CLIMATE RISK PROFILE SERIES

ADAPTING GREEN INNOVATION CENTRES TO CLIMATE CHANGE: ANALYSIS OF VALUE CHAIN ADAPTATION POTENTIAL

Rice, potato, and mango value chains in Koulikoro, Sikasso, Kayes, Ségou, and Mopti zones, **Mali**

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Alliance
Bioversity International
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Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

CGIAR
RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security
CCAFS

ABOUT THIS REPORT

Climate change is affecting agriculture more than any other sector. Increased frequency and severity of drought, flood, heat, and unseasonable rainfall heavily impact rainfed agriculture, ultimately resulting in production losses. In that context, The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) through its climate action lever, are developing climate risk profiles for agricultural value chains in developing countries at the national and subnational level. These profiles build on past work conducted by CIAT and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)in collaboration with the World Bank and other partners, including FAO, USAID, DFID[1].

The present report aims to provide a climate and vulnerability analysis of the Green Innovation Centres (GIC) target commodity value chains. Herein we identify climate change- related vulnerabilities, hazards, and opportunities for adaptation to the same. Ultimately, our goal is to foster awareness of risks and adaptation priorities in the selected value chains and inform climate investments and planning through the recommendations on priority innovations to manage climate risks.

The report begins with an extensive literature reviews of the selected value chains and their key challenges and adaptation strategies. Climate hazards and crop suitability modelling offer insights into potential future scenarios under climate change. These results inform potential adaptation approaches, which are prioritized by in-country experts and stakeholders through an online survey. The top-rated adaptation priorities undergo a cost-benefit analysis. Finally, the results are peer-reviewed by the GIC country office and the Alliance scientific staff.

The **Green Innovation Centres** for the Agriculture and Food Sector (GIC) founded by German Federal Ministry for Economic Cooperation and Development (BMZ) and led by the German Agency for International Cooperation (GIZ) in collaboration with local ministries and programmes, aims to promote agricultural innovation under the *ONEWORLD No Hunger* initiative. Through the GIC, GIZ aims to generate employment raise farmers' income, and improve farmers' education and skills by funding training in good agricultural practices, water management, post-harvest processing, and entrepreneurship.

Planning, data collection and stakeholder engagement →
- Literature review (key documents and datasets)

Climate risk assessment →
- Hazard analysis
- Crop suitability modelling

Identification of adaptation strategies →
- Detailed review
- Gap analysis and identification of climate adaptation
- Online survey
- CBA analysis

Production of the country climate profile and validation
- Peer-review

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[1] https://ccafs.cgiar.org/publications/csa-country-profiles

HIGHLIGHTS

- The Green Innovation Centre in Mali focus on the rice, potato, and mango value chains in five regions: Koulikoro, Sikasso, Kayes, Ségou, and Mopti/Inland Delta. **(Chapter 1, pg.8)**
- Agriculture contributes 42% to the gross domestic product, employs more than half of the Malian population, and supports 80 % of livelihoods. **(Chapter 2, pg.10)**
- Over 60% of household income in Sikasso, Kayes, Koulikoro, Segou, and Mopti is spent on food. **(Chapter 2, pg.18)**
- Rice, potatoes and mangoes are high value agricultural commodities with the potential to reduce poverty, and support livelihoods through increased incomes. **(Chapter 2, pg.12-16)**
- Mali has a clearly established climate governance framework, a national climate action plan, and a climate strategy. **(Chapter 3, pg.19-20)**
- Farmer organizations, microfinance institutions, and non-profit partners in Mali are supporting farmer adaptation efforts. **(Chapter 4, pg.21-22)**
- Climate change is increasing the variability of temperature and rain patterns and the likelihood of hazards such as floods, droughts, and their associated risks. **(Chapter 5, pg.25)**
- Farmers' perceptions of climate change are focused on drought, rising temperatures, and uncertainty around the start and length of growing seasons. **(Chapter 5, pg.23)**
- The implementation and scaling of currently available technologies would further support climate adaptation in Mali. **(Chapter 6, pg.38)**
- Access to critical inputs like improved or climate resilient seed varieties, labor, fertilizers' agriculture equipment and extension services enables smallholder farmers to increase agricultural productivity and resilience. **(Chapter 6, pg.37-40)**
- Enhancing access to financial services, education, agro information, markets are key enabling drivers to boosting rice, potatoes and mangoes productivity.**(Chapter 7, pg.58)**
- Conclusively the adaptation potential for the selected value chains is promising. Significant infrastructure including cold chambers, conservation structures, value addition equipment and warehouses are recommended to improve competitiveness and climate resiliency. **(Chapter 6, pg.37)**

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ACRONYMS AND ABBREVIATIONS

AEDD	Environment and Sustainable Development Agency
CDD	Consecutive Dry Days
CEDEAO	Economic Community of West African States
CIV	Centre d'Innovation Verte
CNCC	National Climate Change Committee
DNA	Direction Nationale de l'Agriculture (National Directorate of Agriculture)
DNGR	Direction Nationale du Génie Rural
DNM	National Directorate for Meteorology
GAPs	Good Agriculture Practices
GDP	Gross domestic product
GIZ	The German Agency for International Cooperation
IER	Institute of Rural Economy
IICM	Integrated Initiatives for Mali's Economic Growth
IFM	Mango Interprofession
IRR	Internal rate of return
LOA	Agricultural Orientation Law
MEADD	Ministry of the Environment, Sanitation, and Sustainable Development
MSP	Multi-Stakeholder Platform
NGO	Non-governmental organizations
NPV	Net present value
ORM	Office Riz Mopti
PANC	National Climate Action Plan
PASSIP	Support Program for the Local Irrigation Sub-Sector
PCDA	Competitiveness and Agricultural Diversification Program
PDA	Agricultural Development Policy
PNCC	National Climate Change Policy
PNISA	National Agricultural Investment Program
RCP	Representation Concentration Pathway
SNCC	National Climate Change Strategy
SOCAFON	Societe cooperative artisanale des forgerons de l'office du Niger
SRI	System Rice Intensification
SRP	Sustainable Rice Platform
PPU	Deep placement of super-granulated urea
USAID	United States Agency for International Development

1. INTRODUCTION

A landlocked country in West Africa, Mali has a remarkably diverse landscape and climate, sub-humid in the south and very arid in the north. Mali's Vision 2025 sets forth the goal of reducing poverty through effective development actions while creating an enabling environment that prioritizes human development. In line with this target, the German Federal Ministry for Economic Cooperation and Development commissioned Green Innovation Centres for the agricultural and food sector as part of the "ONE WORLD – NO HUNGER" initiative in Mali, supported by the Ministry for Rural Development and implemented by the National Administration for Rural Infrastructure (DNGR). **These Green Innovation Centres focus on the rice, potato, and mango value chains in five regions of Mali: Koulikoro, Sikasso, Kayes, Ségou and Mopti/Inland Delta.** Their headquarters are based at the Institut Polytechnique Rural de Formation et de Recherche Appliquée (IPR/IFRA) in Koulikoro, and one training centre per region participates in the implementation of the Centre d'Innovation Verte (CIV), which is attached to the AgrISAN Cluster.

