Priority interventions for transformational change in the Sahel

Working Paper No. 353

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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CGIAR

RESEARCH PROGRAM ON
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To cite this working paper
Abberton M, Abdoulaye T, Ademonla D A, Asiedu R, Ayantunde A, Bayala J, Cofie F, Kane-Potaka J, Sanders Z, Tabo R, Tenkouano A, Tepa-Yotto G, Whitbread A, Worou O N, Zougmore R. 2021. Priority interventions for transformational change in the Sahel. CCAFS Working Paper no. 353. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

About CCAFS working papers
Titles in this series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

About CCAFS
The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is led by the International Center for Tropical Agriculture (CIAT) and carried out with support from the CGIAR Trust Fund and through bilateral funding agreements. For more information, please visit https://ccafs.cgiar.org/donors.

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Abstract

The Sahel region holds both challenges and opportunities for smallholder agriculture/agropastoralism. Market opportunities for food producers in the region have improved due to population growth, urbanization, income growth, dietary diversification and higher output prices. However, alongside land degradation and climate change, an increased dependence on dynamic food (and feed) value chains and on volatile markets indicates the need to address structural constraints such as limited access to high-potential agricultural innovations, ineffective policies, an underdeveloped business environment, poor infrastructure and processing facilities and a generally poor market infrastructure.

To support the agricultural transformation required to meet these challenges, evidence needs to be provided to countries in the Sahel to enable them make informed decisions on policy reforms where and when needed. Several scaling approaches and technological solutions have been demonstrated to be effective and this document outlines proposed priority actions to achieve higher adoption of climate smart agriculture through Public-Private-Partnerships. A particular focus will be on the role of women and youth, both through improved household nutrition (and other attendant health and development benefits) and through improved job creation and wealth generation in various components of selected value chains. Meanwhile, the importance of improved agro-industrialization and trade for income generation and poverty reduction underscores the critical role of enhanced interaction with a vibrant private sector.

This document presents some of the main routes by which R4D can contribute to agricultural transformation in the Sahel towards inclusive and sustainable economic growth, social development and resilience, including climate smart agricultural technologies appropriate to smallholder farming families. This will be achieved through a six pronged strategy: (i) Increasing the efficiency of tree, crop and livestock value chains, (ii) Empowerment and increased employment opportunities for women and youth in agriculture, (iii) Co-creation of context-specific, climate smart innovations to enhance climate resilience (iv) Value addition and improved

nutrition, (v) Improved soil and water conservation and its utilization for production, (vi) Improved policy and institutional enabling environments.

Keywords

Smallholder farming; climate change; agricultural transformation; sustainable economic growth; Sahel regions.

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Acknowledgements

The authors would like to thank several individuals for their excellent participation, collaboration and contribution to the research work included here. They are:

Members of the Committee formed for the Sahel region to support the organization of the Two Degree Initiative (2DI) and the World Bank RFSP investments

Participants of two earlier workshops at (1) the IITA headquarters in Ibadan, Nigeria, during 12-14 March 2019 to promote R4D in the Sahel, (2) the ICRISAT Regional Hub in Bamako, Mali, during 2-3 July 2019, to further discuss and agree on an advocacy and strategy document for the Sahel

The ICRISAT research team: Dr. Michael Vabi, Ms. Agathe Diama, Dr. Haile Desmae, Dr. Dougbedji Fatondji, Dr. Mathieu Ouedraogo, Dr. Hakeem Ajiegbe, Dr. Birhanu Z. Birhanu, Dr. Aboubacar Toure, Dr. Jummai Yila, Dr. Issoufou Kapran, Dr. John Nzungize and Dr. Malick Ba.

The IITA research team: Dr. Alpha Kamara and Dr. Boukar Ousmane

The WECARD/CORAF research team.

Contents

Acronyms

AFDB	African Development Bank
ARI	Agricultural Research Institute
BDL	Bio-reclamation/restoration of degraded lands
BIMAF	Biorisk Management Facility
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
GHG	Greenhouse gases
CEG	Center of Excellence in Genomics
CERAAS	Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse
CORAF	Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricole
CSA	Climate Smart Agriculture
CSV	Climate Smart Village
FMNR	Farmers' Managed Natural Regeneration
GAP	Good Agronomic Practice
ICRAF	World Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
IWMI	International Water Management Institute
ILRI	International Livestock Research Institute
IPM	Integrated Pest Management
LDSF	Land Degradation Surveillance Framework
NARS	National Agricultural Research System

NGO	Non-Governmental Organization
NRM	Natural Resource Management
PICSA	Participatory Integrated Climate Services for Agriculture
PPP	Public Private Partnership
PPS	Peste des Petits Ruminants
PRAPS	Projet régional d'appui au pastoralisme au sahel
SDG	Sustainable Development Goal
ISS	Innovative Small Scale
TAAT	Technologies for African Agricultural Transformation
R4D	Research for Development
RRC	Rural Resource Centre
UN	United Nations
UNICEF	United Nations Children's Fund
WAAPP	West African Agricultural Productivity Programme
WiFi	Wireless Fidelity

Introduction

The Sahel region, defined here as the semi-arid area of West and Central Africa located between the Sahara Desert and humid Savannas, has average annual rainfall between 400 mm and 700 mm (Figure 1). In the region, complex combinations of semi-subsistence tree-crop farming and livestock agriculture constitute the main source of livelihood for 60-80% of population (Faye et al. 2018). The predominantly rainfed Sahelian agriculture and natural resources are threatened because of climate change and the high human pressure (Da et al. 2017). Implications of climate change to agricultural systems and livelihood are presented in Table 1.

With substantial population growth (average 3% per year) and recurring challenges, climate change in the Sahel will compound existing vulnerabilities (USAID 2017). These challenges are linked to environmental degradation, pervasive poverty, access to land, conflicts, rural exodus, low inputs agriculture, and lack of access to credit and markets. Noteworthy among the multiple processes and stressors that shape the region's vulnerability to climate change are:

- Widespread malnutrition, disproportionately affecting children and pregnant women. In 2020, it is estimated that more than 5.4 million children under five will suffer from acute malnutrition, including 2.4 million in six Sahelian countries (Burkina Faso, Chad, Mali, Mauritania, Niger and Senegal) and 12 million people will experience food insecurity;

- Persistently underperforming agriculture due to low productivity induced by a range of biotic and abiotic stresses. Low soil fertility associated with insufficient use of fertilizers and mechanization, leads to high pre-harvest losses, further compounded by high postharvest losses arising from inadequate storage and limited processing capacities;

- Insufficient enabling environment for Sahelian agriculture to boost its performance. Less than 2% budgetary allocation to agriculture against the recommended 13%, mining the region's prospects for food security and household cash savings;

- Rapidly growing human and livestock populations putting pressure on land, water and other natural resources (Tilman et al. 2011, Hertel 2015). With limited off-farm jobs in rural areas, rural exodus, diverse conflicts, seasonal migration, emigration and internal displacement are precipitated (Kirwin and Anderson 2018).

The promotion of more resilient agricultural development pathways can be achieved through: sustainable agroecological intensification in response to demographic growth, sustainable management of soil fertility and natural resources, more profitable access to the agricultural market for producers, mainly family farms (HLPE 2019, Sinclair et al. 2019, Nelson 2020) and gender equity, while ensuring environmental sustainability (Vermeulen et al. 2018)

To address the above, regional projects covering six Sahelian countries (Burkina Faso, Chad, Mali, Mauritania, Niger and Senegal) have been implemented, including: Improving Pastoralism in the Sahel (PRAPS) funded by the World Bank; the Technologies for African Agricultural Transformation (TAAT) Program funded by the African Development Bank (AfDB) and other agencies; and the West Africa Agricultural Productivity Program (WAAPP) funded by the World Bank. A substantial number of other projects described and implemented by CGIAR centers can also be leveraged. The Climate Smart Agricultural Technologies (CSAT) projects are led by IITA in Mali and Niger, and funded by the Norwegian Embassy in partnership with NARS and NGOs. Finally, there is the substantial work done in covering climate information and advisory services by the CCAFS program in the region.

