sides but do not refute this rule: the landscape approach is barely applicable in the context of high input, mechanized agriculture and rather finds its usefulness for low-input, high-labour agriculture.

However, there is also a trend towards farmers adopting practices that involve less labour in order to allow household members to engage in more diverse activity and livelihoods. What matters is the fact that the landscape approach is relevant for all the intensification pathways (taking into account positive or negative interactions), but is fundamentally an ecological approach. It provides a contribution to the agricultural sustainability and agroecology debates, not to mainstream agriculture.

Typically, today's hybrid solutions of agriculture (e.g., trees on farms, cover crops, domesticated forests, multilayer agriculture, mixed cropping, permaculture, organic farming) easily find their niche in a heterogeneous landscape while high input monocultures do not. However, multifunctional landscapes should not be seen as an unambitious option: highly productive landscape mosaics must meet human food needs.

Landscape and crop pest management, pollination or biodiversity conservation

Among all the research items that may be addressed on landscape issues, we prioritize here those related with crop pest management, as they already have been widely explored at landscape level worldwide, and could find applications in Africa in relatively short term.

The landscape explored by flying insects, as for example migratory locusts, is larger than humans' landscape definition. Flying insects (crop pests and their natural enemies) do not have *a priori* field physical frontiers. Natural biological regulation of the crop pests, and plant pollination constitute two kinds of useful interactions. Crop, but also non-crop habitats provide resources for the arthropods (refuges in edges around fields, grass strips, hedges, food sources, alternate hosts, etc.).

At this stage, some knowledge gaps and realistic research perspectives can be discussed; despite the interest for landscape issues, very few studies have been conducted in Africa considering this innovative approach, in comparison with other tropical regions and above all temperate countries. A frontier still exists between ecology and agronomy disciplines, with focus on pollination and conservation of global biodiversity in the former case, and observation of pest abundance and natural regulation in the latter.

To develop research on applied landscape ecology, there is a need to come back to basic knowledge by:

- Identifying pests, their natural enemies (predators, parasitoids and pathogens), their host-plants, particularly in the semi-natural habitats;
- Measuring the efficiency of the biological control by itself (very small egg parasitoid species), and the ways to maintain or reinforce this natural control.

A spatial approach at the landscape scale appears particularly essential in e.g. the following cases:

- To manage resistance to toxins expressed in GM crops (if their use is made in the high input pathway) and new pest resurgence as mirids bugs on GM cotton (USA, China, India);
- To explore a new potential tool in the organic farming pathway.
- To explore the potential of landscapes in boosting natural enemies of pests

Constraints and difficulties can be encountered to implement pest studies relating to the landscape approach, beginning by funding. This strategy needs to mobilize several scientific disciplines, each one with its own investigation methods. Others constraints include the participation of the local communities, growers as well as all kind of stakeholders. Such pest management strategies require a co-construction with all the stakeholders. The effectiveness of pest management with the area-wide IPM strategy has been proved with biological tropical models but it still has to be developed in Africa.

Lastly, and independently of the pathways, the case of the alien invasive pests must be considered at larger spatial scales (a regional approach) which exceed the landscape.

A landscape approach to understand the introduction of new pests (some of them being potentially resistant to insecticides or Bt toxins) appears unavoidable on the African continent because of the increasing world exchanges of goods and passengers. Efficient methods to monitor survey and for the early detection of emerging pests for regulation are needed at a regional scale. This requires the development of knowledge management activities, big data, epidemiologic modelling, alert information and good communication between countries.

3.5.3 Soils and nutrient cycling in different pathways of agricultural intensification¹⁶

Soil is a complex system built on a mineral matrix which contains water, organic matter and nutrients more or less linked to the solid matrix, and which provide a habitat for diverse microbial and faunal organisms and below-ground parts of plants. None of these components are static and they are subject to multiple physical and biochemical interactions, which determine, at any time, their quantity and/or quality. Soil is not a passive substrate but is continuously dynamic under the pressure of its external environment and/or anthropic activities. All these internal and external interactions actually determine the soil fertility i.e. its ability to support and sustain plant growth, but also to deliver soil ecosystems services. Changes in climate and human activities have led to a strong degradation of soil fertility.

Promoting good soil management practices, and passing on to the next generations soil as fertile as it was when inherited, is a responsibility that must be borne not just by farmers but also communities, governments and all kind of agricultural enterprises. Therefore, research must provide generic knowledge in many fields.

Main research issues, common to all the intensification pathways in SSA:

- Better understanding of soil functioning under more complex agricultural practices to assess the best trade-offs between soil ecosystem services
- Taking into account soil diversity and heterogeneity in order to adjust fertiliser applications and other soil tillage practices for recommendations by extension services
- Developing knowledge on the effect of the use of urban waste (solid or liquid) when applied directly without pre-treatment (which is an illegal but common practice)
- Developing models where biological life in soil and interaction with all soil components are really represented as the motor of soil functioning
- Improving knowledge on the P dynamic in soil to enhance its use efficiency by plants and the below-ground interactions of different biological components (microorganisms, roots, soil fauna etc.)
- Associating soil models in integrated or systemic models (crop plant model, farming system model, etc.)
- Conducting a systemic approach (soil plant, field, farm, village, landscape) to understand the response to changing circumstances in any of the individual elements on the other parts.
- Highlighting local knowledge on soil and set up an integrated, systems-oriented, transdisciplinary approach.

In addition, the PROIntensAfrica initiative has shown that there are very contrasting intensification pathways in Africa. It is clear that these different options do not equally

¹⁶ This section is based on an original contribution of Dominique Masse, IRD, “*Soils and Intensification Pathways*”, available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

mobilise 'soil' capital, and that although all the research questions mentioned above are essential, each pathway generates specific questions, which are tentatively detailed below

In the **'High input pathway'** the questions mainly concern the impact of agricultural practices on soil quality and the efficiency of mineral input use, following the idea of reducing the use of chemical fertilizers. It mainly concerns agro-industrial systems, as well as peri-urban horticulture which generally uses large amounts of fertilisers and pesticides. The fate of exogenous molecules or pollutants in the soil and the environment is hard to measure in the various tropical conditions. In some intensive irrigated land, bad agricultural practices, such as deficient drainage, lead to salinization of soil participating to the increase in the area of degraded and later uncultivated land. Soil salinization processes and means to control them are a priority for some countries, specifically those in river basins and deltas. Consequently, a main issue is to research the means for remediating the degradation of soil quality in high input agricultural systems.

The **'Ecological intensification pathway'** recommends a rational use of biotechnology (including GMOs), external inputs, irrigation and mechanisation if these options are economically and socially sustainable. In this pathway, the objective is to better understand soil functioning under complex agricultural practices such as mechanised conservation agriculture that combines diverse techniques including no/reduced tillage, new crop rotations, intercropping, alley cropping etc. Soil models have to resolve the necessary trade-offs in ecosystem services: primary production, mitigation of GHG, biodiversity conservation etc.

Applications of chemical fertilisers seek to replenish stocks of nutrients and organic matter. However, the diversity and heterogeneity of soils should be better taken into account. Considering the variability (soil origin, past cropping systems etc.) is necessary for precision agriculture. Questions concerning phosphorus (P) are also imperative as mining reserves of P drastically decrease. It is necessary to improve knowledge on the P dynamic in soil to enhance its efficiency, as tropical soils have a high P-fixing/blocking capacity. There is then a need for alternative strategies to improve P nutrition of crops, and microorganisms and biological activity in general have to be mobilised.

Measuring and predicting the consequences of increasing legumes in cropping systems, rotations and intercropping systems is important. For the latter, little is known on the below-ground interaction between a legume plant and other plants such as cereals.

Finally, soils are not homogeneous at all scales (watershed, landscape, village and farm). Strong and multiple interactions require a systemic approach to understand the system's response to any changes in individual elements. One action on a specific field can have an impact on another field of the farm, of the agro-system or of the landscape. Animal movements also generate the transfer of faeces and organic matter resources for soil. To simultaneously address these issues, a holistic approach is needed, at field, farm and landscape scales.

The **'Agro-ecology pathway'** is based on the intensification of ecological processes. Concerning soil, research should focus on ecological functioning and biological interactions, and how to enhance soil ecosystem services through ecological processes. The challenge is to develop models where biological life in soil and interactions among all soil components are represented as the motor of soil functioning. Another challenge is to associate other components of agricultural ecosystems: field plants, farm/village organisation and landscape structure. More interactions between models developed at different scales are required.

Agro-ecological practices mostly target family farms and explore local dimensions of agricultural activities. Looping nutrients cycles at the farm, village or small regional scale is an objective to drastically reduce farmers' dependence on external inputs. Recycling of

organic resources is a major issue, and its optimisation requires a good knowledge of the resources available around a farm to adapt their uses in the cropping system. This is particularly important in peri-urban farming systems as they can access more diverse organic inputs.

Another question is how to capitalise on local knowledge. Farmers have strong knowledge of their soils. For instance, while farmers perceive that their soil is degraded, soil analyses may show very little change. Soils scientists have to consider the knowledge that could help to formulate hypotheses on soil functioning. Another challenge will be to set up an integrated, systems-oriented, transdisciplinary approach. This co-construction is essential if more sustainable pathways to soil health are to be created.

Little data are reported in scientific databases concerning soils in SSA for the **‘Organic agriculture’ pathway**. However, the general problematics are very close to those of the agro-ecology pathway with specific issues concerning bio-fertilisers and bio-pesticides. Some questions could also concern excessive use of organic fertilisers more specifically when organic agriculture is adopted by small farms with an intense use of land.

In conclusion, it appears that coordinated and long-term observatories on the consequences of contrasted intensification pathways should be promoted.

- Soil surveys have to be done on a large sample of farms on principal soils and major eco-regions to evaluate the effects of different farming systems on soil quality.
- Future analyses must focus at the farm and farming system scale, and have to be implemented together with other disciplines, to address simultaneously climate, water, plant, human and social sciences.

3.6 Multicriteria Sustainable productivity in major farming systems and farm types

SSA countries have not really benefited from the ‘Green revolution’ (GR) launched in the 60s. This failure is usually justified by diverse constraints that limit the agricultural productivity of smallholder farmers:

- At the field scale: small sized plots, temporal and spatial multispecificities, poor soil quality and unreliable rainfall.
- At the farm scale: small farm size, limited capital for investing in technologies such as inorganic inputs, irrigation, improved varieties, labour, mechanisation, limited capital to engage in diversification in processing, limited vision of farm participation in food businesses.
- At broader scales: inequitable land distribution patterns, poor road and transportation systems, absence of mechanisation chains and retailers, inefficient public and private goods markets (including storage, processing and norms shaping value chains) or lack of access to regional or international markets, lack of credit, unstable political systems associated with poor security (including terrorism), under-investment by national governments and other institutions in specific adapted and ambitious public policies based on strategic capacity building, weakness of agriculture and food business support services etc.

Technological development strategies cannot be ‘top-down’ as they were in the past and should be based on research conducted in a systems approach which is locally grounded. Since the diversity of situations and systems is very high, general recipes are expected to again be unsuccessful. Conceptual barriers are actually more prominent at large scales (mainly political and structural at the national or trans-national levels). At the field and farm scale, research and development stakeholders still need to convince some of their interlocutors that high-input, mixed and low-input systems can operate together and that the choice of different pathways for improving agricultural production is ultimately in the hands of the farmer. We also have to accept that intensification cannot result only in a technical

transition; it needs natural resource management, stable and regulated markets, to be embedded in social structures, and major public policies.

This sub-section aims at scanning a wide spectrum of classical technological, or cropping system, research themes (and sometimes topics). As far as it makes sense, the chapters are conceived with the concern of highlighting how diversified intensification options or pathways may generate diversified research and innovation topics. They are generally built on the same framework: (i) general considerations, and (ii) specific research questions.

3.6.1 Upstream issues: rethinking seeds, fertilizers and pest management governance

To be developed: This item aims to catch the implications of global transitions on inputs' selection, production, utilization, markets' organization and accessibility regarding each PROIntensAfrica pathway. Research should document the role of innovations in agricultural inputs design and their diffusion for managing the transitions. (Ecologic, climatic and energetic transitions)

3.6.2 Mechanization ¹⁷

In SSA, family farming accounts for more than 75% of farms and for the major part of the incomes of the rural population. Agricultural energy is supplied by man (65%), animal (25%), and engines (10%). The historical use of animal traction in Ethiopia was introduced to other SSA countries only in the twentieth century. Motorised equipment carried on the back of man (sprayers) and used at fixed stations (hullers, threshers, motor pumps etc.) diffused significantly with the development of autonomous, compact and light units, which are easy to move. In 1961, the number of tractors in service in SSA (172,000) exceeded that of Asia and the Near East. In 2000, the opposite was true; India, the Republic of China and Brazil had respectively 6.9, 4.4 and 3.7 times more tractors in service than all of SSA. Indeed, 70% of SSA tractors are in South Africa and Nigeria. In SSA, 80% of the land preparation work is carried out using human energy, 15% by draft animal and 5% by tractor, while in Asia 60% is conducted by tractor. However, the agricultural machinery crisis in industrialised countries in the 1980s resulted in a restructuring of agricultural equipment manufacturing, a lack of interest in SSA by these manufacturers, but also in the reduction or even elimination of research, development and training programmes on agricultural machinery in industrialised countries.

- In irrigated rice farming, animal traction, tillers and tractors are commonly used
- In rainfed areas (cereals, cotton, legumes etc.), mechanisation (animal traction, motorisation) mainly concerns soil preparation and transport
- In perennial crop-based agricultural systems (cocoa, coffee, oil palm, roots and tubers etc.), mechanisation mainly concerns plantation maintenance, transport and processing
- Mechanised agro-industrial farming exists in many countries (sugar cane, plantain etc.).