The core element in this effort is the empowerment of small farms and up- and downstream enterprises to apply innovations that increase income, employment, productivity, and climate resilience. To this end, the project aims to promote market-oriented production in the selected value chains of rice, potatoes, and mangoes. Across all these three value chains, there have been interventions to enhance productivity by reducing greenhouse gas emissions (Green Innovation Centre Mali, 2018). Specific objectives also include boosting incomes by 33% for 60,000 smallholders, creating 1,000 new jobs (35% of these jobs geared toward women and 20% geared toward youths), and further education for 100,000 individuals (including 35,000 women and 20,000 youths).

This document presents the climate risk assessment for Mali, focusing on the Koulikoro, Sikasso, Kayes, Ségou, and Mopti regions (Figure 1). This brief yet comprehensive report is meant to inform value chain stakeholders, policymakers, and the private sector about the climate change risks and opportunities in the production of rice, potatoes and mangoes in Mali. It also seeks to facilitate the integration of context-specific adaptation strategies and present Climate-Smart Agriculture (CSA) investment opportunities.

This profile is organised into six sections, each reflecting an essential analytical step in understanding current and potential adaptation options in the selected value chain commodities. The first describes the importance of agriculture to people's livelihoods in the four departments. Section two highlights the policies, strategies, and programs implemented in the three value chains that address climate change, while the third section discusses the governance and institutional resources and capacity. The fourth section discusses the main climatic hazards affecting the three value chains and presents climate modeling results for projected climatic change-related hazards and crop suitability maps. Additionally, it offers an analysis of vulnerabilities and risks posed by these hazards to the respective value chains. The ongoing on-farm adaptation strategies adopted by farmers to cope with these hazards as well as the cost benefit analysis results are discussed in the fifth section. The sixth section provides a synthesis and recommendations.

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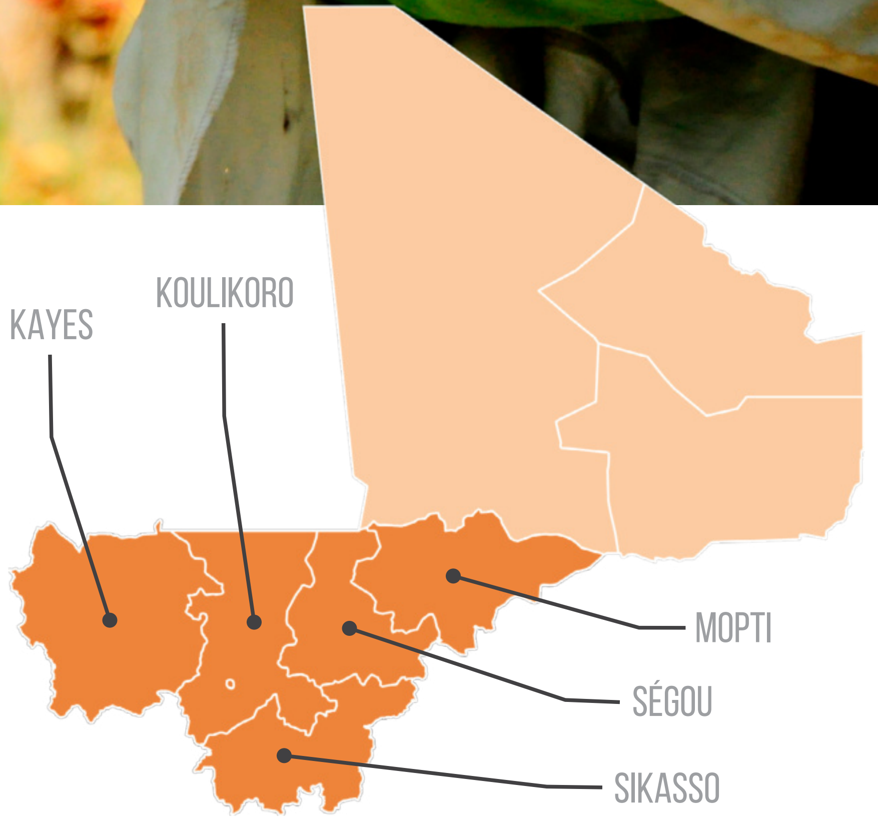

Figure 1. Map of the selected regions in Mali

Mali is a landlocked country located in West Africa. The regions of study are all located in the south of the country.

2. AGRICULTURAL CONTEXT

KEY MESSAGES

- Agriculture is vital to the economic development of Mali as it navigates widespread and multi-dimensional poverty.
- Most Malian agriculture is small-scale, low-input, subsistent, and rain-fed; pastoralism is also common.
- Gender roles limit women's access to land and decision-making ability in agriculture.
- Key crops include rice, potatoes, and mangoes because these have significant nutritional and economic value.

2.1. Economic relevance of farming

Mali's economic development is primarily based on agriculture. Agriculture contributes about 42% of Mali's gross domestic product (GDP) (World Bank, 2020), directly employs more than half (57%) of the Malian population, and contributes to 80% of people's livelihoods (FAO, 2017; GIZ, 2018). Analysis of average annual household income structure shows that agricultural activities contribute the largest share. Specifically, cropping (83%) is the primary source of cash income, followed by herding (12%), remittances (3%), and then non-agricultural activities (2%) (Djiré et al. 2012). Major agricultural exports include cotton, cattle, sheep, and goats; in total, agricultural products account for up to 80% of Mali's annual exports. In 2017, Mali exported cotton, carded or combed, worth US$ 131,992.32 million; live purebred breeding bovine, worth US$ 85,369.03 million; and live sheep, worth US$ 70,590.51 million[2] (World Bank, 2020).

2.2. People and livelihoods

In 2016, Mali's population was 18.341 million, with an average annual growth rate of 3.6%. By 2021, its population is projected to reach 20.79 million, and by 2022, 21.36 million. Sikasso and Kaye have the largest populations, both tying at 18.1% of the total, followed by Koulikoro at 16.67%, Segou at 16.1%, and Mopti at 11.74%. Young people aged 15-29 years old make up more than two-thirds of Mali's population. The male-to-female ratio is 1:1. The percentage of people living in rural areas is approximately 70% (Anuaire Statistique Mali 2016) (Figure 2).

Poverty remains the biggest development challenge, compounded by other underlying factors like geography, desertification, low education levels, and deeply embedded social, cultural, and religious laws and beliefs. Indeed, 41% of the Malian population still lives below the national poverty line (World Bank, 2020). Sikasso has the highest percentage of people in absolute poverty at 65.8%, followed by Mopti at 64.6%, Segou at 55.5%, Koulikoro at 51.5%, and Kaye at 31.6%. Out of the population that resides in these regions, on average 65% are food-poor (EMOP, 2016).