Challenges induced by climate change in agriculture sector in West-Africa Sahel

Land degradation is a major environmental challenge in the region and climate change exacerbates the rate and magnitude of several ongoing land degradation and desertification processes. Human drivers of land degradation and desertification include expanding agriculture, agricultural practices and forest management. In turn, land degradation and desertification are also drivers of climate change through greenhouse gases (GHG) emissions, reduced rates of carbon uptake, and reduced capacity of ecosystems to act as carbon sinks into the future (Olson et al. 2019). Most soils in this region are sandy and pose a great challenge to sustainable management. This is due to inherent poor soil fertility, pressure from rapid population growth and food price volatility, inappropriate agronomic practices and overgrazing.

The drivers of land degradation related to climate change are: gradual changes of temperature, precipitation and wind, as well as changes of the distribution and intensity of extreme events (Lin et al. 2017). Agro-climatic trends in the Sahel show a significant increase in hot days and heat waves that are harmful to agropastoral systems. Temperatures in the Sahel are already close to maximum for plant growth. The effects of increased temperature may affect the pattern of rainy seasons in various ways: 1) Late onset of cropping season with the risk of re-sowing, 2) Early cessation of rainfall which requires varietal adaptation and the tactical planning of farm operations based on climate information, 3) Erratic rainfall patterns with recurring droughts and insufficient rainfall which requires rain water harvesting techniques for increased water infiltration and supplemental irrigation; and a resurgence of heavy rains and floods in other places, 4) higher pressure of pests and diseases and emergence of new ones.

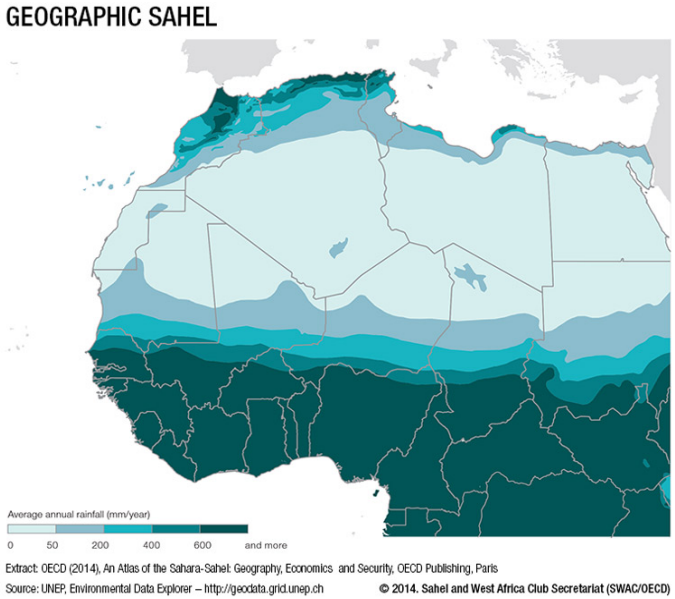
Opportunities and challenges for the Sahel region

The Sahel region is characterized by complex multifaceted challenges, including short irregular rainy seasons and recurrent droughts, resulting in low productivity.

Furthermore, the region is characterized by high demographic pressure, political instability, violent extremism around natural resource use, frequent conflicts, and vulnerability to climate change effects, thus accelerating the degradation of natural resources (Nett and Rüttinger 2016). Despite these constraints, there are opportunities to scale climate-smart solutions for more balanced diets, increased food and nutrition security, sustainable food systems and resilience among the rural population (Bayala et al. 2016, Zougmore et al. 2016, Partey et al. 2018). Due to its hot and dry weather, the region has natural comparative advantages for crop-livestock integration, climate-resilient and -resistant crop varieties as well as tree species and varieties. Also, farmers are more aware of climate change and have been adopting adaptation options including use of improved varieties, crop diversification and more (Abdoulaye et al. 2003). Other substantial key opportunities for the region include abundant solar radiation to be tapped for solar energy and unexploited value chains associated with key commodities in the region, such as millet and sorghum.

Across the Sahel region, agricultural systems are subjected to numerous constraints from production to processing.

The challenges and opportunities described above necessitate interventions to raise agricultural productivity, safeguard and add value to crop products and livestock production, and improve value chains to enhance employment opportunities, especially for women and youth. CORAF/WECARD, ICRAF, ICRISAT, IITA, ILRI, IWMI and the NARS have engaged in development and dissemination of new technologies such as improved crop and tree varieties; livestock breeds; agronomic, livestock and agroforestry practices; and land and water management innovations across the Sahel (Figure 1). Through the TAAT program, a large-scale dissemination effort of these innovations is underway in several African countries including the Sahel. Several NGOs, ARI and UN agencies have also undertaken activities aimed at poverty reduction, improvement of food and nutrition security, sustainable farming systems and restoration of natural resources.



IITA

- Germplasm resources
- Improved high-yielding, stress-tolerant and nutritious varieties and hybrids
- Climate-smart agronomic practices

Climate-smart IPM technologies

- Hermetic storage of grains
- Scaling readiness tool
- Integrated soil fertility management

ICRAF

- Tree germplasm,
- Improved seeds, planting materials and seed systems
- Climate Appropriate Portfolios of Tree Diversity (CAPTD)
- Climate-smart technologies and practices
- Livelihood activities planning tools based on a better understanding of local climate
- Land and landscape restoration

ILRI

- On-farm climate smart livestock interventions
- Integrated feed and health package for improved ruminant production
- Participatory management of conflict over natural resources between farmers and herders
- Inclusive value chain development including strengthening Small and Medium scale Enterprises (SME) particularly for youth and women
- Index-based livestock insurance

ICRISAT/CCAFS

- Germplasm resources;
-Improved high yielding and dual-purpose Varieties and hybrids;
- On-farm climate smart technologies and practices;
- Local Communities and Watershed management
- Models for scaling technologies (promotion of climate-smart villages, demonstrations, PPP for strong seed system and healthy food system, climate-smart mechanization and infrastructure)
- PPPs and business models for digital smallholder value chain orchestration and value creation
- early warning and agro-climatic advisory services

IWMI

- Low-cost irrigation solutions to increase productive use of water
- Farmer-led irrigation development approaches;
- Scaling business models with private sector for irrigation value chain development
- Digital solutions for small-scale farmers to use water more productively
- Mapping potentials for ground and surface exploitations
- Integrated landscape approaches to build climate resilience.
- In-situ water harvesting and storage approaches, including Bhungroo Irrigation Technology (BIT)

Figure 1: CGIAR centers' best-bet technologies promoted in collaboration with CORAF members states and other local partners

Pathways for agricultural transformation in the Sahel through climate-resilient technologies and practices

To reach a large number of beneficiaries, partners have to be enabled to help design transformative and climate-smart agricultural development pathways, which will require:

1. An enabling environment for scaling (policies, government support, capacity development);

2. Climate-smart technologies for crops, livestock, agro-forestry and irrigation;

3. Increasing the resilience of Food Systems for Healthy and Sustainable Diets 18

4. Mechanisms for scaling climate smart innovation in collaboration with other outcome actors using balanced and organized approach towards cooperation between actors in the research, development and private sectors.

In this context, R4D organizations have actively designed, tested and implemented a wide range of promising approaches, practices and technologies for climate-smart agricultural production that are deemed suitable for small-scale producers. A description of these technologies is presented below and as tool kits in the Annex 1 of this document.

An enabling environment for scaling (policies, government support, capacity development)

Building resilience of communities through inclusive climate and weather information services

Access to climate information enables both strategic (long-term) and tactical (short-term) planning of farming and livelihood activities for building resilience against climate change (Dayamba et al. 2018). The expanding availability and access to climate and digital weather advisory services requires leveraging digital innovation and state-of-the-art data management technologies (e.g. Open Data Cube (ODC)) to provide advisory services to small-scale farmers so that they can take informed decisions on timing of agronomic practices and irrigation water application.

Unlocking the full potential of the ODC will translate vast amounts of data into end-user-focused applications that can help inform agricultural water management-related decisions such as water use and availability, risks, water quality and water productivity improvements. In this context, water accounting, flood hazard mapping and agricultural drought early warning system would be developed for the entire Sahel using weather forecast, satellite data and open-source model. This will guide decisions, providing flood and drought analysis for planning and responses, and

inform small-scale farmers in the Sahel region with the aim to improve resilience to climate shocks and variability.