The current process of mechanisation of family farms is constrained by an unfavourable socio-economic environment characterised by low investment in the sector (policies, equipment, training, facilities and infrastructure etc.), as the low purchasing capacity of many farmers makes it difficult for them to access equipment, spare parts etc. In addition, funding difficulties, combined with the low prices of agricultural products compared to the high costs of agricultural equipment, is also a constraint. This process is also held back by the lack of technical know-how and skills among stakeholders (technicians, qualified executives, tractor

¹⁷ This section is based on an original contribution of Michel Havard, "Mechanization" available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvY2c>

operators, mechanics, blacksmiths etc.), and the lack of agricultural equipment adapted to the main agricultural operations in specific contexts.

The process of mechanization of family farms will therefore require significant and long-term human, material and financial investment, and will have to rely more on the private sector and producer organisations (POs)

In SSA, agricultural mechanisation is now experiencing renewed interest. Many governments have prioritised the supply of motorised agricultural equipment (farmers' acquisitions, subsidies, installation of tractor assembly plants) and the setting up of service centres for motorised services. However, in many countries, the requirement for animal traction equipment is far from being fulfilled, and animal traction faces new questions linked to the shift from labour bottlenecks to operations that are difficult to mechanise, such as harvesting and weeding. Government supply of motorised equipment has often been reduced, concentrated and does not respond to the diversity of situations, because it is not based on an in-depth analysis aimed at identifying, characterising and building a demand adapted to the needs of the actors involved.

The development of motorisation has also been conducted by the private sector with firms often linked to China or India, but also to Europe and even Latin America (Brazil). Moreover, these voluntarism approaches repeat the mistakes of the past by not seeking to identify the need for mechanisation in a context where the issue of agricultural employment issue remains essential, to improve the training of farmers to steer mechanisation within the framework of a sustainable agriculture approach, to support land use planning in order to counteract the negative effects of mechanisation, to reinforce the supply of services which must accompany motorisation, such as financing etc.

The development of mechanisation also presents risks, which makes it necessary to quantify and document through research the relations between causes and effects. Namely:

- The increase in inequalities between farm types: small and medium-sized farms having greater difficulties in equipping themselves than large farms
- Increased degradation of soil fertility if precautionary measures are not implemented in parallel
- The reluctance of financial institutions to support investment in agricultural equipment
- Rapid changes in the socio-economic context; in particular the rising cost of fossil fuels. The price of a barrel of oil has increased by 487% since 1990, a trend which seems very high. Access and fuel costs are now major constraints to the mechanisation of family farming.

Proposals for studies and research on agricultural mechanisation

The major challenge for SSA in the coming decades is to equip the sector so it can satisfy the growing demand for the production, conservation and processing of agricultural products. FAO's ecosystem paradigm for agricultural and food systems, *"Produce more with less"*, proposes a vision of the sustainable intensification of highly productive and environmentally friendly crop production.

Agricultural mechanisation in the 21st century must simultaneously be environmentally friendly, economically viable, affordable, adapted to local conditions and, in the light of current meteorological changes, intelligent regarding climate change. The range of mechanisation options available is expanding. Asian technologies are available in SSA, often at low cost (Chinese and Indian materials) and several SSA countries have installed tractor assembly plants.

The mechanisation of agriculture in the past was accompanied by industrial revolution. Therefore, the problem of labour force that was no longer needed in agriculture due to mechanization was resolved by employing them in new manufacturing industries which were

established around the same time. Similar pattern may no longer be relevant. Therefore, the issue of mechanization should be examined in a broader context.

Research to be carried out on agricultural mechanisation should aim to:

Build an appropriate socio-economic environment and accompanying measures for the agricultural mechanisation process. This must be implemented in close cooperation between governments, POs, private sector, research and training structures and support structures to correspond as closely as possible to the needs (demands) of family farmers.

The research actions to be implemented are:

- Assessing the impact of technical conditions and the socio-economic and political environment on the development and performance of agricultural mechanisation.
- Assessment of the impact of motorisation on the economy; In particular the issue of employment could be addressed in the context of a structural surplus of labour and current under-employment of young people.

Research and innovation on the conditions of agricultural mechanisation and mechanisation services

The supply of agricultural equipment is presently conducted through local manufacturing (animal traction equipment, carts), by importing Indian, Chinese and Brazilian materials mainly for motorised equipment, and by some local tractor assembly factories. In addition to this supply of motorised equipment, other needs for agricultural mechanisation may emerge.

The research actions to be implemented are:

- Analysis of the manufacturing, repair and maintenance of agricultural equipment and proposals for a diversified offer adapted to the diversity of situations and affordable for the majority of farmers.
- Analysis of the conditions and factors stimulating the development of innovative agricultural service offers (individual ownership, collective ownership, equipment management methods, provision of services, private sector interventions, the role of the State, economic and policy instruments, facilities etc.).

Production of methods, knowledge and equipment

Environmental issues require a search for new cultivation techniques. The agricultural practices necessary to implement the first three principles of the FAO's *"Produce more with less"* ecosystem paradigm differ according to local conditions and needs, but in all cases are based on the following concepts: i) limitation of soil erosion by minimising mechanical ploughing in order to maintain organic matter, structure and health; (ii) improvement and maintenance of an organic cover composed of crops; (iii) increased numbers of different species, annual or perennial, including trees, shrubs and pastures.

The rapid development of ICTs and robotics in agriculture offers new opportunities in support of agricultural mechanisation in Africa, such as: (i) facilitating farmers' access to information on the prices of agricultural equipment and products for sale; (ii) tools to support the use and management of agricultural equipment; (iii) the use of drones, robots etc.; (iv) the production of references on the use, management and performance of mechanised systems in different contexts.

Research actions to be implemented:

Methodological issues

- Design of multicriteria methods and tools for measuring the efficiency of agricultural equipment

- Production of references on the use, management and performance of mechanised systems in different contexts, taking into account the technical, economic, social and environmental aspects
- Development of approaches and modalities of use of agricultural equipment according to the local 'agro-climatological' conditions, including the consequences of climate change.

These various points are of direct interest to agricultural equipment management support.

Technical aspects of animal traction:

- Quality of the cropping operations by better use in the field of couplings (material and animals)
- Diversification of techniques, including dry tooth work, mono-beef, harnessed sowing

Agricultural equipment:

- Designing more energy-efficient equipment, using solar energy especially for conservation, drying, pumping, product processing etc.
- Designing appropriate equipment for direct sowing and minimum tillage
- Using inexpensive precision agricultural equipment to take advantage of information and communication technology applications
- Identification, development and adaptation of technical pathways and agricultural equipment to meet the needs of farmers, taking into account the farm's sustainability regarding soil protection and fertility; conservation agriculture, land management (anti-erosion measures, hedges, trees, land resettlement); use of agricultural equipment while protecting land

3.6.3 Yield gap¹⁸

Understanding the gaps between potential and actual farm yields can inspire and guide interventions with farmers, their organisations, input suppliers and public policies. Yield gaps are defined as the differences between potential yields levels under irrigated or rainfed conditions and farmers' actual yields. Precise spatially explicit knowledge about these yield gaps is essential to guide the sustainable intensification of agriculture. We recommend key components for a yield gap assessment that can be applied from local to global scales. As data are missing in many regions, a tiered approach can be adopted, with a preferential use of crop growth simulation models applied to relatively homogenous climate zones for which measured weather data are available. There is a need for accurate agronomic and current yield data together with calibrated and validated crop models and upscaling methods.

Given the need for sustainable intensification, understanding yield gaps is essential. First, yield gap analysis provides the foundation for identifying the most important crop, soil and management factors limiting current farm yields and improved practices to close the gap. Second, to enable the effective prioritisation of research, development and interventions. Third, to evaluate the impact of climate change and other future scenarios that influence land and natural resource use. And fourth, results from such an analysis are key inputs to economic models that assess food security and land use at different scales. The agronomic basis of such projections and associated resource requirements can be improved through rigorous yield gap analyses. Indeed, to provide an explicit contrast between intensification pathways, it is necessary to quantify the links between inputs (availability and use), impact on yield, and other services provided.

¹⁸ This section is based on the following article van Ittersum, M. K., Cassman, K. G., Grassini, P., Wolf, J., Tittonell, P., & Hochman, Z. (2013). "Yield gap analysis with local to global relevance—a review". *Field Crops Research*, 143, 4-17, available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1epNFec2UGJoRHMvY2c>

To reach these ambitious objectives, crop simulation models can be used to estimate actual or potential yields. These simulation models are representations of our current understanding of bio-physical crop processes (phenology, carbon assimilation and assimilate partitioning) and of crop responses to environmental factors. Such models have generally been designed to account for the interactions between varieties, the environment and crop management. They require site-specific inputs, such as daily weather data, crop management practices (sowing date, cultivar maturity and plant density), soil properties and specification of the initial conditions at sowing, such as soil water availability, and a model configuration that ensures nutrients are not a limiting factor. Although the specification of weather, soil and management practices in current cropping systems is essential for robust simulations, these data are typically not available for most cropping systems with adequate geospatial details. Besides, models need to be rigorously evaluated for their ability to reproduce measured yields of field crops that received near-optimal management practices, across a wide range of environments and management practices.

Crop simulation modelling is the most robust and often reliable way to estimate the gaps, to capture variability (in e.g. climate, soils and cropping systems), overcoming an 'average' approach and able to deliver probabilistic outputs. So, measures of spatial and temporal variability must also be considered because both the mean and the variability are critical for understanding the opportunities to exploit yield gaps.

A publicly available website with yield gap assessments exists (www.yieldgap.org) could be considered, following a global protocol and making all underpinning data available to users. Likewise, all simulation models are or will be available to the public. Adopting standards will provide transparency, reproducibility and accessibility, and will allow for the continual improvement of the analyses. As has been argued before, open access to underlying data will greatly contribute to efficiency in agricultural research and it seems timely to join forces with several large international initiatives.

Climate constraints often lead to limited expected yields. But soil fertility (linked with nutrient availability) and crop management are the major biophysical limitations to agricultural production across Africa. Assessing this issue with the aim of comparing options, between organic agriculture and high-input options, requires accurate tools and an improvement in research on all the components which support the process.

Besides crop production, the concept of yield gap is relevant also for animal production. Similar research is needed there to unlock potential yield gaps due to factors such as poor genetics, herd management, animal nutrition and health.

3.6.4 Crop protection¹⁹

Throughout proto-history and history, African farmers like those of other continents, have been faced to damage and losses inflicted to their crops by pests, diseases and weeds, which are particularly exacerbated under tropical climates.

This trend was particularly observed in northern countries, but it was also followed in developing countries, where it found its identity in the concept of Green Revolution, which advocated for massive use of mostly external and un-renewable inputs (mineral fertilizers, chemical pesticides, fossil fuels), along with improved crop cultivars and irrigation water. However, while "Green Revolutions" transformed the rural economies of many Asian and

¹⁹ This section is based on an original contribution of Alain Ratnadass, "*Crop protection in agricultural intensification pathways for Sub-Saharan Africa*" available on the D2.4 platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMyV2c>

Latin American countries during 1960–90, the transfer of the same strategies to Sub-Saharan Africa did not have been effective.

Sustainable agriculture started about 50 years ago, mainly with a view to counteract pesticide misuse and abuse, namely a “crop protection” issue. Integrated pest management (IPM) was probably the first among the several concepts that have emerged during the second half of the last century as pathways toward sustainable agriculture, based on the perceived need to break away from the dominant paradigm that gave rise to an intensive type of agriculture associated with artificial conditions, biodiversity reduction and reliance on non-renewable and toxic inputs. However, in sub-Saharan Africa, where family farming is dominant, pesticides are barely used on staple food crops, with the notable exception of cowpea and irrigated rice, being rather reserved for high value cash crops, particularly cotton.

Among the major claimed pathways to sustainable agriculture, as alternatives to high-input intensification, organic farming, agroecology and ecological intensification have well-developed crop protection dimensions. They share several management options, including the use of chemical pesticides, with the notable exception of organic agriculture, and genetically modified plants (except for organic agriculture for both options, and both agroecology and organic agriculture for the latter). Integrated Pest Management cuts across all four pathways.

Scientific priorities and future generic research needs to contribute to sustainable intensification for crop protection

In terms of crop protection, the challenge of food security is that of reduction of losses inflicted to crops by weeds, pests and pathogens. That of urbanization is the development of peri-urban agriculture, particularly for high-value perishable vegetables, with high pressure on land and massive use of inputs, translating into increased pest resistance to insecticides, pollution of the environment and human intoxication.

The main challenge of the globalization of exchanges is the increased risk of introduction of invasive pest and pathogen species, which affect transboundary exchanges (e.g. fruit flies, the tomato leaf miner, banana Fusarium wilt, maize lethal necrotic disease), and also, as quarantine pests, exports to Europe. This is therefore a challenge for sub-Saharan producers to prevent / anticipate the introduction / establishment of exotic pests that have become potentially invasive due to climate change, by better management of the same in the areas of production of export crops.

Regarding climate change, with a “climate smart agriculture” (CSA) perspective, the major crop protection issues facing sub-Saharan producers are:

- To locally manage plant health risks sustained, which are exacerbated by climate change, in view of adapting cropping systems to its effects;
- To adapt crop protection practices in order to mitigate climate change at the global scale, beyond the contribution to mitigation via the mere reduction of losses to pests that results in reducing useless investment in inputs with high carbon footprints.