More than 80% of the regions' combined population has access to potable water due to proximity to water sources. **Access to electricity and education, however, is unevenly distributed.** In Sikasso, 79.1% of people have access to electricity for lighting, whereas only 29.8% have access in Mopti. Education is an important intangible asset, yet the disparity between poor and non-poor households due to resource inequalities and poor school enrollment has significantly influenced youth literacy rates. In poor households, youth literacy rates are approximately 14-28%, whereas non-poor households have 21-38% youth literacy rates (EMEP, 2016). The poverty rate contributes to chronic malnutrition among children, which puts them at greater risk of death and severe illnesses due to weak immune systems. The national stunting rate is 27% of children under age five, and the wasting rate is 9%.

Besides agricultural production, mining is a vital economic activity in Mali due to its richness in mineral resources like gold. The largest mines lie in the Bambouk Mountains in Western Mali (Kenieba Cercle) and are a major source of wealth and trade. Other mineral resources include phosphate, rock salt, and semiprecious stones like quartz, garnet, and epidote. Trading food, animal products, and minerals is a secondary activity for most middle-class and better-off households.

According to FEWSNET, as of 2015, Mali had 21 livelihood zones, which are defined by the availability of natural resources and by their characteristic agro ecological and climatic zones. The livelihood zones relevant to some of our selected regions include the Centre-eastern Millet and Livestock Zone that covers the centre of Koulikoro and Ségou and the eastern part of Mopti. This zone is distinguished by production of rain-fed millet and sorghum of the Gadiaba variety, as well as by livestock rearing dominated by transhumant herds. The main sources of income for poor households in this zone are livestock sales, remittances from urban-based family members, farm and non-farm labor, self-employment, and crop sales (FEWSNET, 2015). The Office du Niger zone in the Segou region specializes in rice cultivation and market gardening. This zone is a densely populated, fully irrigated agricultural area and also features sedentary livestock rearing.

2.3. Agricultural activities

Small-scale, low-input, subsistent, rain-fed agriculture and pastoralism are characteristic in Mali. Agricultural land constitutes 32% of Mali's land area, but 87% of this is used as pasture. Small-scale farmers cultivate 90% of the arable agricultural land and most of the cultivated land (72%) is devoted to staples like cereals, millet, and sorghum. Less than 4% of Mali's land area is arable (Land Links, 2020). Only 5% of cropland is irrigated. The main food crops include millet, sorghum, rice, maize, and peanuts, and its main livestock animals are cattle, sheep, and goats. Fishing is practiced in the River Niger and the irrigation canals of the Office du Niger.

Women's access and rights to land are shaped by statutory, customary, and religious laws. **Under these laws, men maintain the primary rights to land, which limits women's decision-making in agricultural production.** Women are cast into a role of dependency, which makes them more vulnerable to ecological and economic crises. Gender norms are also reflected in the relative areas of land women and men cultivate. According to figures from the 2004 General Agricultural Census, women operate only about 20% of all agricultural plots. More than half (54%) of women cultivate a plot of less than one hectare, compared to 17% of men. The ratio is reversed when the size of the packages increases. Only 1% of women farm a plot of 10 hectares or more, compared to 14% of men.

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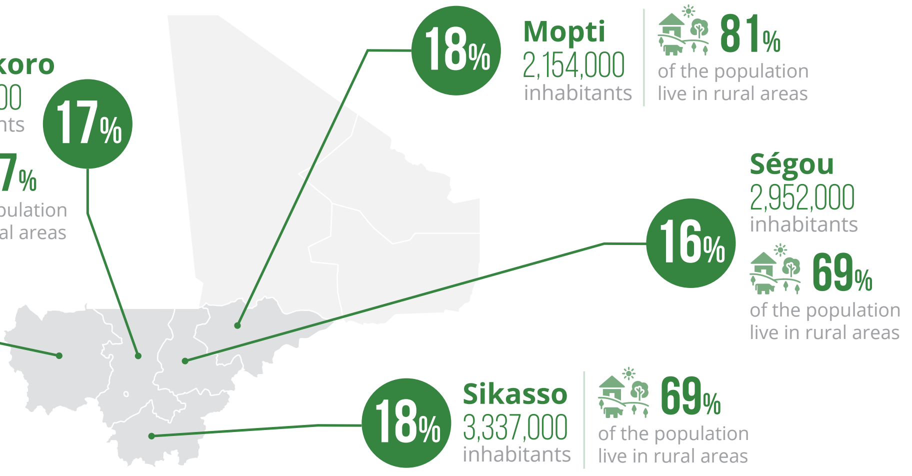
[2] 1 USD = 473.2600 XOF (CFA Franc)

Figure 2. Agriculture and livelihoods

DEMOGRAPHICS

MALI'S POPULATION
18,341,000



FOOD SECURITY

Percentage of **household income** spent on food

Sikasso	52%
Ségou	62%
Mopti	64%
Koulikoro	65%
Kayes	66%

% of the population suffering from **food poverty**

Sikasso	Ségou	Mopti	Koulikoro	Kayes
66-70%	51-55%	61-65%	61-65%	66-70%

Percentage people **undernourished** indicated by MAG*

SIKASSO	SÉGOU	MOPTI	KOULIKORO	KAYES
3.9	4.4	5.4	5.2	3.9

*MAG: Global number of undernourished

Percentage of **children wasted** indicated by MAS*

SIKASSO	SÉGOU	MOPTI	KOULIKORO	KAYES
1.8	2.7	2.5	2.8	1.0

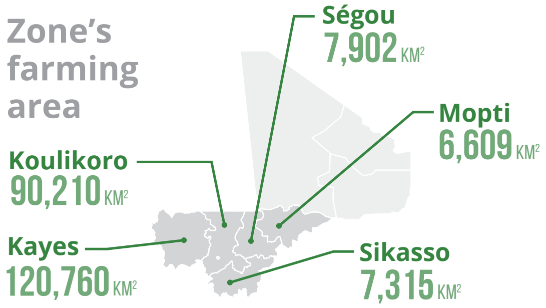
*MAG: Global number of undernourished

FARMING

% of the population **employed** in agriculture production

Sikasso	31%
Ségou	15%
Mopti	19%
Koulikoro	18%
Kayes	14%

Zone's farming area



FARMING ACTIVITIES

Cultivated area for **food crops** vs **cash crops**

	CASH CROPS	FOOD CROPS	FORAGES
Sikasso	430,835HA	300,690HA	17HA
Ségou	716,463HA	73,679HA	20HA
Mopti	644,185HA	16,732HA	17HA
Koulikoro	481,765HA	175,494HA	294HA
Kayes	201,216HA	69,999HA	ND
	0ha 500,000ha 1,000,000ha	0ha 250,000ha 500,000ha	0ha 250ha 500ha