Policy dialog platform to mainstream CSA into national and regional agricultural investment

The Sahel is known to be one the regions most exposed to climate threats with feedback loops both at the regional level and with other regions. This calls for solutions that go beyond a country and even the region. Nevertheless, as we are operating in the region, our approaches will be limited to it without losing sight of the impacts of larger scale. The capacities of stakeholders have been strengthened to generate climate information and develop climate advisory services including their dissemination using ICT tools and evaluating the impacts of their use. Inventory, prioritization, testing and validation of more practical climate-smart technologies and practices have contributed to a compendium of context-specific best-fit CSA options that can easily be taken to scale.

To create the conditions for sustainability, efforts are being deployed to mainstream the principles of these climate-smart approaches into policy regulatory measures at the region and country levels (region and national CSA alliances and strategies) and in the operations at the program and project levels. CORAF already has been building a relationship with the national Climate Change Focal points in its mandate region. The Focal Points have been supported by CORAF through the provision of scientific evidence by a cohort of climate change scientists under the auspices of the African Group of Experts. At the regional level, CORAF was a key member of the organizers that established the West Africa Climate Smart Alliance aligned to the continental CSA under the auspices of CAADP.

Inclusive policy

Improved policies, institutions and capacities to mainstream cross-cutting agricultural sector challenges – particularly gender and coordination – will be embarked upon. The institutional framework needs to be improved to allow better access to markets, notably quality and grades in some cases, but also better mainstreaming of gender concerns in programs and policies. All of these will need continued support in terms of capacity building to empower women and other socially disadvantaged groups to participate in decision making. Conflicting national and regional policies and institutional roles are to be identified and corrective measures undertaken at different levels of governance in countries of the Sahel. Key areas to be considered include seed systems, research, input pricing, fertilizer and pesticides, trade, agricultural sector financing and mechanization.

Increased farmer access to funding

Agricultural financing is a critical bottleneck to the agricultural transformation envisioned here to improve food security and nutrition status as well as to reduce poverty. Approaches such as the inventory credit system or warrantage can quickly improve access of farmers to local funding. However, for big investments, a direct involvement of private capital and the private banking sector will be critical. Meanwhile, agricultural policies can quickly and efficiently change the way farmers, particularly women, access and use innovations and how they can access support

and essential services such as financing. In Nigeria, for example, the introduction of the e-voucher has increased farmers' access to improved varieties and fertilizers in just a few years (Wossen et al. 2017). In the region, expertise and skills are available to analyze and produce reliable information for use by policymakers. Existing programs such as the Regional Strategic Analysis and Knowledge Support System (Re-SAKSS) are providing direct policy support and could be expanded to more specific areas for deeper analysis of access to inputs, product pricing and quality, etc.

Furthermore, there is a need to organize farmers for collective action (buying inputs and selling outputs) which could affect the prices they get (both selling and buying). This can also help with input quality issues and access to information etc. At the farm level, better threshing and cleaning of grains can lead to price premium in the markets and finally, improving access to financing through contract farming, warrantage, crop insurance etc. are also critical interventions for agricultural transformation in the region.

Empowerment and increased employment opportunities for women and youth in agriculture

Population in the Sahel has been increasing and currently its growth rate is estimated at 4.5% annually while the arable land remains constant, showing a need for creation of off-farm agricultural product-based jobs. However, agriculture will remain the main job-creating sector in the coming decades given the current weak status of the rural economy and the fact that migration of poorly qualified youth out of the rural areas is not leading to better lives for them (Haggblade 2005). Therefore, a more conductive environment is needed for these youth to enter the job market smoothly.

Catalyzing of agribusiness and entrepreneurship with focus on youth and women

In many countries, the food processing sector is the largest manufacturing sector in terms of employment. A key characteristic of agro-processing is its strong upstream and downstream linkages, making it a key factor for employment creation and poverty eradication. Furthermore, in all countries' agriculture strategy, the agro-processing value chain is central to Governments' rural development and Development agencies such as AfDB objectives (AfDB 2016). Necessary interventions include value chain development, creation of agribusinesses and entrepreneurship with a focus on youth and women. These approaches can operate across all commodities value chains within and outside the agricultural sector and will be a key point of engagement with private sector partners. With this, youth and women need to be trained, and standard protocols for processing developed to consistently produce high-quality processed products. Indeed, there are opportunities due to the emergence of a middle class and migration of some rural people to the cities, both which have specific needs in processed products.

Making agriculture attractive for youth

Agricultural transformation in Sahel will require improvement in the production tools and methods, both on and off the farm. The sole reliance on rudimentary farm tools, particularly hoes and cutlasses, have for long kept agriculture backward and

made it unattractive for youth while simultaneously making work less efficient. In order to reduce drudgery and improve efficiency of production systems, appropriate mechanization in Sahel will be required. A number of small-scale equipment such as planters, harvesters, ridgers, etc. have already been developed and are currently being deployed. Similarly, value addition equipment (for threshing, grading, grating, extracting, drying, storage, milling and packaging) are being evaluated and disseminated in collaboration with NARS. Introduction of such equipment will certainly make agriculture more attractive while creating opportunities for youth and women in the agricultural sector of the Sahel. These efforts should be coupled with dissemination and use of digital tools to provide information on production technologies and markets to the new generation of farmers. The full potential of digital agriculture should be exploited to allow access and sharing of climate and farm-related information to guide the choice of crop varieties and the development of production plans.

CORAF is maintaining a platform (http://mita.coraf.org/) to showcase a vast number of agricultural technologies developed by research organizations in the region. In addition, a web TV (http://agripreneurtv.coraf.org/) established by CORAF showcases technologies as well as success stories of youth in agriculture in the region. Moreover, a youth mentoring program is linking youth seeking professional coaching to designated mentors on the effective use of a range of technologies that these youth are interested in.

Addressing barriers in gender equity

Common research and development programs and policies highlight significance of women as key players and agents of agricultural growth and productivity, family and national food security, and nutrition, agricultural and/or development projects. To address wide productivity gaps, gender equality/equity approaches have been implemented to increase women's livelihood options (for increasing food security, income, skills and knowledge, and increasing availability of appropriate technology to reduce workload) and strengthen their ability to make strategic life choices and put them into action. Under the just phased-out West Africa Agricultural Productivity Programme coordinated by CORAF, all the participating countries across the region made significant advances in mainstreaming gender in the respective national programs. There are now dedicated gender Focal Points in all these countries, and by the end of the program, all countries had surpassed the minimum limit of 40% effective inclusion and participation of women in various projects.

Investment for resilience being a long-term engagement, investing in climate-smart practices faces tenure issues (land and tree) which prevent landless farmers, including women and youth, from investing in CSA options even when they have the resources to do so (Partey et al. 2018). Access to land and natural resources is therefore key in the Sahel where agriculture is experiencing tenure tensions. These tensions arise from a combination of factors including rural youth population increase, pervasive circular migration of urban investors buying in rural areas, large-

scale foreign acquisitions of lands and the associated transfer of lands from customary tenure to state-titled lands (Haggblade et al. 2010).

Climate-smart technologies, practices and tools

Climate-smart food production can be achieved by promoting a holistic approach to the systemic challenges in the region. A systems approach that enhances access to water for irrigation; bundles water, crop, agroforestry, livestock management; and combines different technical, social and institutional innovations to use natural resources more productively is the need of the hour.

Climate-smart practices, including fertilization, integrated pest and disease management and appropriate planting densities, have been developed for most crops. Some proven practices are presented below:

Adaptive land and water planning

In the Sahel, water availability and access are critical for both crops and livestock. Therefore, local actors have developed a range of water-harvesting or water-saving technologies and practices. Most of these technologies have been improved and made smarter in the face of a changing climate through participatory action research led by national and international institutes. While these well-known technologies work very well at the plot and farm levels, there are challenges operating them at the landscape level.

That is where partnering with specialized institutions such as IWMI, ICRISAT and ICRAF can help, to develop integrated and participatory approaches at field level, for small reservoirs and inland valleys, and sub-catchment and watershed levels. Using integrated landscape approaches and participatory tools and approaches, we bring together various users of water resources in a community, including farmers, fishers and aquaculturists, and pastoralists to design adaptive water management plans that ensure food security, optimal use of water resources and stability within a community.