In any case, the main scientific challenges to sustainable intensification for crop protection in SSA are to learn how best to apply fundamental ecological knowledge to crop protection at the field, farm, and landscape scales, and to involve from the beginning of the innovation process, all concerned actors at the farm and territory levels, and ensure public support at the national and international levels

At the plant and field levels, we highlight the need of having scientific and farmer input into technologies and practices that combine crops–animals with appropriate agro-ecological and

agronomic management. These lines are actually followed in the development of both the push-pull and the eco-friendly net technologies.

At the farm and local landscape/territory levels, a key research issue is the development of spatio-temporal models (scenario testing at regional scales). Controversies embodied in the debates on land-sparing versus land-sharing (or biodiversity “**melting pots**” vs “**hot spots**”) also refer to the increasing consideration of landscape ecology for crop protection goals within the ecological intensification framework.

At the national, regional and international levels, since rural populations will continue to grow, to be socially sustainable, the pathway should be labour-, rather than capital-intensive. By being also knowledge-intensive (a characteristic of agroecology), and putting forward the provision of ecosystem services, it may also be attractive for the young to remain in rural areas and work in agricultural production.

Specificities regarding the 4 main intensification pathways

The **high input pathway** refers to an intensive type of agriculture which successfully increased crop yields (thus warranting economic and to some extent social sustainability), but is associated with artificial conditions, biodiversity reduction and reliance on non-renewable and toxic inputs (thus falling short of warranting environmental sustainability). This has been the dominant paradigm in northern countries; in sub-Saharan Africa, it applies to industrial farms, notably those growing export cash crops, but also, to a certain extent, to the “Green Revolution” approach that targeted smallholder farmers.

Key research issues are:

- Pesticide use
- Transgenic pest-resistant and herbicide-tolerant crops ;
- Land sparing for biodiversity conservation in the high input pathway

The **ecological intensification pathway** strives to utilize the existing land to produce greater yields, better nutrition and higher net incomes. It encompasses ecological, genetic, and socio-economic intensifications

In both ecological intensification and IPM, priority is given to the absence of synthetic pesticide residues in the crop, food, and environment, rather than totally excluding use of pesticides or other chemical substances in the production process – a characteristic of organic farming.

In addition to the main generic issues already mentioned, the main specific research issues are

- Targeted use of pesticides
- Genetic intensification (regarding resistances)
- Biological control
- Physical barriers to pest shifting
- Collective organization in pest management

In the **agroecology pathway**, which refers to a science, a movement and a set of practices that developed in the 1970s–2000s, primarily as a reaction to the excesses of the Green Revolution and its negative impact on small-holders in developing countries. Conservation agriculture, agroforestry, and systems based on crop associations and rotations are typical of this pathway.

Regarding crop protection, in his definition of agroecology, the emphasis of agroecological engineering is on the enhancement of biological processes as replacement of chemical inputs. The implementation of conservation agriculture in most situations is associated with

reduced pest and disease incidence on crop plants. Evidence has been offered of a wide variety of possible mechanisms accounting for this: direct physical effects of tillage (or the lack of it) and of mulching; changes in pest behaviour due to plant diversity; effects of semiochemicals; increased predation, parasitism, or antagonisms; and induced crop resistance through better nutrition. The “push-pull” strategy has pest control as its primary objective since its principle consists in repelling the insect pest from the crop using repellent (“push”) crops and attracting it to the border of the cropped field using trap (“pull”) plants]. Innovative research is expected at all these levels.

In the **organic agriculture pathway**, “intensification” is to be seen in the sense of “changing land use from low value crops or commodities to those that receive higher market prices”

Some organically registered compounds are often of limited efficacy, must often be applied preventively and, in some cases, in relatively large quantities, leading to input-intensive practices with environmental hazards.

One should note that in sub-Saharan Africa as elsewhere, in terms of pest and disease regulation processes, organic farming can be both a research laboratory/prototype for designing innovations and a source of practices to be extended to other types of agroecosystems

Conclusion

Regarding crop protection aspects, agriculture in sub-Saharan Africa may benefit from the experience of the Asian and Latin American Green Revolutions, and from the European experiences in Agroecology and Organic farming.

Conversely, particularly considering the current contexts of global climate change, of globalization of exchanges, and of increased societal pressure against pesticide use, along with the increased risks associated with invasive and emerging pests, agriculture in the northern hemisphere may also benefit from the experience of research in sub-Saharan Africa to anticipate increased pest and disease risks, and to design agroecosystems resilient vis-à-vis these pests and diseases.

On the one hand, under tropical conditions, biodiversity levels, including those of destructive organisms, are higher, and life cycles of pests and pathogens shorter than in temperate areas. On the other hand, high “resource” biodiversity levels in most tropical agroecosystems make it possible to design cropping systems that are more sustainably resilient to crop pests and diseases by relying on increased biodiversity/ecological regulation processes instead of non-renewable and toxic inputs.

3.6.5 Improving annual cropping systems

In Africa food security and economic sustainability of small scale farms account still widely on their annual crops production, its quantity, its quality and its diversity. However, the context of tropical family farms is usually very constrained (climatic, soil, access to information...) and makes it very difficult to intensify and sustain crops production. In many places, conventional “high-input” pathways of intensification are still out of reach for numerous tropical family farmers and/or quite inefficiently applied causing high Yield gaps compared to the potential of these regions. Finally, negative environmental or social impacts often associated with such pathways, especially excessive use of chemicals, may not enable small scale farms to reach higher crop production levels.

Classically, research on annual cropping system address the following issues:

- The dynamics and optimum use of trophic resources in cropping systems, assessing biophysical functioning (production, efficiency) on a cultivated field scale, and their economic relevance on a farm scale (these two scales in a managed territory).
- The dynamics and integrated pest management (insects, diseases and weeds) in the agro-ecosystem, at the scale of the field up to the landscape. It focuses on regulation services done by natural enemies and cultural practices contributing towards reducing the pressure of pests.
- The place and role of the variety in ecological intensification, in interaction with its cropping environment via resources' valorization. Genotype x Environment is the keyword for this issue.
- Quality and valorization of products and by-products of crop plants, in relation with the cropping system
- Understanding and evaluating cropping systems taking advantage of the progress of Information and Communication Technologies (ICT) and applied mathematics to multiply observations in time and space, and to analyze them in mass.

However, the context of tropical family farming is changing in many positive or limiting aspects (climate change, demography, land availability, new markets and new value chains...). Farmers thus need to adapt their main crops management, but at the same time they often need to adapt their whole farm organization to new economic or social contexts and adapt their land and other limited resources management in collaboration with and to satisfy the necessities of other local actors. Farmers have to develop a multiscale and multi-actors adaptive process in order to modify step by step their actual systems. In theory, many options are available for this adaptation (between rainfed organic farming and high input systems including irrigation), even if in the reality, external constraints (may be social, economic, infrastructure or biophysical) limit the available options.

In such a context new Ecologically Intensive System (EICS) have emerged. Such systems may cover different kinds of pathways (ecological intensification, agroecology, organic). They combine both an efficient use of inputs when available and enhanced ecological processes already existing in the agroecosystem. Such systems aim at intensify the crop production by increasing global efficiency of the Cropping production process while decreasing its negative externalities.

These EICS are often pluri-specific combining in time and space main crops and complementary species for agro-environmental services. They also combine different kinds of resources available at the farm level, articulating in a more integrative way the different activities developed by farmers, in particular grazing and agriculture, and optimizing the interactions between them. Finally they can be developed in the context of mechanized systems or adapted to manual crop management. Intensive agro-forestry systems, conservation farming, various forms of organic farming or integrated livestock and agricultural systems are examples of on-going and emerging EICS. Several examples of Crop Ecological Intensification in Africa will be developed in this presentation.

In addition to the traditional research items, new options are now emerging:

- Optimization of natural resources management for an increased availability for the production process (soil, water and nutrient management)
- Improvement of the production process efficiency by increasing and managing vegetal functional biodiversity
- Introduction of multifunctional legumes in the agro eco systems
- Adapting cropping systems to climate change while contributing to mitigation too
- How to co-design with local actors new EICS
- How to work with local stakeholders, through Co-innovation platforms development, on enhancing the conditions for an agroecological transition

3.6.6 Improving tree crop based systems

In a highly constrained context, there is a new global awareness of the role that tropical tree crops (oil palm, rubber, cocoa and coffee) can play in the economic development of SSA. These tree crops are highly productive and meet global demands for which the current supply is insufficient. This is reflected in a significant number of new tree-crop plantation projects, particularly in government-led development projects. Such projects are primarily economically driven, but also have an ecological benefit through their potential for carbon sequestration or the possibility of rehabilitating degraded areas. They also give rise to fears and questions in civil society in the North and in the South, particularly with regard to the preservation of the environment (deforestation, loss of biodiversity and pollution) in Sub-Saharan African countries and the potential for land appropriation by foreign powers (States or multinational companies).

In this context of global change and complex and sometimes contradictory interests, the definition of good agricultural practices that make the best use of land while respecting the environment is more necessary than ever. The overall challenge is therefore to ensure:

- Sufficient and sustainable production capable of satisfying a growing world demand and allowing the economic and social development, as harmonious as possible, of actors in the rural world of Sub-Saharan African countries.
- The preservation of the environment and the mitigation of risks to ecosystems.

In response to this challenge, it is critical to understand and value the factors that allow both the increase in productivity and the maintenance of other ecosystem and social services of agro-ecosystems in order to achieve greater sustainability in perennial tropical systems and to characterise the trade-off between the different components in perennial crop-based systems.

To do this, multidisciplinary scientific research, addressing physiology (plant functioning), ecophysiology (plant interaction with its biophysical and climatic environment), agronomy in the strict sense (optimisation of agricultural practices and valuation of yields), agro-ecology (impact assessment and environmental services) and also socio-economics (operation of farms, actors' methods for adopting systems, incentives for change) are needed.

The overall objectives can be described as follows:

- Improving knowledge on the functioning of tropical perennial crops and agro-ecosystems.
- Developing diagnostic and monitoring tools that ultimately enable producers using tropical perennial crops to optimise their production systems by combining the criteria of agronomic sustainability (technical and economic optimisation of production), environmental services and socio-economics (profitability and acceptability).

In particular, this can be achieved through expertise studies and research activities whose objectives are to:

- Evaluate existing production engineering systems through the development of diagnostic methods (physiological and agronomic diagnostics, environmental and socio-economic impact indicators) and propose improvements to these systems.
- Co-design (together with civil society partners) more sustainable production tree crop-based systems and to evaluate the conditions for of innovation transfer in a real environment.

To meet these challenges, basic knowledge has to be developed in two complementary directions: (i) understanding and characterising the diversity of systems through the identification and quantification of the factors explaining the differences in agro-ecological performance of small farms and industrial cropping systems; (ii) determining overall soil fertility and the maintenance of soil-plant capital as a basis for ecological intensification strategies in tropical perennial systems.

These general questions may be broken down into an even wider spectrum of scientific questions, in which biophysical considerations are linked with social and economic issues, as far as direct development questions on intensification are addressed. As an example, we reproduce in the box below a list of research questions which have arisen from the PROIntensAfrica case study (Cameroon, see D2.3) with a wide diversity of stakeholders: these questions implicitly address the need for building multicriteria performance indicators for comparing diverse intensification pathways, and the identification/quantification of the factors explaining differences in their agro-ecological performance.

Questions to be addressed by research in a specific cocoa-based systems area of Cameroon, PROIntensAfrica In-Depth Case Study

We reproduce here some questions to be addressed by research in a specific cocoa-based systems area of Cameroon, PROIntensAfrica In-Depth Case Study

1. What are the main factors that impact cocoa agroforestry systems (AFS) dynamics and sustainable intensification over the medium and long term: biophysical (e.g. road infrastructure), demographic (population densities, migrations), economic (agricultural markets and prices, wage levels, capital flows) and social (e.g. land access, farmers' organisation)?
2. What are the roles of interactions and coordination modes between the local (farmer strategies, cooperatives, advisory support availability etc.), the national (public policies, traders etc.) and the international (markets) scales for sustainable intensification of cocoa based-systems in Cameroun?
3. What is the role of research and advisory services in changing farmers' practices?
4. How to co-design an effective tool with farmers and other stakeholders to monitor the sustainable intensification of cocoa-based systems?
5. What approaches are most effective to strengthen stakeholders' innovative capacities and knowledge and experience sharing?
6. What are the economic and environmental impacts of strategies adopted by farmers for the management of their cocoa-based AFS plots?
 - 6-1: What are the trade-offs and synergies between cocoa yield, associated products and other ecosystem services provided by diversified cocoa-based systems?
 - 6-2: What are the costs-benefits of the introduction of trees in the system taking into account direct and indirect benefits?
7. What are the ways to improve small cocoa farmers' (SCF) level of life and sustain their activity?
 - 7-1. How to increase SCF revenue from cocoa?
 - How to help farmers to mitigate the impact of climate change on their young and adult plots?
 - How to encourage/guide/assist SCF in rehabilitating/regenerating their old and unproductive plots?
 - How to develop cocoa fertilisation methods adapted to each local environment and guide and enable SCF to adopt them?
 - How to help SCF in the control of biotic stresses, through the use of cost-effective methods?
 - 7-2: How to increase SCF revenue from associated crops (fruit and NTFP (Non Timber Forest Product)) trees?
 - How to link SCF to fruit and NTFP buyers?
 - How to increase the shelf-life and the commercial value of some of the products of the AFS plots through simple processing technology?
 - 7-3: How to increase the role of youth and women in AFS management?
 - What are the drivers and incentives for youth and women's involvement in AFS management?
 - What is the role of food crops in farmers' cocoa-system diversification strategies?
8. How to reduce the impact of cocoa cultivation on forests?
 - 8-1: How to limit the impact of cocoa cultivation on biodiversity in forest areas?
 - 8-2: How to develop alternatives to cocoa cultivation on forest land?