Total number of livestock breeds

	Sikasso	Ségou	Mopti	Koulikoro	Kayes
CATTLE	1,693,270	1,198,250	2,974,370	2,974,370	1,131,320
SHEEP	1,123,500	1,321,950	2,792,475	2,792,475	1,753,605
GOAT	1,345,365	2,093,960	4,025,540	4,025,540	11,775,550
POULTRY	10,040,500	3,781,500	2,813,000	2,813,000	6,671,800

FARMING INPUTS

Distribution of **water uses**

Livestock	0.38%
Others	81.36%
Irrigation	17.72%
Domestic	0.54%

Data only at national level, data not disaggregated across regions

	Sikasso	Ségou	Mopti	Koulikoro	Kayes
NPK Organic manure	11%	70%	95%	52%	63%
Chemical fertilizer	41%	10%	4%	19%	19%
Organic manure + chemical fertilizer	49%	20%	2%	29%	18%
Field pesticides	50%	16%	4%	19%	8%
Herbicides	59%	2%	1%	28%	9%

(% of households)

ACCESS TO BASIC NEEDS

% of the population suffering from **absolute poverty**

SIKASSO	SÉGOU	MOPTI	KOULIKORO	KAYES
32%	52%	65%	56%	66%

% households with access to **potable water**

Sikasso	83%
Mopti	83%
Kayes	83%
Ségou	83%
Koulikoro	68%

% of households with access to **electricity for lighting**

Ségou	52%
Sikasso	79%
Mopti	30%
Koulikoro	53%
Kayes	31%

Youth literacy rate (15-30 years old)

	POOR HOUSEHOLD	NON POOR HOUSEHOLD
Sikasso	22%	38%
Ségou	21%	30%
Mopti	14%	21%
Koulikoro	17%	31%
Kayes	28%	33%

2.4. Agricultural value chain commodities

2.4.1. Rice

Rice (*Oryza sativa*) is an edible starchy cereal grain widely consumed as a staple food crop in Mali. It is relatively high in energy, carbohydrates, and minerals like calcium. **Rice is important for food security and economic development.** The average annual consumption of milled rice per person is 56 kg, and rice contributes 5% to Mali's GDP (USAID, 2018). Rice production employs about 3.5 million people and contributes more than 100 billion XOF of income, including 70 billion for rural people and 4 billion in revenues for the state (N'krumah, Elbehri & Legret, 2013). It is dominated by smallholder farming, including approximately 500,000 family farms with an average size of 1.5 hectares. In 2017, rice production was 2.9 million tonnes of paddy and 1.7 million tonnes of rice. An average farm can produce 5.7 tonnes of paddy or 3.3 tonnes of milled rice, valued at CFA 1 million in local markets[3] (USAID, 2018).

In Mali, 45% of allocated rice land is cultivated using controlled flooding, especially around Ségou and Mopti. In the Office du Niger, rice is cultivated using a variety of irrigation schemes, including total water control, in Sélingué and Banguinéda; along the Niger in Mopti, Timbuctoo, and Gao; and along the Senegal River in Kayes, Kita, Bafoulabé, and Manantali. Rain-fed rice, occupying 18% of allocated rice land, is common around Sikasso, Kayes, Koulikoro, and in parts of the Ségou region. Swamp-grown rice at 12% of land is common in the Central Niger Delta and in the lowlands and flooded plains in southern Mali (Ministry of Agriculture, 2009). Other rice production methods occupy the remaining 25% of allocated rice land.

Key activities at the input supply stage include sourcing certified, quality seeds to increase productivity; sourcing organic manure and fertiliser such as diammonium phosphate and urea; sourcing agriculture equipment such as motorized rotary tillers, power pumps, and threshing machines; and seeking advisory technical support from extension service providers. Seeds are sourced from credible cooperatives, seed associations, and private seed suppliers (Ministry of Agriculture, 2009).

During on-farm production, farmers prepare the land and plant the rice seeds in various production systems. These systems are classified based on water usage method. For example, the natural fluvial flood rice system requires hardier, adaptable varieties compared to irrigated rice systems with total control of water. Rain-fed systems may require varieties that are climate-resilient to produce despite climate risks and hazards. Other key activities include weeding, pest and disease management, and harvesting.

At the postharvest and processing stage for rice, crucial activities include husking, storage, and processing. Husking is carried out by mobile husking machines for the wholesale market and varies considerably according to the varieties, storage, and humidity levels of the paddy (N'krumah, Elbehri & Legret, 2013). For example, when the paddy is a mixture of many different varieties, husking becomes difficult because adjusting the rollers for round varieties will prevent thinner varieties from being shelled, and vice versa. If the rice is too dry when it is processed, breakage occurs, but if it is too humid, it sticks in the machine. Postharvest equipment consists of rice mills, threshers, and hulling/husking machines (Ministry of Agriculture, 2009). Producers generally sell milled rice, with approximately 80% of paddy processed by small- to medium-scale service providers. Besides low-quality rice due to high levels of breakage, the use of mobile, industrial and mini mills results in annual postharvest losses of 150,000 to 300,000 tonnes of rice, which significantly reduces the quantities available for the market (USAID, 2018).

Three postharvest processed products are marketed: broken, parboiled, and local Gambiaka rice. Key marketing activities include linking farmers to buyers, and pricing, promoting, packaging, branding, and transporting the rice. Farmers are organized in cooperatives and groups for collective bargaining to get better market prices; it also reduces their transport, storage, and handling costs. In Segou, gambiaka rice sells to retailers at 217 XOF/kg, parboiled rice at 140 XOF/kg and in Sikasso at 152 XOF/kg, and broken rice in both Segou and Sikasso sells at 100 XOF/kg (N'krumah, Elbehri & Legret, 2013).

2.4.2. Potatoes

Potatoes (*Solanum tuberosum*) are starchy vegetables important in Mali, widely grown for their high commercial and nutritional value. 80% of potatoes are produced in Sikasso; other important regions for potato production include Kati and, more recently, the Office du Niger (ZEF, FARA, and IER 2017). In 2017, potato production was 251,558 tonnes, yield was 214,092 kg/ha, and the area harvested spanned 11,750 hectares.

Potatoes grow well in sufficient light and slightly humid soils rich in organic matter; heavy soils, by contrast, reduce the germination rate and size of tubers, and make harvesting difficult. Average potato cycle is 90-110 days; however, this can vary depending on the variety (*Pamina, Claustar, Aïda, Spunta,* and *Sahel*). Worms, insects, acarians, and fungi often damage their leaves, stalks, and tubers. Preparing the land well and planting appropriate seed varieties are crucial to managing pests and diseases.