Soil and water conservation techniques

Zaï planting pits, water recycling under aquaponic systems and earthen/contour bunds resulted in higher crop yields (30 to 50%), increased supplies of valuable goods and services such as firewood and fodder, increased cash incomes and employment opportunities for youth and women, thereby increasing resilience to the effects of climate change (Zougmore 2018). Similarly, fertilizer micro-dosing, which refers to the utilization of relatively low quantities of fertilizer (< 20 kg ha^{-1}) through point placement of small doses of mineral fertilizer has been developed and is being disseminated. Lastly, organic liquid and solid fertilizers from organic waste recycling by insects (Black Soldier flies) has been recently introduced in the Sahel and is under scaling by private partners/companies.

Bioreclamation of Degraded Land

Innovative approaches to improve soil health through bio-reclamation/restoration of degraded lands (BDL) were developed. BDL is an agroforestry system that reclaims the lost agricultural potential of degraded soils, and it is being scaled out. BDL increases water availability and productivity of the land by increasing water infiltration and harvesting using a mix of resilient woody species and income-generating annual species[1].

Affordable irrigation solutions for small-scale farmers

Farmer-led irrigation (FLI) development has recently been adopted by the African Union as one of the four development pathways for improving agriculture. It has been shown to be more sustainable with high return on investment than traditional scheme development, with higher crop yields and revenues for farmers. Investing in irrigation solutions lifts farmers out of poverty and makes them more resilient to climate shocks and variability. Scaling of FLI irrigation development requires a well-functioning irrigation value chain including access to credit for farmers. IWMI has developed business models to accelerate investment in innovative small-scale irrigation solutions by including private sector parties. IWMI has developed methodologies that use spatial analysis of landscape, weather, and ground and surface water resources to map areas with high potential for FLI irrigation development including solar irrigation opportunities.

IWMI works with public and private partners on designing and evaluating low-cost irrigation solutions. For example, farmers in Mali and Burkina Faso now efficiently exploit shallow ground water resources using shallow tube well, conveyance and water-lifting technologies. It enables farmers to lift water and irrigate crops during the dry season. Wetting front detectors such as the Chameleon sensors guide farmers in a self-learning process to optimize irrigation quantity and timing to their fields and maximize irrigation water and fertilizer use to increase benefits from farming. Training youth to work as service providers to farmers was successful in Mali where farmers create contour bunds in their fields with support from trained service providers.

Finally, solar irrigation solutions are evaluated to be a very cost-efficient, highly profitable and sustainable long-term investment. Business models with private sector involvement are proposed to strengthen the irrigation value chain and to scale solar irrigation solutions to small-scale farmers.

Water resource monitoring for smarter use

This should also include the right to access and to use the water resources in the landscape and by the beneficiary communities. Finally, a good monitoring and evaluation system will be needed, including additional investments in hydro-met infrastructures that will help assess the impacts at scale, collect data, develop a database and generate data-based decision support tools for evidence-based

[1] http://www.icrisat.org/impacts/impact-stories/Converting-degraded-soils-into-productive-land.pdf

decision making for landscape and water resources management. Opportunities in emerging markets for renewable energy in the sector will be valorized through smarter use of water resources. E.g. Solar pumps to be used at a larger scale for domestic and agriculture applications through context-appropriate input access schemes supported by a strong political will and environment.

Land use change and land cover management

ICRAF has developed tools and methods to measure and track regreening interventions such as the Land Degradation Surveillance Framework (LDSF), which aims to understand the underlying processes of land degradation and monitor the impacts of project interventions on soil and land health (Vågen et al. 2013, 2018, 2019). This has implications for our ability to measure, for example, the effectiveness of interventions on soil organic carbon (SOC) sequestration for climate change mitigation. LDSF allows for the measurement of multiple variables at the same geo-referenced location and allows for the rapid assessments of indicators of land and soil health. Coupled with remote sensing, these data are used for producing high quality maps of key indicators and conducting robust statistical analysis on drivers of degradation as well as monitor changes over time (Vågen and Winowiecki 2019).

Integrated soil fertility management (ISFM)

The use of inorganic fertilizers on their own, as per standard recommendations, is not always profitable to many small farmers in West Africa, particularly where rainfall is erratic. By following an Integrated Soil Fertility Management (ISFM) approach, the efficiency and hence profitability of inorganic fertilizers can be improved. ISFM has been defined as 'a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm, combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity' (Vanlauwe et al. 2010, 2017). Increased use of organic and inorganic fertilizers, together with diversification of cropping to include legumes are important tools in restoring or sustaining the soil fertility for the intensive cropping systems of the savannas of West Africa (Vanlauwe et al. 2001, Sanginga et al. 2003, 2015). These 'balanced nutrient management systems' can be further enhanced through the use of improved cultivars that are tolerant to drought, resistant to Striga and use available nutrients efficiently, such as maize cultivars developed at the International Institute of Tropical Agriculture (IITA), Nigeria (Kamara et al. 2005).

The grafting in Farmer-Managed Natural Regeneration (FMNR)

This technique is now being used in situ on individual trees preserved in Farmer-Managed Natural Regeneration (FMNR), giving what is now known as FMNR+ (Ky-dembele et al. 2020). Pure or dispersed plantation with varying densities depending on the niches, including *Adansonia digitata*, *Tamarindus indica*, *Vitellaria paradoxa*, *Ziziphus mauritiana*, etc., are based on grafting. Grafting is a horticultural technique where tissues from one plant are inserted into those of another so that the two sets of vascular tissues may join together. Ecotypes with desired fruit quality traits

(sweetness, size) identified for some species (*A. digitata, T. indica, V. paradoxa,* etc.) and cultivars for others (*Ziziphus* spp) are used in this technology. For instance, the cultivars of improved *Z. mauritiana* (Seb, Gola and Umran) produce fruit in less than six months, which are bigger (19 g) compared with local (2 g) (Kalinganire et al. 2008).

With the Regreening Africa App[2] tool, there is opportunity to allow rapid capture of information on intervention on FMNR, nursery establishment, tree planting and capacity building. Innovative monitoring and evaluation system for assessing programs performances are also determinant.

Climate-smart Integrated Pest Management

Strengthening the resilience of agricultural systems in the face of climate change necessitates the development and deployment of a holistic and smart management strategy of pests and diseases. Managing biorisks in a climate-smart manner includes the large-scale dissemination of efficient and climate-resilient biocontrol agents and the enhancement of ecosystem services. It also underlies the use of suitable biorationals and biopesticides to sustainably reduce pest-induced crop losses without compromising efforts towards a low-carbon economy. The concept is currently being implemented by the IITA's Biorisk Management Facility (BIMAF) in Mali and Niger through the Climate Smart Agricultural Technologies (CSAT) projects. Real-time climate data linked to pest and disease management will also be important.

Integrated management of Striga

Striga hermonthica, a parasitic flowering plant, constitutes one of the most severe constraints to cereal production in sub-Saharan Africa. It parasitizes sorghum, maize, millet, rice and sugarcane, as well as pasture and wild grasses, by attaching itself to the roots of the host plant diverting essential nutrients and leaving the host stunted and yielding little or no grain, often causing yield losses in excess of 50%. Component technologies for effective control methods include use of imidazolinone resistant (IR)-maize, which directly controls Striga below ground and reduces its seed bank; use of maize resistant to S*. hermonthica*; and use of leguminous crops which stimulate suicidal germination and therefore reduce the seed bank. However, Striga control is achieved through an integrated Striga control (ISC) program to provide more flexible and sustainable control over a wide range of biophysical and socio-economic environments.

In addition, cowpea production is currently seriously affected by Striga and Alectra. Control of these parasitic weeds is critical for boosting production of one of the most important legumes of the Sahel in terms of nutrition and income. Cowpea is one the most important exports from Sahelian countries to the coastal ones in West Africa. Therefore, it is a regional trade-enhancing factor that needs to be improved. IITA, NARS and USAID Collaborative Research Support Program (CRSP) have worked

[2] Available for Android on https://play.google.com/store/apps/details?id=com.icraf.gsl.regreeningafrica&hl=en

on these issues and have several technologies available. Options available for control of Striga and Alectra include resistant and tolerant varieties developed and released by NARS, agronomic practices such as crop rotations, strip cropping and, of course, use of chemicals.