3.6.7 Improving horticultural cropping systems

Horticulture includes many diverse crops classified as fruits, vegetables, flowers, aromatics and medicinal plants. They comprise more than 1,000 species. Fruit and vegetables are considered as beneficial to human health and an important source of minerals, vitamins and other antioxidant compounds in human nutrition. But in SSA, vegetable consumption is still far short of FAO's recommended intake of 400g per day or around 150kg per person per year. Horticultural crops are considered as high value and can provide excellent income-generating opportunities for small farmers. Horticultural products are also opportunities to shift from animal-based food to a more sustainable food system based on plant-food, although SSA diets are low in animal-based proteins.

There is a high diversity of horticultural systems in SSA due to: (i) the variability of the climate; (ii) variable altitudes, from sea level to high altitudes; (iii) variable uses of inputs and equipment from subsistence agriculture to export markets; (iv) specific locations in rural areas but also around and within cities. In addition, these systems offer great variations regarding intensification. Due to the high value of the production, farmers are often encouraged to invest in equipment such as greenhouses or to buy external inputs. However, numerous systems are still based on low inputs and/or highly extensive practices, using few chemicals, and are, by nature, rather close to agro-ecological or organic approaches.

Due to the high nutritional value of its products, horticulture should take the opportunity of globally growing demand to: (i) reach the objectives of WHO-FAO recommendations, (ii) respond to changing diets and demand, (iii) continue to supply international markets when SSA has competitive advantages in terms of climate (tropical species), seasonality and diversified products. The sector faces two major challenges: increasing its production of safe horticultural crops and then mitigating environmental impacts, in particular avoiding soil degradation and water exhaustion or salinization in case of specific conditions of irrigation.

Intensification pathways in West Africa (WA) and ProIntensAfrica case studies, have highlighted several problems: improving access to good seed and planting materials, maintaining soil fertility, and integrating livestock and crop production. Few of the PROIntensAfrica case studies directly concern horticulture but all these subjects may have links with the horticulture sector.

The 'High Input' pathway is based on the development of large farms with high investments in the continuation of export farms such as, for example, flower production in Kenya and Cavendish banana production in Ivory Coast and Cameroon. The farms use high-quality planting materials such as hybrid tomato seeds and in vitro banana plants. They grow mainly tropical species such as pineapple or banana. Even if the need for irrigation is limited in humid areas, these systems require major investments (irrigation, warehousing, nurseries, mechanisation). Species less adapted to tropical conditions and grown in the off-season, need to reach very high quality standards for export and require heavy investments in technology and equipment (seed, chemical pesticides, specific fertilisers and greenhouses). For several reasons, the use of GMO varieties is not current at the moment. Transport energy costs are a constraint, particularly for air transport. The evaluation of the environmental impacts of these horticultural techniques, mainly concerning natural resources and ecosystem health, has to be documented. Research is needed to address the case of small vegetable farmers who use conventional chemical products for local markets or export markets. However, the high diversity of horticultural species will not tempt the major companies to innovate in such crops. Despite their high value, food crops occupy far less cultivated land than cash crops such as wheat and maize. Although research has been ongoing for at least two decades, for example on indigenous fruit and vegetables, it has to go further for these neglected crops following the traditional agronomic disciplines: breeding, crop protection, fertilisation and post-harvest techniques.

The 'organic agriculture' (OA) pathway prevents the use of genetically modified organisms, chemical pesticides and mineral fertilisers. In SSA, its development has begun with export markets (cocoa, coffee, cotton, vanilla, mango, pineapple etc.) which require third party certification. The farms are small and medium enterprises, specialising in their export crops. They comply strictly with agronomic specifications under pressure from exporters, which can lead certain principles of organic production, such as maintaining mineral balances, to be forgotten, with a risk of a diminution in soil fertility. So, after a few years, farmers may abandon OA. In response to urban consumers' concerns, national organic markets are emerging alongside new systems such as participatory guarantee systems, an alternative solution based on confidence between farmers and consumers. Further research is required to address the yield gaps between conventional and organic systems, the quantity and quality of organic fertiliser resources and the construction of methods to compare organic and non-organic systems regarding varieties and pest control, for example.

The 'agro-ecology' (AE) pathway focuses on resource use patterns which respect the natural functioning of ecosystems, but it also combines with social organisations and a global landscape approach, for instance integrating trees and livestock.

The horticulture sector could benefit from the diversity of horticultural species and could associate numerous companion crops among legumes or trees, to develop agroforestry, for example, at field and landscape levels. One of the objectives of the research is to quantify the effects of associating crops and rotations at field and landscape scales for pest and disease control and managing soil fertility. Plant breeding work will be required, including on companion crops. This research will be driven locally. The diversity of crops and regional production levels will require the involvement of the human sciences, including geography, sociology and anthropology.

The 'Ecological Intensification' (EI) concept is based on genetic, ecological and social intensification. It combines the results of the three previous pathways. Research should explore indigenous biological tools to increase production. The diversity of indigenous species might be a strong advantage to exploit their ecological services and find solutions based on biological processes. As with the HIA pathway, agribusiness companies have already invested in the biological control of pests and diseases, both aerial and telluric. This pathway focuses more on highly specialised horticultural farms using all the ecological tools available from agribusiness companies and modern economic regulations, for example carbon credits with the objective of voluntary offsetting.

However, the technical solutions must not disturb the fragile equilibrium of local agro-ecosystems, in particular when the introduction of exotic living organisms is proposed. As local knowledge and local adaptation of crops are the basis of this concept, research will be needed at the local level. Research will have to investigate in-depth both farmers' practices and to adapt the overall solution to local ecology.

3.6.8 Livestock intensification pathways²⁰

Livestock constitutes a substantial component of African agricultural production, contributing about 30-40% of agricultural GDP in many SSA countries. There are around 320 million households keeping livestock in SSA. In pastoral societies, livestock is the prime resource and the largest non-land asset they own. Pure pastoralism mostly occurs in non-equilibrium ecological systems. However, the herding, livestock owning population, are rarely entirely nomadic, but more often sedentary even if the young men following livestock seasonally.

²⁰ This section is based on an original contribution of Philippe Lecomte, "*Livestock system intensification*" available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMyV2c>. Comments have been provided by Maria Wurzinger, Niemi Jarkko, and Gert Nyberg.

Livestock contributes to food and nutrition security through the provision of animal-sourced foods (meat, milk and eggs). It is a source of income and capital assets, as well as a source of draught power and manure for farming. Around 10% of the population of SSA is primarily dependent on livestock, while another 58% partially rely on animals. Nearly 60% of the value of edible livestock products is generated by cattle, in the form of meat and milk, while small ruminants and poultry generate around 20% each (AU-IBAR 2009). Where livestock has important social, cultural and economic relevance in Africa, the improvement of production efficiency can significantly change the livelihoods of households and help small-scale farmers in rural areas out of poverty. Many argue that public and private investments in the intensification of smallholder livestock systems would clearly help people use their livestock enterprises as pathways out of poverty.

Regarding cattle and small ruminants, livestock farming systems in SSA are mainly pastoral or agro-pastoral (crop-livestock) in nature. Pastoralists are mainly transhumant, adapting the feeding of local breeds to resource availability, with an increase degree of partial sedentarisation of peoples and the main household settlement, with the keeping of a limited number of productive animals around centres and along milk roads. Agro-pastoralists are the largest group of livestock farmers in SSA. These are sedentary and combine highly interacting crop and livestock management and may practice short or local transhumance during the wet season to avoid damage to field crops. All these systems are generally very low input and/or highly extensive. They use very few chemicals, medicines or imported concentrate feed and are by nature quite agro-ecological or organic in their management. Intensified industrial systems are rare and mainly limited to poultry meat and egg production.

Livestock systems in SSA are in a paradoxical situation. They have to take opportunity of an overall rise in the demand for protein and changes in diets in the rapidly increasing and urbanising population, while the availability of natural resources is dwindling and/or are affected by changing climate and land use. Recurrently animals suffer from decreases in the quality of seasonal forage, with the problem most often occurring during the progression from the wet season to the dry season. Due to elevated mortality and low fertility rates, production efficiency is particularly limited in SSA. The sector has to increase production while simultaneously mitigating environmental impacts and promoting the highly social and ecological roles of livestock.

General research needs

Where there is transition from pastoralism to agro-pastoralism, the traditional knowledge systems does not cater for management knowledge in the new agropastoralism situation. There is hence need for new knowledge and science. This is in contrast to a common assumption that agropastoralism is a “passing” stage on the transition from pastoralism to crop based agriculture. The Triple L Research Initiative www.TripleL.se addresses this issue. Specific policy gaps, for livestock based agropastoralism are needed.

Research needs common to all the livestock systems are listed below: Methods for improved fodder quality and quantity production, supplementary feed possibilities and requirements, agroforestry for agropastoralism, crop-livestock interaction, herd composition, breeding programmes, quality and hygiene of the products, livestock markets and marketing, value-chain development, gender balance changes in the transition from pastoralism to livestock based agropastoralism. In addition, traditional pastoral systems should be supported by research on how to enable corridors, emergency pasture areas (refuge grazing areas) and livestock insurance systems.

Specific research needs according to specific intensification pathways

Regarding intensification pathways in West Africa (WA) and through PROIntensAfrica case studies, milk intensification can be considered as a relevant example for considering the various issues at work, the pathways and the research needs for intensification.

Research for intensification requires an interdisciplinary approach by combining animal nutrition, health and breeding research as these topics are highly interlinked and require simultaneous attention.

Participatory dynamic systems modelling of various intervention strategies can help to identify the most suitable and socially accepted pathway for livestock intensification.

Demand for milk in SSA is rising exponentially; imports of milk powder and butter oil constitute a heavy burden for the States. Small scale dairy producers could become important suppliers of fresh milk for the local small chains or large milk industries that are emerging in many cities of SSA. The promotion of private investment in the conventional agriculture (CA) pathway, based on the development of large (or mega) farms housing imported high genetic merit cows, fed with irrigated local forage and supplemented at a high energy cost with large amounts of imported maize and soya, would be the most effective and high-performing solution from a technical and economical stance. However, it is a pathway offering poor sustainability. Research needs on technical aspects are limited as it is an intensification model seen elsewhere in the world and the process has been mastered and promoted by the usual major players in the agribusiness. That said, such a model could have a economical training effect for smaller scale farming systems in an agricultural landscape. Its partial adaptation to small or medium-size farms should be better documented. Such transfer of high input technology to small or medium-size farms is however not so easy and straightforward and is definitely limited to favourable conditions. In addition, this strategy creates a lot of dependency on external inputs, which might lead to sustainability problems.

Under a sustainable agricultural intensification (SAI) pathway, based on the pillars of genetic, ecological and social intensification, the pathway would support more sustainable development as it considers more explicitly local knowledge and ecological services such as carbon sequestration, while adopting a rational use of external inputs, biotechnology, irrigation and mechanisation to increase the productivity of land, animals and labour as well as household income. The pathway shares the same objective as the conventional approach in increasing production volumes, but it also requires dedicated research and development to better integrate local agricultural and livestock sectors and to handle the externalities and mistakes in the conventional pathway, which generally reduces environmental and social sustainability. Private investments and public-private partnerships are highly compatible with such an approach

The agro-ecology (AE) pathway optimises ecological processes; it also combines social and technical changes throughout the agri-food chain or food system. Maximising input productivity or increasing production volumes are important but not the central goal; this pathway is mainly dedicated to welfare and food equity concerns. Rather, the goal is to optimise yields using the natural and ecological processes involved in agricultural production and reduce the use of external inputs. Providing production systems with autonomy from chemical inputs and large infrastructure requirements are also key objectives. Such a pathway mainly targets small-scale farms and local and national market improvements. There is a large research need for improving performance in autonomy and to scale-up organisations.

The organic agriculture (OA) pathway emulates ecological systems and cycles and does not use genetically modified organisms, chemical pesticides, medicines and mineral fertilisers. It

doesn't exclude the procurement of long-distance inputs as long as they are organic. The main objective is to improve quality traits to meet consumers' social and health demands, which should allow producers to demand better prices. Such a pathway is mainly ruled by the definition of market conditions that are certified in different ways; intensification is a more recent concern in this pathway. There is evidence that the yield gap between conventional and organic practices could be reduced. Although in SSA, short circuits and local anchorage for organics are still rare and should be better promoted.

Regarding livestock and milk development in SSA's agricultural landscape, there appears to be much potential for sustainable intensification and, furthermore, rather than a sole or uniquely technical and conventional model, the coexistence of different pathways is both possible and relevant to SSA. It could be highly synergistic to support authentic food chains and sustainable agricultural development in many agricultural landscapes in SSA.

3.6.9 Roots, Tubers and Bananas²¹

In a number of countries running through the humid tropics in Africa, roots, tubers and bananas (RTB) are the most important staple crops and the dominant commodity. Across this group of countries, the contribution of foods derived from RTB to total calorific needs from all sources ranges from nearly 25% in Nigeria to close to 60% in the Democratic Republic of Congo (DRC)

Because of low productivity, current production of RTB crops in SSA does not meet basic food security needs in rural areas, and is often uncompetitive with imported staples from international markets on urban markets, resulting in missed smallholder income opportunities. As more people move to cities, value chains for RTB crops will need to be reconfigured to improve efficiency, convenience and reduce post-harvest losses so as to compete with imported staples.