Important activities during input supply include sourcing potato seeds, sold at 1000 CFA/kg; subsidized fertiliser, estimated at 11,000 CFA/bag; and organic manure, at 22 CFA/kg. The main input suppliers for potato production are CikelaJigi, Mali Yiriden and La Sikassoise (Kergna & Dembélé, 2017). These service providers and suppliers are mainly concentrated in Sikasso.

Major operations during on-farm production include land preparation, planting, watering, and fertilisation, crop protection, and harvesting. Land preparation involves deep plowing and seedbed preparation. Tubers are planted at a depth of 5 to 10 cm, watered regularly and fertilised using compost manure. On farm activities are the most labor intensive due to the frequency of activities and number of people needed.

In the postharvest and processing stage, farmers sort tubers in the field and condition them in netted bags (Kergna & Dembélé, 2017). Potatoes can be stored for 1-3 months in a cold, dark room. Unfortunately, a lack of proper facilities and poor storage conditions have contributed to postharvest losses at a rate of about 30-50%. Before marketing, potatoes are graded in three major sizes: big, medium, and small. They are then traded by retailers and by wholesalers who come from Mali, such as from Sikasso or Kati, and from neighboring countries like Burkina Faso and Ghana. 80% of the market is in Sikasso. Retail potato prices vary from 100-300 CFA/kg and could be up to 600 CFA/kg for urban consumers. Quality and size affect the pricing of potatoes (Kergna & Dembélé, 2017).

2.4.3. Mangoes

Native to South Asia, mangoes (*Mangifera indica*) are a nutritionally rich fruit and a good source of various vitamins and minerals. In Mali, mango production makes up 0.5% and 0.3% of total production volume and value respectively. For many farmers, mango production is an important source of income, especially during the off seasons. The mango season in Mali is from March to June. Production is dominated by small-scale farmers in plots of up to 2 hectares who grow mostly local varieties. Commercial varieties, such as Kent and Valencia, are geared for export. Mango production is estimated to range from 500,000-750,000 tonnes (USAID 2018). Sikasso is home to approximately 90% of mango growers and producers in Mali, and yields the country's highest number of mangoes at 94% of the total production,

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[3] 1 USD = 572.78 XOF (CFA Franc)

followed by Bamako at 3% and Koulikoro at 2%. 79% of mango producers irrigate their crops, and the remaining 21% rely entirely on rainfall. (Kerga, Dembele and Fatunbi, 2017).

Mangoes are propagated either by seed or vegetatively. They require rich, well-drained soils about 3 meters deep, without impermeable layers. Their crop grows best with 500-1000 mm of mean annual rainfall at an altitude between 0-1200 m. **Compared to other crops, mangoes are relatively tolerant to drought.**

Key activities at the input supply stage include sourcing fertilisers and manure, necessary agriculture equipment like power pumps for irrigation, mango seeds or propagating material for planting, and technical support through extension services provision (Kerga, Dembele and Fatunbi, 2017). Mango seedlings are normally sourced from nurseries, and they require 2.5-3 years to establish making this a key activity in mango production. Important actors at this stage are mango service providers, nursery operators, and suppliers of seeds and other inputs.

During on-farm production, irrigation is crucial, especially for the first few years. It promotes flushing and hinders flowering so that the mango trees can increase in size more rapidly. Once the mango tree is mature, irrigation stops to allow for flower initiation. Irrigation also makes it possible to practice intercropping during the establishment phase with other horticultural crops such as papayas, bananas, pineapples, or vegetables. Other important activities at this stage are crop protection, especially against fruit flies. This is done through integrated pest management or use of bio pesticides, and is sometimes facilitated by collectors and exporters to ensure product quality is maintained.

Postharvest handling and processing of mangoes involves sorting, calibration, palletizing, packaging, and chilling. These activities are mainly carried out by agro-processors and exporters. Just before the harvest season, middlemen buy fruits from farmers. After the harvest, they collect them from the farms and resell them to exporters and agro-processors. Though relatively low, mango is also processed into juices, pulp or dried. Agro processors like Comafruit are known to export mango puree and concentrate while semi artisanal companies like Mouna-Utrafle make juices. Important actors at this stage therefore include middlemen, exporters, aggregators, collectors, and agro-processors (USAID, 2018).

In local markets trading of mangoes is done by retailers and wholesalers. Product marketing benefits from many, various mango trade service providers. These include packaging service providers, exporters, transporters, wholesalers, and customers. At the national level, more than 20 enterprises are grouped into two large associations of mango exporters: the Association Malienne des Exportateurs de Fruits et Légumes, created by the Centre Malien du Commerce Extérieur, which includes more than two-thirds of exporters; and the Association Professionnelle des Exportateurs de Fruits et Légumes, comprised of air freight exporters (Kerga, Dembele and Fatunbi, 2017). The Interprofession de la Filière Mangue (IFM) which is an association of mango value chain actors supports different aspects of the mango value chain.

2.5. Agricultural sector challenges

The principal hazards affecting crop and livestock productivity in Mali include changing precipitation patterns, frequent and prolonged dry spells, heat stress, pests, and disease incidences. Under climate change, cropping seasons are projected to become uncertain and pastures insufficient, leading to food insecurity. In particular rice, potatoes and mangoes are constrained by numerous challenges as discussed below.

Despite the vital role, rice plays in Mali livelihoods and food security, many farmers face numerous challenges. Among them, inadequate access to inputs, information and extension services forcing farmers to rely on available local knowledge. This has led to varietal impurity since farmers use their own inexpensive poor quality seeds (N'krumah, Elbehri & Legret, 2013). Varietal mixtures affect timely harvesting and consequent activities like husking, preservation and parboiling. Furthermore, poor paddy quality produces broken rice that has lower market value. Below par infrastructure such as storage houses, roads, markets increase costs of production significantly reducing final gross margins. The high-risk nature of rice production, price volatility makes financial services such as credit facilities to obtain better inputs limited for farmers (USAID, 2018). The fragmented nature of the rice business has encouraged entry of many players and actors, this leads to isolated, disharmonized initiatives that are contradictory and non-beneficial to smallholder farmers.

Potato farmers are constrained by access to proper seed due to domination by expensive imported seed from Europe. Inadequate skill and human resources limit available local potato seed multiplication. Furthermore, poor access to credit contributes to low purchase of fertilisers, seeds or hiring labor. Farmers are thus reliant on manual ploughing of land and irrigation with gourds, which is labor intensive (Kergna & Dembele, 2017). Coupled with lack of formal training on GAPs and processing activities commercialization is constrained by poor storage facilitates e.g. cold chambers, warehouses. Many farmers therefore sell their produce immediately at very low farm gate prices.

Mango production requires high initial production costs or investments especially for modern mango orchards. High poverty rates and inadequate access to agriculture credit locks out many mango farmers. Lack of proper capacity building for small scale producers, processors limits their knowledge of and access to innovative technologies and agriculture equipment, such as efficient irrigation systems. Moreover, lack of warehousing capacity, conditioning centres and adequate conservation technologies account for 40% postharvest losses of collected mangoes. Lack of quality control through product traceability limits mango exports (USAID, 2018).