Aflasafe and aflatoxin management system

Aflatoxins are potent human carcinogens that suppress the immune system, stunt child development, and often kill people and animals. It is estimated that up to 60% of maize and groundnut crops can be contaminated with aflatoxins leading to 1.6 million disability-adjusted years annually. The profitability of poultry and fish industries is deeply curtailed by aflatoxin-contaminated feed and there is evidence that poultry farmers are willing to pay for options to reduce aflatoxins in their feeds (Johnson et al. 2017). Crops with unacceptable aflatoxin levels face trade sanctions. Aflatoxin can be managed to improve access to markets, increase profitability of the poultry industry and reduce human exposure to aflatoxins, thus improving health. Aflasafe is a biocontrol product that consistently reduces aflatoxins by more than 80% during pre-harvest and postharvest stages, and throughout the value chain.

Fodder bank

ICRAF has developed a woody species fodder bank technology that can help improve and adapt peri-urban and urban livestock raising while reducing the pressure on natural resources (Place et al. 2011, Bayala et al. 2014). A fodder bank is an enclosed area of concentrated forage legumes reserved for dry season supplementary grazing. It can be preserved from natural vegetation or from densely planted woody fodder species at 2 m spacing between rows and 1 m spacing between plants on the row. Candidate species include *Pterocarpus erinaceus*, *Pteorcarpus lucens*, *Kigelia africana* and *Gliricidia sepium*. They are planted and managed to produce large quantities of green feed during the dry season (March–June). This is a high-quality forage with 18–22% crude protein levels.

Integrated feed and health package for improved small ruminant production

In the Sahel, there is significant potential for improving livestock production systems, notably small and large ruminants. NARS and international institutes have developed efficient livestock feeding systems that could help reduce the feed scarcity challenge and improve feed quality in the Sahel. Working with NARS and the private sector, we are introducing in communities the local production of insect meals for livestock feed formulations.

it has been demonstrated that simple interventions involving disease control, improved nutrition and better management lead to marked positive effects on small ruminant performance and productivity. This feed and health package developed by ILRI entails deworming and vaccinating sheep and goats against main diseases such as Pasteurellosis and Peste des Petits Ruminants (PPR). In addition to healthcare, there is strategic supplementation of the small ruminants to improve their performance. The feed supplement is based on available feed resources. This

integrated feed and health package led to doubling of the household flocks within one year.

Least cost ration for profitable sheep fattening

Sheep fattening is an increasingly important economic activity in the West African Sahel, particularly in and around Tabaski, the Islamic festival of Eid-al-Kabir. It is extremely attractive to poor farmers, including women, in the region. Traditional sheep fattening is characterized by feed waste as feeding is on an ad hoc basis depending on available feed resources. From several feeding experiments conducted by ILRI – both on-station and on-farm – optimal feed combinations for sheep fattening have been developed which entails feeding levels of between 600 and 900 g per day of cowpea hay or groundnut haulm, and 400 g of millet bran along with ad libitum feeding of roughages such as bush hay, millet stover and/or sorghum stover. The fattening duration should be between 60 and 90 days to be profitable. https://cgspace.cgiar.org/handle/10568/72736

Increasing the resilience of food systems for healthy and sustainable diets

With high population growth rates[3] across the Sahel, increasing crop, tree and livestock production is the main objective to be addressed within the context of agroecological sustainable intensification under climate change conditions. Interventions to be developed and deployed are improved varieties of trees and crops, livestock breeds, and quality local feed formulations, enhanced seed systems, improved plant materials and the promotion of appropriate mechanization. Other opportunities include the dissemination at the community level or in pastoral groups of technologies for animal feeding using insect sources. A substantial increase in agricultural yield and output is expected to be realized by implementing interventions aimed at speeding up the adoption of improved agricultural technologies. This is to be accompanied by a comprehensive support program for the private sector and engagement of agro-dealers in the seed and improved planting value chains.

Climate-smart and high-yielding varieties

Increase in agricultural productivity is highly dependent on the availability and use of quality planting materials. The CGIAR centers and partners have developed and are promoting well adapted varieties and hybrids of the major crops and trees in Sahelian countries. Many high-yielding and drought-tolerant crops and dual-purpose varieties with end-user-preferred traits have been developed by various R4D institutions in the region. These include millet (high-yielding and dual-purpose), sorghum (high-yielding, disease/pest-resistant and dual-purpose), maize (drought-tolerant with breeding progress being made with respect to Fall Army Worm resistance), groundnut (high-yielding, drought-tolerant disease/pest-resistant and dual-purpose), cowpea (high-yielding, disease/pest-resistant, Striga-resistant,

[3] One of the highest in the world.

drought-tolerant and dual-purpose), cassava (high dry starch content, high-yielding) and fruit trees (climate appropriate portfolios). These improved materials are being scaled out and are largely being adopted by farmers. In clonally propagated crops, tissue culture, aeroponics, semi-autotrophic hydroponics have been implemented with potential impacts on the seed systems. Also, the release of improved varieties of legumes and cereals coupled with improvements of seed laws are having positive effects on seed systems. CORAF is hosting the Secretariat of the Regional Seeds and Seedling Committee under the auspices of the tripartite agreement among ECOWAS-CILSS-UEMOA. Significant improvements have been made in variety registration at national level as well as in improving the link between national variety registration and the regional catalogue. Efforts in the harmonization of seed regulations have yielded significant dividends by fostering regional trade and encouraging private sector involvement in the seed value chain.

Across the Sahel, the development of many seed companies offers great opportunities for seed production, distribution and marketing. In addition, links have been developed and are being nurtured between CG centers and the NARS based in the region; these linkages have facilitated processes of varietal selection and release. There are also interventions focused on the introduction of improved forage species and improved livestock breeds with high meat and milk production.

Food and nutritional security are associated with food quality, quantity and diversity. The cereal-dominated starch-based diets of the Sahel have led to severe malnutrition due to low levels of the micro and macro elements in daily food intake (WHO 2009). Significant experience and expertise are available in conducting food consumption and nutrition surveys, which are critical in determining the status of population health and the value of nutrition-related interventions. There are a number of routes to reducing malnutrition and hidden hunger, specifically deficiencies in vitamins and minerals. Significant progress has been made on biofortification, particularly in cassava and maize, through breeding of varieties with enhanced provitamin A. Biofortification in millet, sorghum, maize and cowpea has led to the development and release of iron- and zinc-dense crop varieties; Opportunities for developing syrup sorghum varieties are also emerging.

Production of crops protected with comprehensive aflatoxin management strategies contain significantly less aflatoxins—and are more nutritious— than crops produced and handled using traditional practices. Such strategies are used at scale in Nigeria, Senegal, The Gambia, and Burkina Faso.

Cropping system diversification

Diversification is a risk-reducing strategy and also a source of income and nutrition. With improvements in genetics, some crops such as soybeans could be an interesting option for Sahelian countries as it provides good source of proteins for both human and livestock.

Another route requires to make a better use of the biodiversity available by increasing the diet diversity index. Both local and exotic fruits and vegetables are available throughout the year and, with more strategic use, can help addressing

most of the hidden hunger issues of the region. Despite livestock being a dominant activity, its products are not used to address the deficiencies. In addition, wherever possible, introduction of more productive root crops such as cassava could increase resilience and make the systems more food secure. Finally, within the existing systems, improvement of local indigenous legumes such as Bambara nuts, and cereals such as fonio would have positive effects on both nutrition and incomes.

The dissemination of integrated aquaculture and vegetable production will increase availability and consumption of vegetable and fish products by children and pregnant women. Consumption of animal source food has been widely reported to be important for the cognitive development and growth of children.

Timber and non-timber forest products (NTFPs)

A forest product value chain can concern both timber and non-timber forest products (NTFPs) with related ecosystem services, including providing fruits containing vitamins and micronutrients to balance the starchy diets of the Sahel. Promising activities are designed to develop the timber and NTFP value chain of priority and/or strategic trees while establishing new plantations to replace aging and less productive trees to maintain these NTFPs.

Horticultural crops

Horticultural crops involve cultivating woody species planted at 20 cm x 20 cm spacing between rows and plants with possibilities of fertilization and irrigation for intensive production of fresh vegetables throughout the year of *Adansonia digitata* (Baobab) and *Moringa oliefera* (Moringa). This technology was developed to enable rural households to meet their food needs with exceptional nutritional quality foods that can be marketed (Bationo et al. 2009).