RTB crops offer high potential yields, but farmers often realize less than half that potential due to the use of poor seed system" (RTB are vegetatively propagated crops and planting material consist of seed tubers, cuttings, suckers, etc.) of limited genetic potential; biotic and abiotic constraints; and poor management practices. Broad experience shows that robust market demand is the most effective driver of agricultural technology adoption. Conversely, limited institutional arrangements that support markets, policy, knowledge, and technological development restrain yield potential. Hence there are several strategies needed to make use of the full potential of RTB crops to exit poverty:

Women's farm yields are typically much lower than men's, reflecting specific gender barriers that lower women's productivity, including competing priorities (e.g., child care), and limit their access to information, good quality seeds and technology. Low productivity in turn prevents women farmers from taking full advantage of market opportunities and the chance to increase income.

As vegetatively propagated crops RTB appears to be less susceptible to extreme climatic events (such as short drought period) than others crops such in first place cereals. For example changes in cassava climatic suitability by 2030s as predicted by EcoCrop indicate increases in the vast majority of areas, and especially seem to occur in a greater proportion over currently cropped areas and where the most significant production is reported.

²¹ This section is based on the CGIAR report on the CRP called "*Roots Tubers and Bananas*", "RTB Proposal 2017–2022", available on <http://www.rtb.cgiar.org/>

Research issues

In a context in which, as urbanization comes with changing consumption patterns, with an increasing demand of cereals (specially rice and wheat) at the expense of RTB, research is expected to address the following objectives:

- Discovery research for enhanced utilization of RTB genetic resources: develop and apply leading-edge science toward faster and more precise development of user-demanded varieties, and to enhance the long-term conservation and use of genetic diversity.
- Adapted productive varieties and quality seed of RTB crops: make available good-quality planting materials of a diverse set of high-yielding RTB varieties that are adapted to the needs and preferences of different stakeholders in the value chain.
- Resilient RTB crops: close yield gaps of RTB crops arising from biotic and abiotic threats and to develop more resilient production systems, thereby strengthening food security and improving natural resource quality.
- Nutritious RTB food and added value through post-harvest intervention: support the fuller, equitable, and sustainable utilization of RTB crops for healthier diets and improved income opportunities.
- Improving livelihoods at scale: improve livelihood resilience by scaling RTB solutions in agri-food systems, that urbanization comes with changing consumption patterns: as a matter of fact, rice and wheat (for bread) have an increasing importance at the expense of RTB

3.6.10 Irrigation and intensification in Sub-Saharan Africa²²

In many Sub-Saharan African regions, where the climate is too dry to easily develop and intensify rainfed crops, irrigation has been introduced for almost a century, primarily to develop export crops (cotton). After the independence, a new objective was given to irrigation: boosting agricultural intensification and national development. But technically and economically the results from these two periods were often disappointing. Farmers were not involved in the design and management of the schemes and received little benefit from irrigation incomes. During the 70s and 80s, the Sahel region of Africa experienced several severe droughts. Beside the large irrigation schemes already in place along some main rivers, governments and NGOs developed many small irrigation projects to prevent hunger. But irrigation, large or small, requires investments to extract and convey water, and to use it efficiently (unit costs are often in excess of US\$10,000 per hectare). With the arrival of the Structural Adjustment Programmes era, African States could no longer finance the development of irrigation and international donors were not willing to continue developing a sector seen as inefficient and too State-dependent. Efforts were made to liberalise markets, disengaging from the State and promoting Water Users Associations. Alternative 'low-cost' development models were tested, for example in the inland valleys in the Savannah regions. Nevertheless, the 2008 global food crisis also affected Africa and made it clearer than ever that food security remained a vital challenge for many African countries. The FAO Director-General at the time, Jacques Diouf, declared that "*water management is a key element in food security*" for Africa at the Sirte Ministerial Conference in December 2008. At the same Conference, a 20-year programme detailed the irrigation and hydro-energy investments required in each African country at a total cost of \$65 billion. But as public funds remained scarce, this led to a large opening up of the irrigation sector to large international investors and the promotion of public-private partnerships, putting land and water grabbing issues at the top of the irrigation agenda. Moreover, irrigation is facing climate change, which affects the performance of irrigated cropping systems and throws into question their contribution to greenhouse gas emissions. It is also faced with the fact that it represents the largest use of fresh water in Africa and therefore is increasingly in competition with other uses which are developing, and can also lead to conflicts between actors and countries.

²² This section is based on an original contribution of Jean-Yves Jamin and Stefano Farolfi, "*Irrigated systems*" available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMyV2c>

During a ministerial meeting in 2013, members of CILSS (Interstate Committee for Drought Control in the Sahel) from six Sahel countries issued the 'Dakar Declaration' setting a target of one million hectares of irrigated land in the Sahel by 2020 (430,000ha was irrigated in 2013). But many other countries are willing to develop irrigation in other parts of Africa affected by droughts (e.g. Ethiopia) or in more humid regions where irrigation can help stabilise farming systems by increasing yields and allowing dry season cropping (e.g. Ivory Coast, Ghana etc.).

Regarding intensifying pathways in Africa, irrigation is in itself an intensification pathway. As stated by the FAO: *"...since the beginning of crop cultivation, irrigation has been used to compensate for the lack of precipitation. In rice cultivation, irrigation also controls the water level in the fields and suppresses weed growth. Crop yields are higher and the risk of crop failures is lower in irrigated agriculture. Because the risk of drought stress is lower on irrigated land, farmers are more likely to spend on other inputs like fertilisers. Irrigation may also increase cropping intensity, allowing farmers to cultivate several crops per year on the same field."* But this does not mean that the future of irrigation will be using more funds to build more schemes, and more water, more land and more inputs to produce more food. Different types of schemes need to be developed to meet the various edaphic conditions of the different regions (e.g. large rivers, lakes, small rivers, inland valleys, peri-urban areas etc.). New cropping and farming patterns need to be tested to meet the requirements of more efficient, more diversified and more sustainable systems. In regions where livestock breeding used to be the most important land use, crop-livestock integration is also a challenge both technically and socially.

3.7 Cross-cutting themes

11 cross cutting themes, where the application of modern science will play a major role in Africa's agricultural transformation have been identified. These themes require adopting a wider perspective in order to perceive political, ethical, technological, economical social and environmental issues that are incredibly linked with agricultural issues. The list below is not exhaustive but the themes have been identified as major challenges for Science and Innovation research in Africa.

3.7.1 Biosciences and technologies ²³

This section explores what could be a stimulating Research and Innovation agenda regarding plant breeding in Africa, taking into account different possible pathways or options towards intensification. Some of the items are relevant and analogous in the context of animal breeding as well.

The most important impacts of the crossbreeding of the staples that feed Africa as well as recent advances in, and potential of adopting crop biotechnology for germplasm improvement and management in this continent are known: more and more, Africa becomes better equipped to play a major role in developing and deploying new plant breeding techniques to address food security and sustainability of the natural resource base.

In addition, the emergence of Agroecology and Organic farming systems in SSA requests new paradigms and new breeding targets. At present, conventional varieties are still used by organic farming.

²³ This section is based on an original contribution of Rodomiro Ortiz, SLU, "Genotype Management in Sub-Saharan Africa. A Briefing of Plant Breeding", available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMyV2c>

However, it is unreasonable to assume that they will always perform better than specific varieties, designed and bred in order to match the global (including ethical) principles and growing conditions that goes along with Agroecology or Organic farming. When breeding for such alternative farming systems, the breeding challenges remain similar: can we get varieties that are highly productive, resistant or tolerant to biotic and abiotic factors, and high resource-use efficient.

African farmers produce cereals, legumes, fruits, vegetables, root and tuber crops, as well as industrial crops that partially meet the continent's demand for food, feed, fiber and fuel. Most crop yields in Africa remain low as compared with world averages, although they benefited from some genetic improvement programs. Moreover, most African staples originate from other continents, and the success of their breeding programs stands on importing genetic diversity from their centers of origin and diversity.

Literature reviews emphasize the prospects of successful deployment of new biotechnologies in plant breeding. However, addressing the global challenges effectively will require an holistic approach, combining in depth understanding of plant breeding methods and principles together with understanding of smallholder farmers strategies and needs, as these are the major contributors to SSA agriculture.

Crop biotechnology in Africa

Biotechnology can provide tools and products to address some of the challenging issues affecting African agriculture. These tools include tissue culture for mass propagation of clean planting materials, DNA markers for aided breeding and genetic engineering, which should be used by plant breeding programs when appropriate. The legal framework for using crop genetic engineering must be science-based to ensure sound regulatory and technology transfer systems that guide the uptake of agro-biotechnology in Africa.

Various successful plant breeding programs have been driven by both public research on genetics, genetic resources, germplasm enhancement and genomics and private sector investments that use such knowledge on developing genetically enhanced seed-embedded technology through conventional methods, genetic engineering and DNA marker-aided breeding. Transgenic cultivars have been released since the mid-1990s. In 2015 only, 17.3 million farmers of 28 different countries grew 179.7 million ha of transgenic cotton, maize, alfalfa, eggplant, papaya, poplar tree, squash and sugar beet, when, worldwide, the four most important transgenic crops were soybean (83%), cotton (75%), maize (29%), oilseed rape or canola (24%).

Micro-propagation is knowledge-intensive. It significantly reduces pathogen incidence and may dramatically improve yield when coupled with good agronomic practices. For example, bananas obtained by tissue culture are more responsive to irrigation than traditional bananas. A strategic whole value chain approach with tissue culture technology should therefore include awareness creation and information outreach, access to tissue culture seedlings, agronomic best practices, post-harvest handling best practices and linkage to competitive markets. Due to lack of, or little incentives in Africa, the private sector does not produce and disseminate large-scale healthy and improved planting materials to small farmers. Hence, a sound mechanism for scaling up sustainably the decentralized delivery of healthy planting materials for these crops needs to be sought.

International and national public plant breeding has provided foundation germplasm, breeding lines, near-ready cultivars for various crops, and more recently molecular breeding tools for most important seed crops that feed the world, namely maize, rice, and wheat, but to a lesser extent for dryland cereals, pulses, roots and tuber crops or banana and plantain. Appropriate investments in molecular marker-aided breeding, or clonal crops, could

undoubtedly speed-up breeding accuracy and progress, and provide significant levels of calories intake to a fast growing population. The availability of adequate breeding material, physical maps, genomes sequences, high-throughput genotyping, and precise phenotyping will also enable in the coming years the emergence of new molecular breeding approaches, in particular for the clonal crops.

Research options

In plant breeding, the reproductive biology and the breeding system of the plants determine the choice of methods. The most popular staples through the African continent include self- and cross-pollinated species, which have disomic (cassava, cowpea, groundnut, barley, maize, pearl millet, rice, sorghum, tomato, wheat), trisomic (plantain, banana), tetrasomic (potato, *Musa* hybrids) and hexasomic (sweetpotato) inheritance, sexual (seed crops such as cereals and legumes) and vegetative propagation (clonal crops such as root and tubers plus banana and plantain), plus annual (most crops) and perennial production (banana and plantain). Inbreeding species are the above cited legumes and most cereals except maize and pearl millet, while these two cereals and most clonal crops show outbreeding. Hence, the improvement of these crops efforts relies on understanding the conceptual underpinning of plant breeding and genetics, as well as for the sustainable use of genetic resources in their improvement.

Plant breeding can give more emphasis to the utilization of wild species and landraces for the development of elite progenitors and cultivars adapted to the environmental conditions where African farmers will grow them. Selection should give priority to traits related to host plant pest resistance, adaptation to stressful environments (drought, waterlogging, heat, salinity, poor soil fertility), resilience to climate change, efficient input use (water, fertilizers) and produce quality that adds value. The genetic enhancement of crops grown in Africa will benefit from understanding the types of gene action for economically important traits and by using techniques that improve breeding efficiency from the laboratory work to field trials, including the utilization of bio-techniques that facilitate the genetic manipulation of plant species.

Research advances in these areas should continue improving our knowledge of, provide insights on both crop genomes and germplasm, and enable a higher knowledge of trait and phenotype diversity.

In parallel, or eventually within a concerted framework, the development of cultivars adapted to organic farming principles and conditions can be successfully achieved if plant breeding programs combine the selection of the progeny in optimal and organic or low-input environments. A modality of this option, is to only carry out selections of selected generation progenies, developed by conventional breeding procedures, under optimum organic environments to determine their value for cultivation and use in further testing; this is advantageous, particularly when there is limitation of financial, human, and institutional resources, or when specific terms of reference are specified.

In addition, It is widely recognized that conventional plant breeding has been more beneficial to farmers in high-potential environments or those who can profitably modify their environment to suit new cultivars, than to the poorest farmers who cannot afford to modify their environment through the application of additional inputs and cannot risk the replacement of their traditional, well known and reliable varieties. Participatory plant breeding (PPB) is seen by several scientists as a way to overcome the limitations of conventional breeding by offering farmers the possibility to choose, in their own environment, which varieties suit better their needs and conditions. PPB exploits the potential gains of breeding for specific adaptation through decentralized selection, defined as selection in the target environment, and is the ultimate conceptual consequence of a positive interpretation of

genotype · environment interactions. Genetic variability is generated by breeders, selection is conducted jointly by breeders, farmers, and extension specialists in a number of target environments, and the best selections are used in further cycles of recombination and selection. Technically, the process is similar to conventional breeding, with three main differences. Testing and selection take place on-farm rather than on-station, key decisions are taken jointly by farmers and the breeder, and the process can be independently implemented at a large number of locations. New varieties reach the release phase faster than in conventional breeding, and are better suited to farmers' needs and willingness to invest in inputs and management. Release and seed multiplication activities concentrate on varieties known to be farmer-acceptable. And this option is compatible with all the intensification pathways.