Other factors also limit agricultural growth and productivity. Deeply rooted religious and cultural laws reinforce persistent inequalities. Gender norms, traditions, and land rights make it difficult for women to be equal partners in agriculture. Under formal law, individuals or entities can own and transfer land; however, majority of the Mali population obtains, holds, and transfers land under customary laws. Under these laws, inheritance is the most common method of land acquisition, and it usually follows a patriarchal lineage system (Land Links, 2020). In one rural commune, for example, approximately 40% of land titles were issued to government officials, 35% to the state, 19% to private businesspersons, and only 1% to small-scale farmers (Land Links, 2020). This situation directly contributes to the stagnation of agriculture, and the continued vulnerability of the population to shocks.

Reliance on markets makes the Malian population vulnerable to market volatility. In Sikasso, Kayes, Koulikoro, Segou, and Mopti, it was noted on average 60% of household incomes are spent on food purchase to supplement their diets (Anuaire Statistique Mali 2016). The worsening impacts of climate change and variability on agricultural production, compounded by pervasive poverty, make the poor population vulnerable to market volatility and consequent fluctuations in the prices of food and other agricultural inputs and outputs (GIZ, 2018). Infrastructural constraints continue to hinder export growth, especially because Mali is a landlocked country, and the time required to clear land borders creates bottlenecks that delay shipments (OECD/FAO, 2016).

3. POLICIES, STRATEGIES AND PROGRAMS ON CLIMATE CHANGE

KEY MESSAGES

- Mali has developed a strong framework of environmental law and policy, including the National Climate Change Policy (PNCC), the National Climate Change Strategy (SNCC), the National Climate Action Plan (PANC), the Agricultural Orientation Law (LOA), the Agricultural Development Policy (PDA), and the National Agricultural Investment Program (PNISA).
- In keeping with these policies, numerous programs have been developed, including some that are relevant for the rice, potato, and mango value chains, such as the Support Program for the Local Irrigation Sub-Sector (PASSIP), the Competitiveness and Agricultural Diversification Program (PCDA), and the Integrated Initiatives for Mali's Economic Growth (IICM) project.
- These programs could strengthen their responsiveness to local context and cross-sectoral linkages, as well as supporting additional ministries to engage in implementation.

Mali has developed several policies, strategies, and action plans integrating national adaptation guidelines with reference to the Strategic Framework for Growth and Poverty Reduction. Mali's Nationally Determined Contribution recognizes that two-thirds of the country is arid and semi-arid and gears planned adaptation efforts towards a green economy and a country resilient to climate change. The National Program for Adaptation Actions (NAPA), adopted in 2007, is aimed at developing priority activities for different sectors that address Mali's urgent needs related to the adverse effects of climate change. In 2011, the country developed its climate governance framework: the National Climate Change Policy (PNCC), the National Climate Change Strategy (SNCC) to operationalize the policy, and a National Climate Action Plan (PANC) to enact the strategy objectives (Zamudio, 2016). Agricultural policies developed by the government in support of the selected value chains include the Agricultural Orientation Law (LOA) adopted in 2006 that aims at promoting sustainable, modern, and competitive agriculture based on family farming. The Agricultural Development Policy (PDA) 2011-2020 and the National Agricultural Investment Program (PNISA) adopted in 2015 together identify strategic investments in five value chains: rice, maize, millet and sorghum, inland fisheries, and livestock products.

In line with these policies, many projects and programs have been developed and implemented in support of the selected value chains. The Support Program for the Local Irrigation Sub-Sector (PASSIP) has the following objective: "the rural population of Mali uses the economic potential of local irrigation for sustainable and autonomous agriculture." The Competitiveness and Agricultural Diversification Program (PCDA) aims to improve the productivity, quality, and economic performance of the fruit and vegetable sectors. Other projects include the Integrated Initiatives for Mali's Economic Growth (IICM) project funded by the United States Agency for International Development (USAID) under its Accelerated Economic Growth Program, which aims to strengthen the technical and organizational capacities of actors in several value chains including the rice, potato, and mango value chains. The IICM project is developing alternative solutions in response to climate change issues. In addition, the Mango Interprofession (IFM) brings together all the actors in Mali's mango sector, such as nursery operators, producers, processors, trackers, and export traders (Onibon, 2018).

The cited policies and programs in Mali are clear examples of strong policy guidance for climate change and agriculture. Recent climate policies and plans broadly align with current strategies and sustainable development goals. These policies, however, will need to acknowledge local contexts and cross-sectoral interactions. For instance, whereas climate change issues are mandated to the environment ministry, it is important that entry points are considered for other line ministries to ensure proper policy and program implementation.

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4. GOVERNANCE, INSTITUTIONAL RESOURCES AND CAPACITY

KEY MESSAGES

- A variety of institutions are furthering the adaptation of Malian agriculture to climate change, including the National Climate Change Committee (CNCC) and the Environment and Sustainable Development Agency (AEDD), in conjunction with various government ministries, and the National Directorate for Meteorology (DNM).
- A variety of international agencies also offer support, such as the German Agency for International Cooperation (GIZ), USAID, the Netherlands Development Organization, and the Food and Agriculture Organization of the United Nations.
- Other partners that benefit the selected value chains include the Office du Niger, the Ségou Rice Office (ORS), the Office Riz Mopti (ORM), the société coopérative artisanale des forgerons de l'office du niger (SOCAFON), the Institute of Rural Economy (IER), IPR-IFRA, and the DNA.
- A Multi-Stakeholder Platform (MSP) could improve collaboration and efficiency.

In Mali, several institutions are at the forefront of transforming agriculture in a changing climate. They include the national government, regional government departments, NGOs, universities, community-based organisations, international development partners, and the private sector. Most work with or through government ministries and departments. Institutions responsible for environmental sustainability, natural resource management, and implementation of Mali's climate strategy are led by the National Climate Change Committee (CNCC), set up in March 2011, and the Environment and Sustainable Development Agency (AEDD), established in 2010. CNCC implements the national climate change policies and plans while the AEDD coordinates and evaluates the implementation. To support implementation activities Mali set up a climate change fund in 2012 to mobilise financial resources (Zamudio, 2016).

The ministries of Agriculture, Environment and Sanitation, Livestock and Fisheries, Planning and Spatial Planning, and Energy and Water conduct research, assessments and support development and implementation of climate change adaptation plans. The National Directorate for Meteorology (DNM) is the focal point for coordination on climate change initiatives and monitors the implementation of adaptation projects (USAID, 2012). International development partners finance many climate change and agriculture initiatives administered by local organizations. They include the German Agency for International Cooperation (GIZ), USAID, the Netherlands Development Organization, and the Food and Agriculture Organization of the United Nations, whose programs and projects address issues related to agriculture, food and nutritional security, poverty reduction, and enhancement of rural livelihoods through improved standards of living. Other interventions include capacity building through training on GAPs, natural resource management, and health, peace building, and social equity programs.