Mechanisms for scaling climate-smart innovation in collaboration with other outcome actors

Mechanisms for scaling innovation in collaboration with the private sector or other outcome actors are as follows:

Research infrastructure

The conservation of the diverse genetic resources and animal breeds also needs to be addressed through ex situ conservation and a more effective utilization of agro-biodiversity. The Sadore Regional Genebank at ICRISAT-Niger presents huge opportunities for genetic pool conservation and exchange of materials with NARS, development agencies, NGOs and farmers at different scales. The Genetic Resources Center of IITA in Nigeria has more than 15,000 accessions of cowpea, a collection of African maize landraces, and of Bambara groundnut and African yambean – two underutilised legumes with great potential for the Sahel under climate change. Relatively better-equipped research facilities (e.g. the Center of Excellence in Genomics (CEG), fields, laboratory (with ELISA kit for aflatoxin detection), NIRS, ED-XRF facility for grain micronutrient analysis, soil and plant analytical laboratory,

Striga hermonthica screening facility, pearl millet downy mildew screening facility, high throughput abiotic stresses phenotyping platform) exist in the research stations located in Niamey and Bamako. The CERAAS in Senegal has first-class research facilities on improving adaptation to drought in the Sahel region. The West Africa Biotechnology center, well equipped plant health and food technology laboratories in Ibadan, the One-health centre (BIMAF) in Cotonou are all examples of R4D facilities on which to build a strategy to support agricultural transformation in the Sahel. These facilities contribute to enhanced research outcomes and capacity building.

CORAF remains committed to working with its diverse partners including the National Agricultural Research Institutes, universities, CGIAR centers, the private sector, farmer-based organizations, and a host of development partners. Under the current Strategic Plan (2018 – 2027), the Regional Centers of Specialization (RCoS) are the face of the implementing structure of CORAF across the region. At the moment, there are eight RCoS based on key priority value chains (Table 1).

Table 1: Different regional center of specialization of key values chains promoted

No	Priority Value Chains	Center of Specialization
1.	Dry Cereals	CERAAS - Senegal
2	Maize	INRAB - Benin
3.	Fruits & Vegetables	INERA - Burkina Faso
4.	Livestock	INRAN - Niger
5.	Rice	IER - Mali
6.	Roots and Tubers	CSIR - Ghana
7	Aquaculture	ACRN - Nigeria
8	Banana and Plantain	CNRA – Cote d'Ivoire

The RCoS, as the coordinating units of the commodity-based projects, ensure joint planning, resource mobilization, cost sharing and implementation. The RCoS and associated diverse partners that make up the NARS will handle country-level implementations. They will also coordinate training, knowledge sharing and transfer of T&Is across the region. The RCoS will also serve as convening centers for expertise from CGIAR centers (e.g. AfricaRice, ICRISAT, IITA, ILRI, IWMI, etc.) and foundations (e.g. AGRA and Syngenta Foundation for Sustainable Agriculture), as well as USAID Feed the Future Innovation Laboratories with relevant projects and expertise operating in the region.

Business incubation centers

Revealing business possibilities to key stakeholders may facilitate the development of a conducive business environment making agribusiness more attractive to youth and women. To capacitate youth and women to seize this opportunity, incubation centers for training and enterprise development will be critical to skill them in

entrepreneurship (with posttraining business opportunities and enhancing existing local youth/women-led small enterprises) and develop managerial, administrative and operational capacities.

The innovative agripreneur program initiated in IITA, which is today the base for the ENABLE youth program of the TAAT project could be expanded and generalized in the Sahel region to offer youth opportunities to create their own businesses and provide vital services to enhance several value chains critical for the agricultural transformation of the Sahel region.

Significant experience and expertise have been gathered in youth agripreneurship and in ways of developing small agribusinesses along crop value chains, combining great opportunities with business plan development and financing. The Business incubation platform of Ibadan is an opportunity for close collaboration with the private sector. The Tubaniso Agribusiness and Innovation Centre (TAIC) in Samanko (Mali) has a vision to be a center for delivering on four business lines for startups in the Sahel. The Innovation and Technology City (Sadore research station) was developed around clusters (agribusiness, health, education and more). The center could host startups and small-medium enterprises, trainings and certification (university for technical/professional training), a coding academy, a business center, a national data center and assembly lines for digital and other equipment including computers, tablets and solar panels.

Site-specific technology kit deployment and technology parks

A systemic framework to assess the enabling environment and enhance scaling of irrigation and water management technologies has been developed and implemented in six countries (Ghana, Mali, Burkina Faso, Nigeria, Ethiopia and Sudan). Solutions to overcome systemic barriers in ISS scaling are being co-designed and implemented through a research-private sector partnership complemented with innovation grants and multi-stakeholder dialogues in Ghana, with potential for implementation in other Sahelian countries. This scaling approach helps to maximize inclusive and equitable benefits as well as gender-, youth- and nutrition-sensitive ISS investments to support resilience. Furthermore, IWMI's framework for the analysis of social transformation process to support local and national development planning processes is a potentially useful tool in multi-stakeholder dialogues to enhance transformation in the Sahel. Through the TAAT program, the TAAT-Water Enabler, led by IWMI, and Africa RISING in Ghana and Ethiopia, several irrigation and water conservation technologies and practices to improve crop and water productivity of staples (e.g. wheat, rice and sorghum), high-value crops (e.g. fruit and vegetables) and irrigated fodder are being demonstrated. The technology toolkits led to significant increases in crop yields and reduction in water use creating interest in thousands of farmers. IWMI has developed various capabilities to help countries manage the extreme climate shocks that are affecting farmers. Some of these capabilities are the flood forecasting app for Nigeria and a new prototype drought monitoring system for Senegal with potential application in other Sahelian countries.

IWMI's recommended guidelines and business models for water reuse and circular economy have been adopted by public and private actors in the region. Overall,

IWMI's result is exerting a positive influence on government policies and on-farm practices in some countries. As a result of these efforts, the time is ripe for major investment and scaling across the Sahel.

CORAF has established a partnership with Kansas State University under the auspices of USAID. The vision of this Innovation Research, Extension and Advisory Coordination Hub (iREACH) in West Africa (WA) is a strengthened CORAF to meet the objectives of its strategic plan more widely with its broad range of partners throughout the region. The establishment and operation of technology parks is one of the key activities of this partnership. iREACH will initially focus on regions within Ghana, Senegal, Mali, Burkina Faso and Niger that USAID has prioritized in its Feed the Future (FtF) and Resilience strategies. Through iREACH, CORAF will ensure coordination, information sharing, collective engagement and alignment of activities to increase the efficiency of these investments and programing, which will allow better implementation of USAID and other donor programs (both centrally funded and those funded by country and regional missions).

Systems modeling

Several crop recommendations have been made to improve crop productivity in West Africa. These recommendations are, however, site-specific and cannot be extrapolated to other areas in the region. Agronomic field experiments conducted at similar locations provide reliable and valuable information source on crop management (Kassie et al. 2014), but collecting exhaustive data at multiple locations to support management decisions on a larger scale is limited by time and logistical costs. Also, experimental data are expensive, as they require several years of experimental data gathering. Moreover, experimental trials do not report consistent results from year to year and from site to site because nutrient management of maize is site-specific. Thus, most crop management recommendations cannot be extrapolated to wider areas (Kasika et al. 2015). This is simply because soils vary considerably in terms of their properties. Researchers in the region have calibrated and validated crop and soil simulation models that are used to simulate the performance of crop varieties and crop soil management technologies over areas. These models can be used to scale out ready-to-use crop and soil management technologies across the Sahelian region.

There is also a need to develop a holistic perspective on the use of climate information and a range of decision support tools (models) to help policymakers and other stakeholders at various levels of the landscape to manage and promote climate-resilient interventions. Within regional limits, CCAFS-ICRAF-ICRISAT-ILRI-IITA and the NARS have developed the capacities of key stakeholders to use projection tools for climate and its potential impacts (analog, scenarios, climate/yield projections using models) in programing investments and planning activities.

The Rural Resources Centers

Developed by ICRAF, the Rural Resources centers (RRCs) concept is driving innovation in the delivery of extension services that responds to the needs of farmers (Degrande et al. 2014 and 2015, Takoutsing et al. 2017). RRCs use a farmer-centered approach, which focuses on developing farmers' capacity to innovate at all

points in the agricultural production and marketing chain (Degrande and Arinloye 2019). The centers facilitate interactive learning and networking – among farmers, and among farmers, researchers and other stakeholders.