Conclusion

Throughout the history of crop production there has been equal reliance on improvements of genetics versus improvements of crops and resource management. In many instances, especially in resource-poor environments, there has been too much emphasis on the genetic enhancement component of the equation while advances in crop and resource management practices have struggled to transfer from researcher to farm or failed to be scale-up across communities.

Research is expected to propose integrated methods, the variety being at the heart of the cropping system, and a major component of sustainable agriculture.

3.7.2 Genetic diversity and intellectual property.²⁴

Crop and farm animal diversity contributes to many fields directly or indirectly linked to intensification's strategies and pathways: market-oriented development, agrobiodiversity conservation, ecological stability and agroecosystem resilience, community based development, cultural and indigenous rights, food and nutrition security and long-term adaptation to changing environmental conditions.

Jointly, existing regulations for seed and genetic resources management cover a wide set of areas such as seed marketing, quality, and certification, intellectual property and access and benefit sharing legislations, risk management. They also concern many actors and stakeholders such as farmers and their organizations, NGOs, breeders in public or private sectors, researchers, gene bank, curators and policy makers. The resulting complex landscape of rights, responsibilities and institutional settings generates tensions among this set of actors, affect their practices and significantly drive agriculture intensification dynamics.

These tensions and controversies are part of agriculture history and more recently of structural transformation of agriculture. But the necessity to address new, highly problematic and specific challenges for SSA's agriculture invites to pay a greater and renewed attention to seed production, use, exchange and ownership (in relation or not to fertilizers and pesticides, which problematic are closely connected).

Some research addresses the seed regulatory framework and its possible improvements. Other tackles the need for a broad change in governance frames and promote a better participation of farmers and their organizations in this governance. But a consensus emerges on the difficulties of current systems to face SSA's challenges. In particular, the approach of

²⁴ This section is based on project, "*Adaptive Governance for Coexistence of Crop Diversity Management Strategies Project* », Agropolis Foundation flagship project, 2016-2019, available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

seed as a marketed product protected by strong intellectual property right may not adequately respond to the diversity of situations of SSA's agricultural and agri-furniture markets and organizations. Corporates find it difficult to invest significantly (which is the case of dedicated project in breeding and in other inputs' development) when profitability's perspectives are uncertain and when markets remain mostly informal. Credit system's failure and farmers' weak financial possibilities are real constraints.

One governance challenge lies today in better aligning the regulatory framework with the dynamics of biophysical systems (and the living nature of the object concerned), while taking social systems into full account and paying attention to market failures. Addressing the first part of the proposition, the whole genepool need to be considered, including the genetic diversity represented in production populations. Besides, an informational component is also embedded with this material in the form of both scientific information and farmer's practical knowledge and know-how.

Actual practices of seeds' management in SSA reveal the existence of diverse seed systems (related or not to the agri-food-system concerned and somehow to the different agriculture intensification pathways). These seeds' systems operate under a variety of different norms and are embedded in various networks of actors (at local, national and even global levels).

Research related to crop and farm animal diversity governance strategies involves undertaking multi-disciplinary approach to characterizing the discrepancy between seed and genetic resource policies and crop diversity management practices. This would involve

- Documenting the coexistence and specific functioning, in SSA, of multiple interrelated crop and farm animal diversity management strategies from the field to the national and regional and international scales Research should analyze actors' strategies, and the norms they mobilize to conserve, use and exchange crop and farm animal diversity with the aim of comparing these norms with the ones currently in place in the broader regulatory framework. The measure of this discrepancy between current practices and existing policies is a powerful way to infer and propose new governance mechanisms adapted to the diversity of SSA's situations and intensification pathways.
- Measuring the performances of the different systems identified, using an innovative set of multicriteria indicators (environmental, economic, institutional and social, at different levels and for the different groups of actors). The objective should be to rely these performances to intensification pathways' global performances and development.
- For farm animals:
 - Characterization of local breeds and identification of specific adaptation traits (relevant to adapt to climate change).
 - Develop breeding strategies for various production systems, but especially for smallholder, low-input systems.

3.7.3 Large Scale Land Acquisitions (LSLA) ²⁵

Large scale acquisitions are at the scope of the debates when it comes to land issues in SSA. LSLA refers to the acquisitions of land for agricultural purposes by investors, public or private, national or foreign. Large scale acquisitions are the result of global phenomenon. Access to natural resources has become a major economic preoccupation. Together with population growth and dietary changes, the growing demand for food, fiber or biofuel is the primarily consequence of this phenomenon. The liberalisation of trade and price volatility also contribute to increase this rush for land. If this phenomenon can be observed worldwide, it remains a major preoccupation in Africa since they account for a significant portion of the

²⁵ This section is partly based on the Landmatrix website (<http://landmatrix.org/en/>) and reports, and on the HPLE report n°2 (2011) "Land tenure and international investments in agriculture". An indicative list "LSLA references" is also available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

available arable land. According to the land matrix, 642 deals have been initiated since 2000, covering around 23 923 000 hectares. Whatever its importance, LSLA phenomenon enlightens structural potential changes in farming structure and questions land access for family farms.

Those land deals are an opportunity for governments which expect to diversify their resources, to generate more income and to stimulate investment to modernize the agricultural sector. Land initiatives are presented as contributing to the modernization of the agricultural sectors directly through large scale investments or through positive pull effects. Investors are often seen as developers and high expectations come with land deals in terms of investment in local infrastructures, financial incomes, jobs creation etc. It is stated that land investments will have a positive impact on food security and enhance rural development. However, a major issue of operational implementation seems to appear with a clear gap between signed and effectively implemented deals. The production, infrastructure and employment expectations are often not fulfilled due to several reasons: managerial and technical difficulties might appear; investments are not as important as expected or sometimes those acquisitions are strategic positioning to secure land in a long term strategy. Besides, even when the projects are implemented, little is known about the actual types of investments made and their impact on the level of mechanization, employment... Evidences now show that terms of the contract are crucial in large scale acquisitions to avoid a degradation of rural population's livelihoods. With the development of land markets, governments and international organizations need to be aware of these land issues on order to assure land tenure security to vulnerable people and promote sustainable land management.

Three main fields of research regarding LSLA and agriculture intensification should therefore be given priority.

- Performances of large scale agriculture resulting in large scale land deals have to be more closely measured and analysed, including their technical, economic, environmental and social impacts. These measurements don't aim to stigmatize farmers or corporate, but to document modernization constraints of large-scale farming. The idea is that these constraints concern more or less the whole agricultural sector (and the connected food systems), but that large-scale farming examples illuminate the challenges to address. This concerns mostly PROIntensAfrica high input and ecological intensification pathways.
- Research should observe how LSLA influence agrarian structures agrarian structures overall directly or indirectly (i) through other processes or ii) trickledown effect on local farmer – infrastructure development, service development...
- Research should pay more attention to the coexistence of different agriculture models and intensification pathways, crossing structures and crop systems at territorial level. In that sense, territories concerned by LSLA are particularly interesting. The controversy of competition versus positive articulation when different forms of agriculture coexist is relevant to promote sustainable intensification at meso-economic level. In the same vein these areas are hot spots to document agriculture global transformations.
- Finally, research should continue to focus on land access and on legal and customary, private and public, individual and collective legal frameworks regarding land appropriation and uses. The LSLA phenomenon invites to revisit this already dense research theme.

3.7.4 Big data management and NTIC ²⁶

Digital technology is the new driver of growth in Africa. The continent has seen exceptional growth in this sector, driven mainly by mobile phones. At the same time, African innovation

²⁶ This section is based on an original contribution of Joël Sor, "Big Data and NTIC" available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

and start-ups have emerged. Some countries have invested heavily in new technologies and data analysis, for example the Ivory Coast will launch the second most powerful data centre and computer platform in Africa.

The challenge in the use of new information and communications technologies in agriculture is the ability for Africa to access and use the new ICT platforms now available to make science and technology information available to a wide range of end users across the continent.

This challenge faces two major issues:

A broadband network: High speed internet access should not be an exception but a reality for the majority of African researchers. Progress has been made in Eastern and Southern Africa and in West and Central Africa broadband to connect all universities and research centres is being organised. This is a prerequisite in order to process a large volume of data locally. The European programme Africa Connect 2 (2015-2018) is available to support this type of network.

Agronomic research is also a big data issue: Actually dealing with all the information than can now typically be obtained falls under the category of big data. Namely, agronomic research has to deal with (1) huge volumes of data (for example, satellite images, environmental databases, information about crop cycles and farming techniques etc.), (2) very heterogeneous data (satellite images, numerical and textual information, specific databases usually with completely different formats etc.) and often expressed at different spatial or time scales, and even with information obtained in real-time (meteorological and environmental databases etc.).

Information is the key input for any risk management activity and the following are of great interest and must be investigated in an agricultural context:

- Meteorological and climate information. Meteorological information (e.g. changes in rainy seasons with a shortening of duration, and less rain in drought) has an impact on risk management in agriculture. For instance, climate instability (causing natural disasters such as storms or drought) is important information enabling us to investigate the evolution and impact of climate change.
- Satellite image information. Satellite images and images available over different periods are highly relevant sources for evaluating the variability of agricultural in a double context of early warning and climate change.
- Production levels and yields. Types of crops, farming techniques and irrigation to manage yields must be considered in the evaluation of agricultural risks.
- Plant and animal health (pests and diseases). In order to study agricultural risk management, we have to investigate the biological, ecological and epidemiological components of vector-borne disease introduction, emergence and spread.
- Prices of commodities and inputs. Long-term trends in agricultural commodity prices must take into account information from both local markets and producer prices for livestock. Studying this allows us to analyse and better understand price volatility.

One of the main goals in big data is to take into account all the available information or data to provide the expert with indicators that are relevant for evaluating associated risks. Traditional and new data analytics techniques (such as data mining, text mining and visual analytics) must then be used in order to significantly aggregate the available information to provide useful information and, more importantly, to extract new useful knowledge, i.e. new unknown indicators, new models or patterns that may be used by the expert in order to efficiently evaluate in real-time agricultural risks.

3.7.5 Innovation in partnership²⁷

Why is innovation key to changing African agriculture and making it more productive and sustainable?

Agricultural research has traditionally used a linear model of innovation, in which researchers produce knowledge and new technologies, pass them over to an increasing diversity of extensions services (public even though their numbers and funding were greatly reduced in the last 2-3 decades, not-for-profit such as NGOs or private for the better-off farmers), who in turn teach and train farmers in the hope of provoking adoption. In this model, it is through large scale adoption of “improved” technology by farmers that the expected and desired impacts (such as increased yields) are achieved. However, many studies have reported limited adoption, especially by African smallholders. One of the key reasons why such approaches often fail to work in Africa has to do with the fact that adoption does not follow a linear process, and also that linear approaches are poorly adapted to the challenging context faced by most smallholder African farmers.

In the wake of research aiming to understand the true nature of innovation processes, the concept of **agricultural innovation systems** (AIS) has emerged in the last decade. It places emphasis on the highly interactive nature of innovation, usually involving a diversity of stakeholders over time, such as research, education, private sector, government and NGOs, farmers-innovators and farmers organizations. It also recognizes the importance of the so-called enabling environment (infrastructure, institutions, policies, etc.) in triggering and driving innovation and adoption. It also puts to the fore the complex nature of innovation, which typically includes technological and social dimensions. Finally, the AIS concept and perspective offers a way of rethinking the design of the interventions needed to develop and disseminate innovations.

Recent studies and projects conducted in Africa have shown the diversity of existing agricultural innovation systems and processes, as well as the potential of novel approaches to innovation such as the use of innovation platforms to spur innovation, or the importance of local innovation. At the same time, these studies have also documented the many constraints to innovation experienced by African farmers, especially smallholders who usually still frequently suffer from challenging or degraded natural resources, inadequate infrastructure and service provision (including such basic services and financing, insurance, extension, education or health), or poor and unsecure access to national and international markets.

Priority research areas on innovation

There are still many unsolved issues related to the kind of innovations and innovation approaches needed to make sustainable intensification with and by family farmers happen. For one, it supposes modifying or adapting existing research approaches and methods, in order for research to be more demand-oriented and supportive of a greater diversity of farmers but also of other stakeholders that drive agricultural transformation. Also, one cannot overemphasize the need to focus on capacity development and at times empowerment of the many stakeholders, and especially family farmers, who need to get involved in the transition to sustainable intensification.

Below, we provide a non-exhaustive and non-prioritized list of research issues and questions related to innovation and SI, classified under various themes. All of them warrant systematic research in the future adapted to the diverse contexts under which family farmers operate.

²⁷ This section is based on an original contribution of Bernard Triomphe, IICA CIRAD, “*Research need on Innovation*” available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMvV2c>

Generic research on approaches and methods

A premise is that research on SI needs to be much more participatory, inter-disciplinary, multi-scale and systemic than it has conventionally been done until now if it is to be successful and truly support the transition to SI by family farmers. An additional premise is that it has to mobilize far beyond formal research institutions: it also concerns farmers, farmers' organizations and other local actors, CSOs and NGOs, input suppliers, private sector firms and governments. Increasingly, research on SI will have to be a collective undertaking implemented in the name of and by multi-stakeholder alliances working within the framework of formal or informal innovation systems or networks with a strong interest on and commitment to SI.