Connected with these efforts, Mali has other institutions and partners that support agricultural development and in particular, the rice, potato, and mango value chains. The Office du Niger, which is the main rice production centre in Mali; the Ségou Rice Office (ORS); and the Office Riz Mopti (ORM), all support the development of rice. This sector also benefits from the intervention of the société cooperative artisanale des forgerons de l'office du niger (SOCAFON), a cooperative company of blacksmiths specializing in the production of rice-growing equipment. All the priority value chains benefit from research and advisory support institutions such as the Institute of Rural Economy (IER) and IPR-IFRA of Katibougou. The DNA also supports the provision of quality seeds (Ministère de l'Agriculture, 2009; Coulibaly Y. et Ouologuem A., 2014).

To enhance institutional coordination on all initiatives linked to climate change adaptation in agriculture, it is paramount to have a Multi-Stakeholder Platform (MSP) or an alternative coordinating mechanism that builds partnerships, fosters knowledge sharing, improves transparency, and reduces the duplication of work. This will improve inter- and intra-institutional collaboration to avoid disharmony and overlapping efforts. It will also refine the alignment of programs and projects to national-level targets, frameworks, strategies, and development plans, which is key for proper monitoring and evaluation of national adaptation progress.

5. CLIMATE CHANGE-RELATED RISKS AND VULNERABILITIES

KEY MESSAGES

- The most pressing climate issues Mali faces include increasing heat stress, changing precipitation patterns, and droughts.
- Projections indicate the suitability of rice will decrease, the areas suitable for growing mangoes will shift, and because potatoes will continue to be unsuitable, other crops might profitably replace them.
- Farmers are aware of climate change and are taking adaptive measures to respond; their education and other social, economic, and cultural factors condition their perceptions and responses.

5.1. Farmers' perceptions on climate change

Many studies across the five regions suggest that farmers are generally aware of the changing climate. Local knowledge and perceptions about climate change and its impacts can determine the adoption of adaptation options. In particular, a study conducted in N'Goukan in the Cercle de Koutiala, Southern Mali showed that many farmers were aware of climate change and assessed climatic risks and hazards based on the impact they had on crops and livestock (Traore et al. 2015). Many reported experiencing dry spells because of changing rainfall patterns, increasing temperatures especially in the dry season, and uncertainty about the start and length of growing seasons, because these risks negatively impacted productivity. Farmers' adaptive measures included adjusting planting dates, the use of short-maturing varieties, and crop diversification (Traore et al. 2015).

Similarly, in the Cinzana commune in Segou Cercle in the Segou Region of South-Central Mali, farmers perceived a decrease in annual rainfall variability and increased temperatures as the main factors of climate change and variability. Meteorological data corroborated their observations. More than 50% of farmers referred to tree flowering for weather prediction, while 38% monitored animal migrations. Other factors used to predict weather patterns included wind intensity and direction and high temperatures. **Many farmers attributed the reduced length of the rainy season, reduced crop yields, loss of vegetation cover, and declining soil fertility to climate change.**

This study also confirmed that education level, literacy rates, age, and sociocultural factors can influence farmers' perceptions about climate change, variability, and adaptation. For instance, there are low literacy rates among the farmers in Cinzana (Halimatou et al. 2016). Only 13.4% have accomplished secondary school education. Therefore, many rely on local knowledge for information. Moreover, many depend on subsistent farming as their main source of income. Millet is a major crop in this region; 46% of the farmers chose it for high productivity, while 21% choose it for its resistance to drought (Halimatou et.al 2016). **These statistics suggest that local farming communities have strong narratives about climate change events and risks, and they may not necessarily inform the choice of adaptation options because of the complexity of other environmental, social, and economic drivers.**

5.2. Climate change and variability: historic and future trends

Agriculture in Mali is mainly rain-fed and faces negative effects of climate change such as droughts and floods and the associated degradation of natural resources. The irregularity of the pluviometric and hydrological regimes due to climate change leads to a decrease in the flow of rivers and streams, the rapid drying of lakes and ponds, a decrease in the annual recharge of aquifers. This consequently leads to great variation in the rice productivity per hectare for various rice farming systems (Rapport provisoire d'évaluation des capacités nationales de planification de l'adaptation aux changements climatiques, MEADD/AEDD/GIZ, version provisoire). Potato production must also contend with important environmental constraints exacerbated by climate change, such as extreme heat, drought, and soil degradation (Plan d'investissement d'une agriculture intelligente face au climat au Mali, 2019). Night time temperatures play an essential role in the formation of starch by potatoes. Ideal temperatures fall between 15 and 18°C, while temperatures upwards of 22 °C seriously hamper tuber development (InfoResources, 2008). Mango production also depends on climatic factors. Irrigation water is limited, and the increasingly late onset of the growing season exposes mangoes to attack by fruit flies (Document d'Orientation Stratégique pour la chaîne de valeur mangue dans la CEDEAO, International Trade Centre (ITC)/ CEDEAO).

Our climate data analysis highlighted that across the regions, historical annual mean precipitation, measured in mm/year from 1981-2015, varied from 250 mm-1250 mm, while annual mean temperatures varied from 26°C-30°C (Figure 3). The rainy season fell between June and September. Dry spells characterised by less than 50 mm of rainfall were experienced in April, May, and October. August received the highest rainfall, 150 mm to 250 mm per month. In Mali, rising temperatures are an important climate stressor for both people and agricultural production. From 1981-2015, the regions studied have been experiencing an average of 80 days in season 1 with maximum temperatures greater than or equal to 35°C, with the northern parts of these regions, like Mopti, experiencing more than 120 such days.[4] **Future climate projections indicate that heat stress will increase drastically across these regions.** Extreme heat events could last for months especially in the northern parts of Koulikoro and Mopti, where we expect up to 157 days with heat stress in season 1.

Future climatic projections indicate significant increase in the number of consecutive dry days (CDD), which will frequently reach more than 35 days, leading to a high risk of droughts in season 1. In 1981-2015, across the regions under study, CDD has shown moderate increase with a few extremes over the years, leading to CDD variation of 12 to 25 days (Figure 4).[5] Comparison of historical and future trends indicates that moisture stress is also expected to increase across these regions by 5 to 20 days.[6] The northern part of the selected regions with a high CDD will experience significantly higher moisture stress than other areas. While Segou will have the highest mean of days with moistures stress at

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[4] The total number of days with a maximum temperature greater than or equal to 35°C (NT35) for a season serves as an indicator of heat stress.

[5] The number of consecutive dry days (CDD) with precipitation < 1 mm/day serves as an effective measure of extremely low precipitation and seasonal droughts.

[6] Moisture stress is estimated as the number of days with an actual-to-potential evapotranspiration ratio below 0.5.