Index-based livestock insurance

There is a lack of instruments for financial protection against covariate risks (e.g. drought) in smallholder agricultural or pastoral systems to support financial resilience. Therefore, ILRI has developed Index-based drought risk financing toolkit for pastoral and agropastoral dryland systems which has been very successful in East Africa where 25,000 pastoral households were protected in Kenya and Ethiopia and over 10 million USD payouts during 2016-2017 and 2019 droughts. Feasibility studies are underway in the Sahelian countries for the roll out of this index-based livestock insurance scheme for the agropastoralists in the region.

Agro-processing, postharvest handling, food safety

Another challenge in the region is aflatoxin contamination in maize, sorghum and groundnut. ICRISAT has supported ELISA-based aflatoxin detection. IITA has developed several biological control products, such as Aflasafe, which are being deployed alongside the promotion of good agricultural practices (GAP), and improved drying, handling, and storing technologies.

In the Sahel, Aflasafe products are registered for commercial use in Nigeria, Senegal, The Gambia and Burkina Faso, while products are currently being tested in Mali and Niger (Bandyopadhyay et al. 2016 and 2019, Senghor et al. 2020). Pesticide residue reduction options also exist for improvement in food safety and trade in the region. Several training sessions are being organized with NARS and farmers on the rational use of pesticides and good practices for avoiding misuse and overuse of agrochemicals.

Important interventions will aim at promoting commercial agriculture by improving postharvest management practices, enhancing downstream and upstream business activities while supporting linkages of smallholders and small enterprises. This will also involve harmonizing product specifications and standards. Some critical value chain interventions that could improve farmers' incomes include the scaling of hermetic storage to allow farmers to be more in control of when to sell, especially for cowpea (and groundnuts), thereby reducing postharvest losses. This also has significant health implications by reducing the use of harmful pesticides in storing grains.

Effective use of mechanization on scales

The African and Sahelian landscape is changing rapidly and the rural population is aging; youth migration due to increased opportunities in the urban areas is also contributing to this. Therefore, mechanizing agriculture and agribusiness becomes a critical issue, especially if youth are to be more interested in this business. Climate-smart mechanization appropriate for smallholder farmers include planters, weeders and threshers and more recently, the mobile cassava processors. Furthermore, technologies such as strip cropping (also known as 2 by 4) allows farmers to reduce labor demands and weed infestation, thus increasing productivity in cereal-legume

systems. IITA's holistic farm-to-processing approach to mechanization, used for cassava in Nigeria and other countries, could be a model for the Sahel region if adapted to its crops. Introduction of existing machines for plowing, planting (including fertilizer microdosing), weeding, fodder chopping, grating, sieving (and other processing techniques), packaging etc. will be needed to transform the Sahelian agriculture and respond to the labor shortage in rural areas.

The Smart Food campaign

This initiative complements other activities aiming at creating a demand pull for farmers by generating awareness and interest from consumers, industry and influencers. The overall aim is to diversify diets with nutrient-dense and environmentally and climate-smart foods in the Sahel. The Smart Food initiative promotes better nutrition with a focus on diversifying staples with Smart Foods to have a major impact. Millet and sorghum, that are nutrient-rich, drought-tolerant crops, and can support communities in the Sahel to improve their nutrition, are a priority along with key legumes and vegetables. The initiative has started working with researchers, consumers, farmers, food processors, health workers, policymakers and influencers like the First Lady of Niger who is a Smart Food Ambassador, to increase the benefits and uses of millets and sorghum. By building awareness to support diet diversity, wellbeing and livelihoods of rural communities and farmers, the Smart Food initiative, through its activities and campaign has the potential to improve nutrition in the Sahel where undernutrition, malnutrition, obesity and anemia are already prevalent.

Improvement in food quality, and reduction of mycotoxin and pesticide residue contamination in food chains will therefore be critical factors to tackle in order to feed into the ongoing Smart Food campaign with millet, sorghum, legumes and vegetables. On a high priority are high-iron and high-zinc millets and sorghum and high-vitamin A vegetables, along with highest legume protein sources complemented by millets to create a complete protein. However, many other approaches are possible; hence, a holistic approach is required which brings together different facets of dietary diversity, processing, reduced food losses and food safety. Significant experiences and expertise were gathered while conducting food consumption and nutrition surveys to determine the status of population health. It is proposed here to start with evaluating the available technologies across the Sahel to produce catalogs of recipes with an emphasis on food technology scaling. Some areas to start build the excitement and momentum for demand for Smart Foods are: (1) creating an annual Smart Food fair for each country (based on the Niger First Lady's Annual Millet Fair). This will highlight millets and sorghum and biodiversity, the training for chefs and consumers – collecting recipes through competitions and showcasing, (2) Training for processors on product development, recipe development and sharing best recipes and processes, (3) Bring in other influencers as Smart Food Ambassadors and engage them in developing the program further.

Multi-stakeholder Innovation Platforms

Innovation platforms (IPs) are hubs that bring together different stakeholders to identify solutions to common problems or to achieve common goals. They ensure that different interests are taken into account, and different groups contribute to finding solutions. IPs allow synergistic actions and reflection among clusters actors on defined entry points that matter the most to the stakeholder. IPs provide engagement networks for value chain actors to find common concerns and win-win solutions through mutual learning activities and demonstrations of innovative knowledge and/or improved practices.

Platforms create opportunities for actors to exchange experiences and receive technical and advisory services that are tailored to their needs. Particular emphasis is placed on access to knowledge, interactive learning and networking among producers, and between producers and other actors including advisory services, non-governmental organizations, scientists, microfinance institutions, etc. It is a powerful tool for the successful uptake of innovative agricultural practices and knowledge adapted to the rural context.

Deployment of digital tools in support of agricultural transformation in the Sahel

Extension delivery services in the Sahel currently face two primary barriers, namely, cost-effective utilization of extension workers given significant budget constraints, and the establishment of effective feedback systems between local and national extension bodies. There are opportunities in ICT-related advisory services. With current multiple challenges, there is a need to improve the access and quality of services available to farmers and to use ICT in demand-driven extension processes. Building on IITA's experience, initiatives can (i) design, test and pilot and deploy ICT-based agribusiness solutions for the food production chain; and (ii) support the deployment of an end-to-end tailormade ICT-based platform with solutions to address diverse challenges across the food production chain. Against this background, digital tools, early warning systems for resource management, disaster preparedness, mitigation, relief, and reconstruction efforts will be important. Development and implementation of actionable strategies in addressing smallholder aggregation are required.

Making a CG Sahel Farmer App would provide farmers with seed advice, agronomic advice, water advice, rainfall prediction/flood warning, market prices, etc. by integrating or bundling different technologies and themes. Another comprehensive and effective monitoring, evaluation, accountability and learning system would provide quality data to inform the Results Framework of all interventions. The digitalized M&E system serves both as a day-to-day management tool to guide project implementation, and a mechanism for periodic assessment of projects' performance to gauge their impact. A key outcome of M&E system is to enhance the understanding of the factors that improve the livelihoods of projects' beneficiaries through data-informed output delivery.

A balanced and organized approach to cooperation between actors from the research, development and private sectors

In order to support agro-processing with better linkage with the private sector and community engagement, options are presented as follows:

Postharvest technologies require strengthening partnerships among farmers into small enterprises that can help them take charge of more steps in value chains. These small enterprises are more likely to adopt technologies when the technology adoption is driven by business orientation, economies of scale, access to credit and services, shared risk, and stronger negotiating power.

It is shown from past experience that the tree-crop value chains have engaged in collaboration with the private sector to develop technology packages to strengthen the capacity of stakeholders and the productive system through a series of activities including the integration of beekeeping in agroforestry parks to improve productivity of trees while producing honey; training of farmer trainers on improved trees and NTFP, production techniques, planting, maintenance and grafting; improved techniques for the collection, storage facility constructions for group selling, processing and value adding creation for diversified income generation from local, regional and international niche markets.

ICRISAT also relies on its network of private bio-factories for production and supply of beneficial organisms for controlling major insect pests. This is based on its long experience on biological control of the millet head miner and recently with the fall armyworm.

Conclusion

For climate-smart agriculture, the consortium has actively implemented a wide range of promising approaches, practices and technologies, suitable for smallholders in the Sahel regions. The implementation of these approaches, practices and technologies would allow smallholders to improve their incomes and to create an employment environment for youth and women. However, development is a long process and externalities of these approaches, practices and technologies, even if already visible and perceptible somewhere, may not be visible and appreciated right now elsewhere. Indeed, to preserve a healthy environment conducive to agriculture and to ensure food security, we must continue to move forward in order to achieve the development of our population in an environment where population itself becomes aware of the need to preserve the climate.