Under such premises, the following topics and issues seem especially relevant:

- Understand better innovation at play in agriculture as related to intensification dynamics. This includes putting special emphasis on documenting and assessing local innovation dynamics, which is hypothesized to take place among myriads of smallholders across Africa but is rarely visible as such.
- Document and learn from what is already known or on-going about SI with family farmers and other local stakeholders. Identify the diversity of farmers' needs and desires with respect to SI.
- Co-design robust and cost-efficient systemic participatory approaches and frameworks at various relevant scales by involving in the design key and legitimate players of the agricultural sector (including, but not limited to, the farmers themselves), and by taking into account the needed adaptation of such approaches to key features of the local /regional / national context. This may include developing the needed approaches and tools, including modelling, allowing to take into account the multiple scales affected by SI.. It may also include putting emphasis on adapting approaches allowing to link farmers better with markets such as Participatory Market Chain Analysis or also localized agrifood systems
- Strengthen the **capacity to innovate** of key actors of the agricultural sector including government medium decision-makers, researchers and faculty, NGO staff, and farmers' organizations
- Develop relevant approaches to scaling of successful experiences (technologies and approaches)
- Better target SI research: with whom and for whom should SI research be conducted?
- Ensuring research results and actors' experiences are made more accessible, shared widely in face-to-face and virtual forums for supporting the transition to SI at scale. This may entail developing online platforms for free sharing of relevant innovation experiences told according to a minimum common framework and in a variety of formats (including analytical reports, videos, fiches, etc.)

Generic research on institutional & policy issues, education and training

- Identify ways for ensuring an efficient coordination of the transition to SI by family farmers, allowing synergies of interventions and activities of all those involved and a coherent distribution of roles and responsibilities among them. Identify what research can actually do, what roles it can and should play in the SI transition process.
- Identify the types of innovation systems and processes needed around SI at the various relevant scales.
- Improve the governance of research and other public R&D actors, and their responsiveness to family farmers' needs and demands with respect to SI.
- Identify conditions and structural /organizational changes (including needed changes in "postures" of organizations) needed for effective scaling-up of SI systems and practices at all the relevant scales and institutional levels.
- Find ways of influencing policy makers, and developing /adjusting policies and policy instruments which may favour SI innovation and transition.
- Assess the actual or potential effects of different types of possible subsidies, safety nets and insurance schemes on SI transitions. Determine whether and how payment schemes for ecosystem services and other forms of public payments may contribute to motivate family farmers to embark on a transition to SI.

- Identify which capacities need to be strengthened to achieve transition to SI, which skills, which knowledge should research and educational institutions develop to create the needed capacities to support the transition to SI among the various stakeholder groups involved.
- Develop sustainable mechanisms for providing farmers with access to financial services, one of the prerequisites for spurring innovation related to SI

Specific intensification pathway-related research needs

Conventional & Ecological intensification pathways

- Characterizing the types of farming systems most likely to be able to follow the CA
- Develop and strengthen the service providers needed at various scales for providing inputs, advisory services, etc.
- Develop the ability to develop and negotiate contracts between buyers of ag. produce and private firms

Organic and agroecological pathways

- Rescue, systematize, assess and share the traditional agricultural knowledge of local farming communities which is compatible with agroecological and organic agriculture and could form the basis for future innovations
- Develop a set case studies on (successful) transition to organic and agroecological agriculture using a common analytical framework and a set of participatory indicators allowing a critical multidimensional assessment of such trajectories
- Assess and develop appropriate labels (both at the national and international levels) that could both help recognize products obtained through such pathways, and also make them more profitable for smallholder farmers to produce.
- Develop circuits and value chain which could ensure that African smallholders can sell at a rewarding yet fair price quality produce to urban African consumers on local and national markets
- Identify and assess at all relevant scales the actors who are most likely to support such pathways as well as those most likely to resist them
- Develop multi-stakeholder platforms at relevant scales (local, regional, national, international) that would help coordination of efforts among main actors interested in these pathways, as well as lobbying of appropriate government bodies

3.7.6 Collective actions²⁸

Individual strategies need collective support to spread innovation. This is particularly true for smallholder and family farms, but it concerns indeed most of the crop and food systems in Sub-Saharan Africa. Three main complementary domains require collective action in order to strengthen farms and food business capacities to achieve sustainable intensification:

- Natural resources
- Agronomic, livestock and processing technical proposals including genetic material
- Market access and regulations.

Two domains are technical by nature but the third one is in the fields of economics. Nevertheless, it appears central: if sustainable intensification is to become a widespread reality, it has to grow on a sustainable economic base within a regulated market economy.

Sustainable management of natural resources requires investments in land improvement that go beyond the capacities of each farm taken individually: this includes for example, the

²⁸ This section is based on an original contribution of Pierre-Marie Bosc, available on the D2.4 contribution platform. See also the publication: Bosc P.M., Eychenne D., Losch B., Mercoiret M.R., Hussein K., Mackintosh-Walker S. 2001. The Role of Rural Producer Organisations (RPOs) in the World Bank Rural Development Strategy. Reaching the rural poor. Background study n°8. World Bank, Washington DC

construction of irrigation and drainage works, terracing, the upgrading of soil fertility, anti-erosion works, improvement of houses and buildings, proper fencing, tree planting, the building-up of herds, etc. As far as investment in land is concerned, the rights of the family farms and smallholders have to be secured including all the access rights to common property resources that are strategic assets for a majority of smallholders and mostly for those pastoralists that rely on these resources to secure their livelihoods. Collective action is needed since such investments go far beyond the financial and labour investment capacities of single farms. Usually farmers (and their families) improve natural resource management collectively and without any support. These efforts are rarely documented, and assessed as a contribution – mainly through labour – to the sustainability of the farming systems. But collective action regarding natural resource management is not a simple exercise since like in all societies their management relates to overlapping situations between customary laws and emerging new rules, which generate tensions. Customary regulations are flexible, adaptable and are able to integrate new dimensions.

Assessing the level of investments in natural capital and the conditions for customary regulations to enhance sustainability requires research based on empirical materials in order to generate appropriate generic recommendations for action.

Agronomic or livestock and proceeding technical solutions including genetic material promoted by research often require high labour input and collective investment in landscape management; they are often knowledge intensive, thus requiring collective and public investment in knowledge generation and dissemination with close collaborative work between research, extension and farmers and small food businesses. Indeed, this can be expanded to food proceeding and other segments along the food-systems, anytime individual unit are constrained by their size and power ship.

The technical proposals tend to be site specific, and prospect for wide diffusion of ready to use type of solution appears limited. Collective focus groups discussing the comparative advantages and drawbacks of possible technical solutions proposals from research or suppliers' firms can strengthen the individual (or small units) capacities to undertake changes. These collective groups are by nature local: exchanges among these groups can reinforce the collective action at territorial levels and set up the bases for the organisational movement to link up with national bodies.

Market access and market regulation dimensions. Markets, through improving the conditions under which smallholders sell their products and transform the products, can make a difference and in all cases are key conditions for sustainable development. Three main challenges (and research themes) can be identified for which collective action can support individual strategies.

- The capacity to generate higher income through adding value locally to the products. Equipment, machinery and even know how are often beyond individual investment capacities and here collective action can make a difference. Investments in processing allow long-term preservation of products is a way to overcome low market infrastructure, smooth seasonality of production and incomes, and a strong means to keep value-added at smallholder and territorial levels. Food processing and other value-adding at the farm level or small and medium industries need to be strengthened as a component of the smallholders' livelihood strategies, increasing the autonomy and capacity to access better market conditions.
- The improvement of marketing places, marketing conditions and proceeding conditions. Investments in infrastructure (storage, cold storage, electricity, clean water, pavements, access, bank branches, regulated weights and measures, but also processing all along the food chain to consumers); investments in the modern management of the markets themselves, and, in rules such as quality grades and standards and weights and measures that are effectively enforced by public officials. Upstream, at the farm level, training, market information, business advisory services and producers' organizations are critical for traditional markets to function better; public investment

is decisive here. Downstream, investment in public goods and their collective management through collective action enhance the links between farmers, small food businesses, brokers, retailers and consumers

- The establishment of rules and regulations to limit price fluctuations. Collective action from local to national level is also a need to implement regulations at national level to complement local regulatory mechanisms: for instance mechanisms to limit imports when national production can meet the demand but suffers from unfair competition. This option supports the development of a fair market economy that limits dominant positions.

Research has to document the empirical base to support these recommendations: what are the impacts of collective action in:

- Small-scale processing unit through diversified indicators: added value kept locally, employment, income distribution, etc.?
- Improving marketing conditions? What impacts on the local farms and food businesses?
- Regulatory mechanisms from territorial up to national conditions: how far does it improve the market linkages of smallholder farmers?

In all these three domains collective has a key role to play to favour sustainable intensification, but all the organisations representing smallholders (in production and proceedings) are not structured along these lines. Strengthening the institutional structure of the smallholders at several coordinated levels in order to promote their capacity to invest, to improve their productivity through sustainable intensification and to strengthen their voice to negotiate related investments that increase their returns from their own investments is needed.

This strengthening capacity process is a long-term investment that requires public support added to the contributions of the members (often in-kind or in time devoted to collective tasks). Specific attention and research are required to document the conditions that favour the linkages between local collective action groups and other levels of organisations in order to speed up up-scaling mechanisms

3.7.7 Public policies evaluation

To be developed: We introduce the research agenda context and stakes with a specific warning: technical changes and markets forces are not the only drivers of agriculture intensification. Public policies play a major role in agricultural evolutions and in the specific choices to enhance and promote one pathway or another. This role will remain and it's simply impossible to analyse intensification dynamics without evaluating and analysing the policies designed to increase agricultural performances. Today, sectorial policies dedicated to agriculture, shift to more global policies. Around the world there are evidences of linkages between public goods dotation, trade policies, social protection instruments, etc. and agriculture intensification. SSA lacks policies evaluation and adapted methodologies to address the way policies influence agricultural intensification.

3.7.8 Multi-criteria Evaluation

New agricultural systems are required to satisfy societal expectations such as higher quantity and quality of agricultural products, reducing environmental impacts and manage natural resources in a sustainable way, and creating more and decent jobs. However, identifying and implementing more suitable agricultural systems is difficult due to conflicting objectives among stakeholders, and to the wide diversity of scientific disciplines required to solve agricultural issues. In economy for instance, the debates and controversies around the substitutability of the different assets (paying for school and education to replace exploitation of non renewable assets, including in agriculture) crystalize these tensions. Therefore,

designing models to assess the sustainability of agricultural systems requires adaptable and multi-criteria decision aid methods.

Sustainability issues have driven academic researchers towards the definition of methodological tools to assess the impacts derived from products and services to measure and compare them regarding their impacts on ecological, economical, social and cultural parameters. Moreover, as the results have to be shared, they must be clear and understandable to a broad public, explaining clearly the conceptual and methodological choices made to construct them. In the evaluation of complex agricultural socio-environmental systems, uncertainty often arises and the quality of decision processes can be a high concern. Defining integrated approaches to assess sustainability of innovative agricultural practices then requests multidisciplinary, multi-methodological, and systemic approach. The task is harder when trying to evaluate sustainability all along the food systems.

Multi-criteria analysis tools

Evaluation tools have been designed, for public policies, but also in order to assist a variety of stakeholders at the local and regional level, for taking decisions. The direct impact of farming is complex to measure due to methodological difficulties (impossibility of measurement, complexity of the system) or practical reasons (time, costs). Indicators aim to measure agricultural sustainability as a function of biophysical, chemical, economic, and social indicators. They appear to be an alternative way of guiding land use decisions. However, the use of an exaggerated number of indicators may desperate decision-makers. Particularly in the tropics, where strategic or local land use decisions are mainly a result of traditions, rules, rights or even based on the informal opinion of local experts rather than on implementation of Decision Support Systems for environmentally sound resource management.

In addition, human knowledge of how to compare complex agricultural systems is incomplete and much of what is thought to be known about this topic is actually imprecise and sometimes incorrect. Yet, decisions must be made despite uncertainty and knowledge gaps. Therefore, tools to support local decision-makers must be flexible, should not enter into too much detail or precision, and should allow for an adaptive strategy, which promotes “learning through management”.

As an example, among many other initiatives, we advertise here the MASC model²⁹, which is a multi-criteria assessment tool designed to assess the performance of cropping systems in terms of their sustainability. It is based on a decision support system and aggregates qualitative evaluation criteria arranged in a tree-like structure. The overall performance of different farmer's cropping systems is evaluated. Incorporating participative methods, MASC allows the farmers to become involved in determining the weights allocated to different criteria, thereby enabling them to introduce their personal vision of sustainability into parameter settings.

In parallel to classical multicriteria models, one of the most comprehensive environmental assessment methodologies, Life Cycle Assessment tools enable evaluation of the environmental impacts of anthropogenic activities along a supply chain. Its implementation raises many scientific questions. In the case of tropical cropping systems, the objective may be for example to understand and model environmental emissions based on the diversity of

²⁹ MASC, a qualitative multi-attribute decision model for ex ante assessment of the sustainability of cropping systems; Sadok, W., Angevin, F., Bergez, J.E. et al. *Agron. Sustain. Dev.* (2009) 29: 447

environments and intensification pathways. They are also focusing on the relationship between initiatives and impacts. Cropping system life cycle assessments show that the impacts vary by crop, environment and type of practice. Life cycle assessment can help guide production methods so as to compare them through their environmental impacts. LCA can also be used to compare alternative products, processes or services; compare alternative life cycles for a certain product or service; or identify the parts of a life cycle where the greatest improvements can be made.

Standards regarding evaluation of global food system, not only vertically, but also horizontally, measuring impacts of combinations of value chains, at landscape and territorial levels, are rare and mostly context specific.

A standard framework to improve through research multicriteria analysis and evaluation tools consists of the following distinct steps:

- Goal and scope definition, which includes defining the system boundary and functional unit of analysis,
- Life cycle inventory (LCI), which includes identification and quantification of all inputs at each stage of the life cycle included within the system boundary,
- Extension of conceptual and methodological work to scaling-up indicators to landscape, food-systems or territorial levels,
- Impact analysis and interpretation of impact analysis.

3.7.9 Ecosystem Services from Sustainable Agricultural Intensification³⁰

The most basic human needs for water, air and food are provided by ecosystems and are often referred to as ecosystem services (Millennium Ecosystem Assessment, 2005). Ecosystem services (ESs) are supported by and depend on biodiversity, and it is generally held that reduced biodiversity in ecosystems is associated with a loss of services. Given the need to feed an increasing human population, ecosystems are increasingly dominated by agriculture, i.e. oriented towards delivering provisioning services of food and fodder. At the same time the long-term sustainability of feeding the human population depends on the supporting and regulating services that underlie the provisioning of food.

Agriculture, by definition, reduces the complexity and biodiversity of ecosystems and has profoundly changed water and nutrient cycles, which has contributed to the degradation of land and water resources and even to climate change. It is estimated that the expansion and intensification of agricultural activity is imperilling 5,407 species. So the challenge is one of achieving *sustainable intensification* of agriculture, where the productivity is increased without undermining agro-ecosystems' biodiversity and the associated delivery of ESs.

Depending on the intensification pathway there may be associated negative impacts on the regulating, cultural and supporting ecosystem services (trade-offs) but sometimes also positive impacts (synergies). There are temporal trade-offs (current benefits come with future costs), spatial trade-offs (where benefits in one area come at a cost in another), and service trade-offs (if management is principally for one service, this comes at the cost of other services).

Intensification pathways change soil properties and processes. One of the means to achieve sustainable intensification is through strengthening the supporting services that underpin the provisioning services delivering agricultural products

³⁰ This section is based on an original contribution of Jeremy Haggard and Freddy Van Lust, NRI, "*Ecosystem Services from Sustainable Intensification*" available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMV2c>

The ESs perspective on sustainable intensification leads to considering the broader objectives and indirect or non-desired effects of agriculture beyond provision of food. There is a strong case for changing the way we approach agriculture, not only for the environment but also to ensure the productivity of agricultural systems in the long run and many technical options are available for achieving sustainable intensification of African agriculture.

Perspective for research: evaluate the potential of intensification practices on ecosystem services delivery.

For example, **agroforestry** has the potential to provide provisioning services such as food (including fruits and medicinal plants), source of energy and fodder, regulatory services including microclimate modification, erosion control and soil conservation, carbon sequestration and pest control, and supporting services namely, biomass production, soil fertility improvement, biodiversity conservation and pollination. However, great differences in biodiversity and ecosystem service delivery exist between plantation and agroforest than between agroforest and natural forest. This suggests that land use change from natural forest to an extensive agro-forest puts less pressure on the environment than further intensifying agroforests into plantation. However, production is higher in plantations, so this is an example of a trade-off between provisioning and supporting/regulating ESs necessitating financial incentives to maintain agroforests.

Conservation Agriculture (CA) also changes soil properties and processes, although the exact impacts highly depend on the agro-ecological characteristics. For example, comprehensive studies of the extent to which CA has an influence on the emission of the potent GHGs N_2O and CH_4 are scarce. Although wetter conditions with zero-tillage have been found to increase N_2O emissions, other studies found reduced emissions or no difference. Besides, water infiltration under CA increases while runoff and soil erosion are greatly reduced. With increased residue retention, total N content increases, although N availability is variable. Therefore, nitrogen fixing cover crops or mineral N are a necessary element in CA to improve or even maintain yield levels. The combined effects of CA lead to a higher biodiversity and a more diverse soil biology, includes beneficial bacterial and fungal species, which can be associated with suppression of pathogens, although more research is needed. However, there is a threshold before the CA principles actually achieve the ESs described above. Insufficient levels of mulching in combination with zero-tillage can fail to deliver ecosystem services of an increased SOM, soil moisture and erosion control.

Ecological engineering is closely related to the concept of *ecosystem restoration* which aims at recovering ecosystems using 'natural' wildlands as a reference condition. However, viewing restoration as 'design' induced a shift towards the restoration of specific ecosystem services, i.e. the various benefits that natural systems can provide to humans. A well-documented example of ecological engineering in Africa is the Push-Pull system, developed by the International Centre of Insect Physiology and Ecology (ICIPE) that helps controlling lepidopteran stem-borers and parasitic weeds in the genus *Striga* affecting in cereal production in Africa. The leguminous Desmodium crop suppresses the parasitic weed *Striga* by a factor of 40 when compared with maize monocrop, and Desmodium's N-fixing ability increases soil fertility, while being an excellent forage for cattle. Livelihood benefits include reduced costs and dependency on expensive pesticides and herbicides and a higher resilience to pest outbreaks. There may also be options for livelihood diversification through improved fodder.

The use of **GMOs** is another agricultural practice that might impact the provision of ES's. In general, studies linking genetically modified traits to ecosystem processes at longer time scales remain rare, but current research indicates that most of the effects of genetically modified organisms (GMOs) on ecosystem processes are indirect and are the result of associated changes in management strategy rather than a direct effect of the GMOs. The

literature seems to support the statement that compared to conventional monocultures, GM crops are environmentally more benign, but there is little evidence that GM crops will contribute to the delivery of vital ecosystem services in diverse smallholder farming systems.

The intensification pathways show different impacts on the provisioning services delivered by agro-ecosystems in Africa. The intensification of provisioning services comes with one or more of the following:

- Higher yield of the main (staple) crops
- Revenue from increased crop variety (such as fruits from trees, beans from cover crops, fodder from field edges, etc.)
- Less work put into the farm
- Less chemical inputs put into the farm

Research could seek to further demonstrate the relationship between productivity sustained by natural biological processes, external inputs and improved soil ecology.

The relationship between agroecological approaches and genetic improvements has been contentious; whether or not genetic engineering and ecological engineering achieve synergies or become entrenched as alternative paradigms for pest management remains to be seen. The development of the latter discipline into a more rigorous branch of ecology will allow it to contribute to the challenge of meeting our needs for agricultural products in a sustainable fashion. It is worth observing that the current global Innovation System for agricultural research is orientated towards the support and expansion of genetic engineering compared to agroecological research, since there are few private incentives for investments in the latter. Much of the concern about GMOs seems to be more related to the dominance of the private sector in this innovation, and equity of access, than the technology per se.

Research could evaluate the contributions of different sustainable intensification practices to regulating and supporting ecosystem services. Some systems such as Agroforestry appear to contribute to almost all services, while for others the outcomes are less certain. Much research remains to be done to establish the degree to which a suite of ecosystem services can be maintained whilst productivity is increased, and whether the intensification should be per unit land or per unit food produced.

3.7.10 Foresight capabilities/ analysis of critical technologies³¹

There are major uncertainties over how technology development will transform production systems, in connection with changes in food demand and according to the availability of natural resources, the political and societal will to promote one or several agriculture models and the role assigned to agriculture in local and national development strategies.

We have emphasised the fact that today's agricultural challenges cannot be tackled using only conventional generic research approaches with their focus on commodities, breeding and waste management. What is required is a much more locally specific type of research which also involves non-biological research relating to the social, institutional and policy dimensions beyond the economics of the food system. But we also know that the relevance of the old formulas is highly questionable. The complexity of sustainable intensification for development and FNS requires new strategies and the production of innovative knowledge. Therefore, future-oriented research is necessary for assessment and design, taking into account the long-term implications of current scientific and technological breakthroughs and streams, paying particular attention to the employment issue.

³¹ This section is based on an original contribution of Robin Bourgeois, "*Foresight capabilities/ analysis of critical technologies*" available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMyV2c>

Regarding the four PROIntensAfrica intensification pathways, many questions can be raised. What are the conditions required for these different pathways to be implemented in different countries? What does a country need to do to steer its agriculture along one (or another) pathway? Can these pathways co-exist within a country or are they incompatible/competing with each other? There are also assumptions that these pathways would lead to very different agricultural structures and have different implications on food production, employment, use and future availability of natural resources. But this requires further evidence. In particular, it requires the building of scenarios at different scales, to anticipate the direct and indirect effects of the implementation of one pathway (or of a combination of pathways) in the long-term. These scenarios should consider the multidimensional aspects of agricultural intensification, the cross-influence of internal and external drivers (at local and international levels), the interdependency between agriculture and the rest of a nation's economy.

In a nutshell, foresight in a science agenda for intensification must be scrutinized, focusing not on the desirable global outputs that the agenda is expected to produce (more food, better use of resources etc.) but on the type of technologies the agenda will produce and the impact these technologies will have on the livelihoods of people (including winners, losers, employment, income, sense of dignity etc.). An agenda on foresight and technological innovation would therefore have to focus more on the technologies we want rather than the science we want, and this requires societies which are in a position to understand what they want by exploring the long-term implications of alternative technologies, documented by research.

This kind of innovative research and knowledge production, and its connection to the plant, field, local and global scales, requires a deep methodological investment. Part of this investment relies on multicriteria studies on intensification performance and impact.

3.7.11 Urban and peri-urban agriculture³²

Urban and peri-urban agriculture (UPA) are part of SSA's food and nutrition security, employment and wealth equation and require specific attention. Their intensification shouldn't be reduced to a question of professionalization. In doing so, research and innovation would be ignoring the complexity of benefits in the urban context that are not directly related to production. On the contrary, such a position requires the documentation and analysis of the diversity of UPA practices and functions. Sustainably intensifying urban agriculture may mean fully recognising its contribution to the urban system as well as to food security and turning that recognition into positive actions.

First, this means leading research and educating farmers on the various intensification techniques, both low-tech and high-tech, of general crop management and the use of environmentally friendly techniques that favour the recycling of waste and water, while simultaneously encouraging municipal authorities to commit to facilitating this recycling. Urban agriculture often involves inexperienced or migrant agricultural workers whose agronomic knowledge is likely to be less certain than the typical rural agricultural worker. Specific knowledge on pest biology or dynamics, for example, is limited and there is a real demand among producers for training in crop management. Training should be an integral part of an overall strategy for the sustainable development of urban and peri-urban agriculture in Africa.

In addition, existing research has neglected the role of indigenous species, even though it has been established that their promotion (particularly indigenous African vegetables) would

³² This section is based on an original contribution of Elodie Valette, "*Urban and peri-urban agriculture*" available on the D2.4 contribution platform <https://drive.google.com/open?id=0Bz1YBNqX1eprNEc2UGJoRHMyV2c>

contribute to the implementation of sustainable and resilient production systems in Sub-Saharan Africa.

Following the work of researchers, it falls to local and national authorities to facilitate the interest in and support for the various forms of urban and peri-urban agriculture, without focusing on commercial peri-urban activities. In other words, to uncover ways to intensify production through the multiplication of installations and forms of agriculture in cities, and recognising the essential role of these micro-agricultural systems. Research efforts need to better characterise these forms of agriculture and the farmers involved. It is also important to consider the often overlooked role of women in urban agricultural production. This means better quantifying the extent of UPA and their contribution to food security, family incomes and the local economy.

Again, this means better qualifying their extent (what land is involved? Is the situation precarious or not? What is the agronomic condition of the soil? Is there competition over land use? etc.) and qualifying and quantifying the dynamics of urban and peri-urban areas while characterising the large-scale loss of farmland and increased fragmentation in order to provide better information for public planning decisions. Here, information is critical to enable elected officials, who are often poorly versed in agricultural issues, to approach the question as a benefit to the urban system rather than a nuisance.

Finally, research on the various impacts of urban and peri-urban agriculture is a continuing process. Research on UPA has primarily addressed questions of water and soil pollution and rarely broached the issues surrounding the durability of the complete urban system. Research conducted on the development of production systems that conserve water and soil, and strive for minimal environmental impact on these resources, is a priority, as is the need to consider both high and low-tech options in agro-ecological and ecological intensification pathways that address the diversity in urban and peri-urban agriculture in SSA. Reciprocally, advances in ecological intensification, agro-ecology and organic agriculture in urban locations will benefit intensification pathways in rural areas.

3.8 Conclusion

This document is the fourth and final deliverable that the WP2 had undertaken to produce during the execution of the project. It comes after three other documents which have already been delivered:

- A literature review about experiences and research and innovation results obtained with a large spectrum of intensification pathways
- An assessment framework including a list of criteria and indicators for evaluating effects, impacts and drivers of different pathways of intensification at plot, farm, communities, and public policies scales
- Light case study and in-depth case study reports of identified cases, including a synthetic cross-analysis report (month 19).

These building blocks will be later in the project confronted (i) to the case studies conclusions, (ii) to the vision and criterion as developed by the other WPs, and (iii) to a realistic future Europe / Africa partnership. From these confrontations, the final ProIntensAfrica R&I agenda will be derived.

Concerning the confrontation with case studies, this work will be done by systematically matching the conclusions of the case studies reports with the "drivers" part and the "research agendas" part. This will allow to update the proposals made in D2.4, which actually come from the literature review rather than field experiments. We can also make them more concrete and real, incorporating in particular the question of drivers, which will make the link

between research and innovation. Finally, it will be possible to visualize how specific research and innovation initiatives could benefit stakeholders on the ground.

This analysis will be prepared by WP2, and the results will be discussed at the Lisboa Writeshop in January 2017.

In addition, it is planned to develop interactions between WPs during the writeshop of Lisboa. By that time, we will have more outputs from other WPs to finalise a more compact and coherent proposal. In particular, the question of governance and funding mechanisms (competitive or non-competitive calls, co-construction, co-management, etc.) will be essential in order to draft the way in which the R & I agenda will be structured.

Finally, the issue of the Europe / Africa partnership will also be raised at the Lisboa meeting. Depending on the options chosen, it will be possible to sort out the possibilities that will be realistic and have some chance of being implemented.