Moving forward

Over the years, tree, crop and livestock production systems in the Sahel have been subjected to the effects of climate change. Climate-resilient and sustainable food production is necessary to enable transformational change in the Sahel. A number of approaches to implement climate-smart agriculture can be employed, including

though not limited to, adapted stress-tolerant varieties, water-smart irrigations under integrated agriculture and aquaculture systems (aquaponics), GAP (Good Agricultural Practice) and climate-smart livestock interventions. To trigger systemic changes in building climate-resilient and sustainable food production systems, R4D would strategically target a) Cost-effective technical innovations to enhance water access through the use of renewable energy and managed aquifer recharge system; b) integration of technologies warranting that constraints they address do not stand alone c)Institutional innovations to include private sector-centred approaches to reach scale; d)Financial innovations to reduce up-front costs of investment through PPP, private sector or other type of partnerships depending on technology, target groups and market segments; e) Technical and social innovations to improve efficient natural resource use through interactive learning f) Gender and social inclusion to enhance equal access to, and benefits from more climate-resilient agriculture for various vulnerable groups (e.g. women, pastoralists, youth, etc.).

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Appendix 1: Technologies and innovations promoted by CGIAR centers for the Sahel

Climate-smart crop varieties	Terminal drought-tolerant sorghum and pearl millet varieties Multi-purpose sorghum and millet for human consumption and livestock feed High-yielding, multiple stress-tolerant groundnut varieties High-yielding, dual-purpose and multiple stress-tolerant cowpea varieties Maize varieties with tolerance to biotic and abiotic stresses Support to private sector for seed delivery in maize
Cultivation and marketing practices	Seeds systems - Mini seed packs Village seed banks Insect meals for livestock feeds Fertilizer microdosing technology using a bottle cap Organic fertilizers from organic waste recycling Biological control of pests On-farm aflatoxin management centered on biocontrol products and appropriate management strategies ICRISAT's The Sahelian Eco-Farm (inter-cropping system) Warrantage or inventory credit system Soil conservation practices Site-specific nutrient management using modelling and scaling tools Contract farming Use of PICS bags Youth and women empowerment for agripreneurship
Ecological land and water use	ICRISAT's African Market Garden (a low-pressure drip irrigation system combined with a crop husbandry package) Integrated aquaculture and agriculture (annual and perennial vegetables, fruit trees) Bio-reclamation of degraded lands Local community-led watershed management Solar-powered micro- irrigation Groundnut sheller and frame groundnut stripper Mobile choppers for utilization of crop residues Seed planters
Agricultural water management solutions	Low-cost irrigation solutions to increase productive use of water, such as the Chameleon sensor Farmer-led irrigation development approaches; Business models for scaling water solution with private sector for irrigation value chain development

	Digital solutions for small-scale farmers to use water more productively Mapping potentials for ground and surface exploitations for small-scale irrigation development Integrated landscape approach to build climate resilience using a set of participatory mapping and planning tools In-situ water harvesting and storage approaches, including Bhungroo Irrigation Technology (BIT) Solar irrigation kits for sustainable exploitation of shallow ground water Extension materials for 14 water solutions for irrigated and rainfed agriculture Drought and flood risks tools for agriculture. Assessing the enabling environment and providing recommendation for scaling water solutions (including policy, implementation and informal institutions)
Climate-smart technologies and approaches	Climate Smart Agriculture compendium Country CSA profiles Country CSA investment plans Digital platform for technology Climate Smart Village (CSV) Participatory Integrated Climate Services for Agriculture (PICSA), improved climate information and decision-making tools enabling small-scale farmers to improve their resilience in the face of erratic rainfall and increasing temperatures. Biopesticides Biological control Hermetic storage (PICS bags) Crop and cropping system diversification
Household fruit and vegetable garden	A 36 m^2 fruit and vegetable garden using improved plant materials of fruit tree species *Ziziphus mauritiana* (jujube), *Tamarindus indica* (tamarind), *Adansonia digitata* (baobab) and vegetable tree species baobab and PKM1 variety of *Moringa oleifera* combined with annual vegetable crop species such as Amaranth (A 2004), Corchorus (Bafia), Okra (Batoumabé), and Roselle (Samatan) to be established for each household for improving household diet diversity and nutrition security.
Rural resource centre & innovation platform	The Rural Resource Center (RRC) concept, developed by ICRAF, is driving innovation in the delivery of extension services that responds to the needs of farmers. RRCs use a farmer-centered approach, which focuses on developing farmers' capacity to innovate at all points in the agricultural production and marketing chain. The centers facilitate interactive learning and networking – among farmers and between farmers, researchers and other stakeholders.
Regreening Africa App	Regreening Africa App is a mobile-based android application that helps users to collect information on how farmers are managing and protecting trees on their farms. The App supports simple text and numeric data, images, and location data of trees and nurseries. It allows users to collect data offline and upload it to a server once the device is connected to mobile network or WIFI.
Development of value chains	Facilitate relationships with financial and market opportunities Agribusiness and entrepreneurship promotion Private sector engagement Access to financial services

	Access the local, regional and international market.
Land Degradation Surveillance Framework (LDSF)	LDSF was developed by ICRAF as a response to a lack of methods for systematic landscape-level assessment of soil and ecosystem health. The methodology is designed to provide a biophysical baseline at landscape level, and a monitoring and evaluation framework for assessing processes of land degradation and the effectiveness of rehabilitation measures (recovery) over time.
Integrated feed and health package for improved small ruminant production	It has been demonstrated that simple interventions involving disease control, improved nutrition and better management lead to marked positive effects on small ruminant performance and productivity. This feed and health package developed by ILRI entails vaccinating sheep and goats against main diseases such as Pasteurellosis and Peste des Petits Ruminants (PPR), and deworming. In addition to healthcare, there is strategic supplementation of the small ruminants to improve their performance. The feed supplement is based on available feed resources. This integrated feed and health package led to doubling of the household flock within one year.
Least cost ration for profitable sheep fattening	Sheep fattening is an increasingly important economic activity in the West African Sahel, particularly in and around Tabaski, the Islamic festival of Eid-al-Kabir. It is extremely attractive to poor farmers, including women, in the region. Traditional sheep fattening is characterized by feed waste as feeding is on ad hoc basis depending on available feed resources. From several feeding experiments conducted by ILRI both on-station and on-farm, optimal feed combinations for sheep fattening have been developed which entails feeding levels of between 600 and 900 g per day of cowpea hay or groundnut haulm, and 400 g of millet bran along with ad libitum feeding of roughage such as bush hay, millet stover and/or sorghum stover. The fattening duration should be between 60 and 90 days to be profitable. https://cgspace.cgiar.org/handle/10568/72736
Index based livestock insurance	There is lack of instruments for financial protection against covariate risks (e.g. drought) in smallholder agricultural or pastoral systems to support financial resilience. Therefore, ILRI has developed Index-based drought risk financing toolkit for pastoral and agropastoral dryland systems which has been very successful in East Africa where 25,000 pastoral households were protected in Kenya and Ethiopia and over 10 million USD payouts during 2016-2017 and 2019 droughts. Feasibility studies are underway in the Sahelian countries for the roll out of this index-based livestock insurance scheme for the agropastoralists in the region.
Mechanization	Mechanization allows the engagement of relevant stakeholders committed to the development of micro, small and medium enterprises (MSMEs) and NGOs in crop-livestock value chain. The designing crop stalk crusher has greatly helped in alleviating the problem of crushing stalk for animal used during dry-season while contributing to business services. Drudgery reduction: Models of motorized threshers, groundnut harvester and groundnut sheller increase groundnut productivity while reducing drudgery for women farmers in Mali, Ghana and Nigeria. In 2015 ICRISAT worked with the Agricultural Engineering Unit of the Institute for Agricultural Research (IAR), to identify and develop an appropriate motorized groundnut thresher that cut down the time and effort needed to shell groundnuts, by women. The performance parameters of the thresher included a cleaning efficiency of 97%, grain damage of about 4% while scattered grain was estimated to 4% compared to over 20%previously. Public Private partnership

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