130 days, Sikasso will experience the largest increase in the number of days with moisture stress from 103 to 117 days (Figure 5). In the rainy season, P5D – an indicator of flood risk, the maximum 5-day running average precipitation – has historically remained below 20mm. Future climate projections indicate that flooding P5D will increase across the regions studied from 0 to 10mm. This overall increase of P5D suggests a concomitant increase in flood risk throughout the regions. Similarly, projections of future P95 – an indicator of heavy rainfall, the 95th percentile of daily precipitation – will slightly increase but remain below 20mm.

In summary, this climate projection shows that the main risks are heat stress and changing precipitation patterns, as well as droughts affecting crop productivity and suitability. Heat stress is projected to become an important hazard in the future, with up to 160 “hot” (Temperature >35°C) days in some years and regions (Figure 6). Dry spells are projected to become 10 days longer by 2050. Similarly, the number of moisture-stress days is projected to increase from 100 to >140 days on average, thus reducing the length of the growing season, which will become less suitable for cropping. Flooding (P5D) and flash-flooding (P95) risk are not high, but tend to increase significantly in the future.

Figure 3. Historical mean annual precipitation (left panel) and annual mean temperature (right panel) for Koulikoro, Sikasso, Kayes, Ségou, and Mopti Zones of Mali.

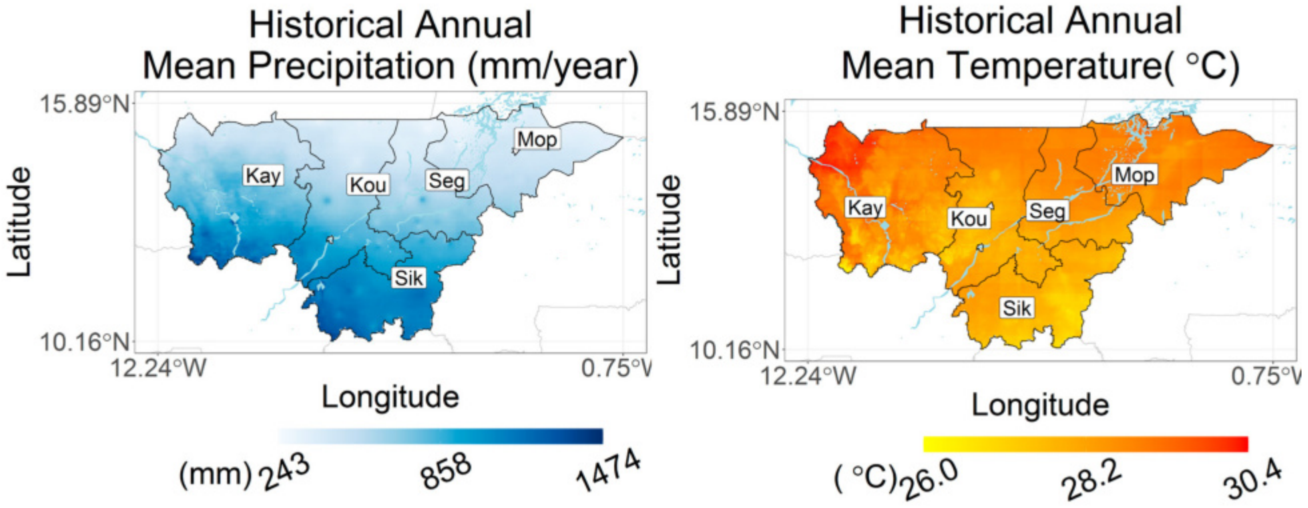


Figure 4. Historical (left), future projected (center) and projected change (right) for the maximum number of consecutive dry days within the year (average of last 30 years) for Koulikoro, Sikasso, Kayes, Ségou, and Mopti Zones of Mali.

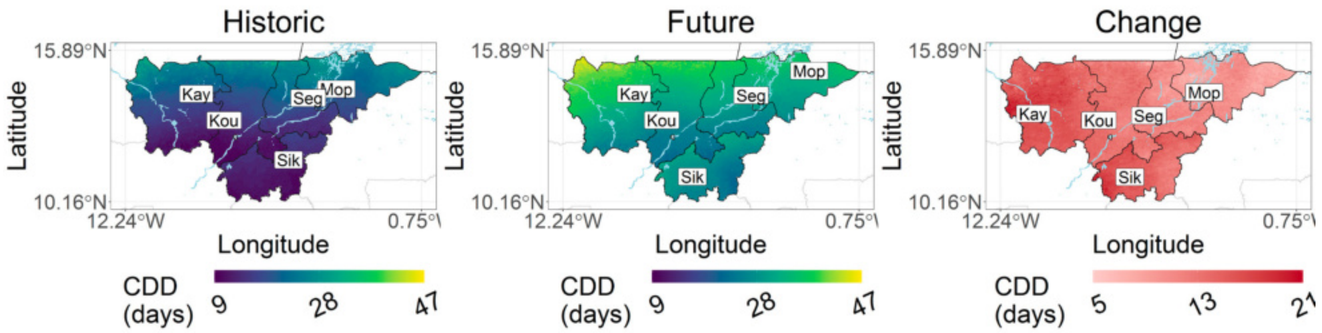


Figure 5. Historical (left), future projected (center) and projected change (right) for the number of moisture stress days within the year (average of last 30 years) for Koulikoro, Sikasso, Kayes, Ségou, and Mopti Zones of Mali.

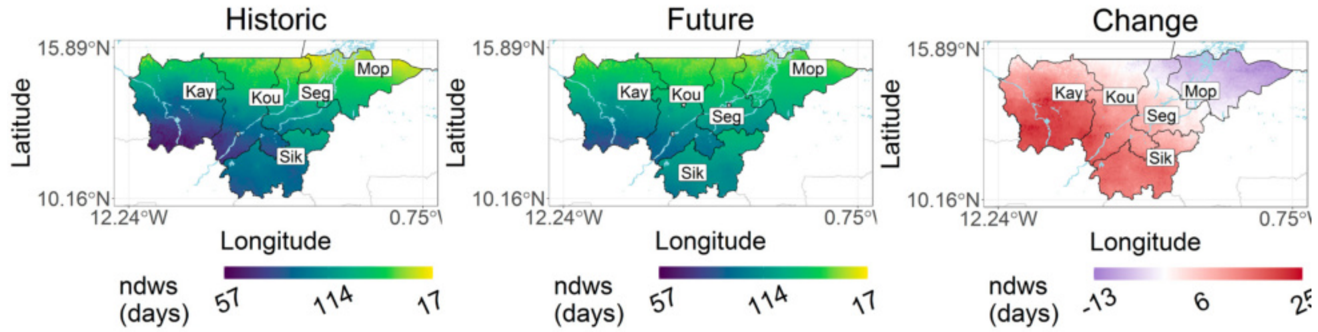
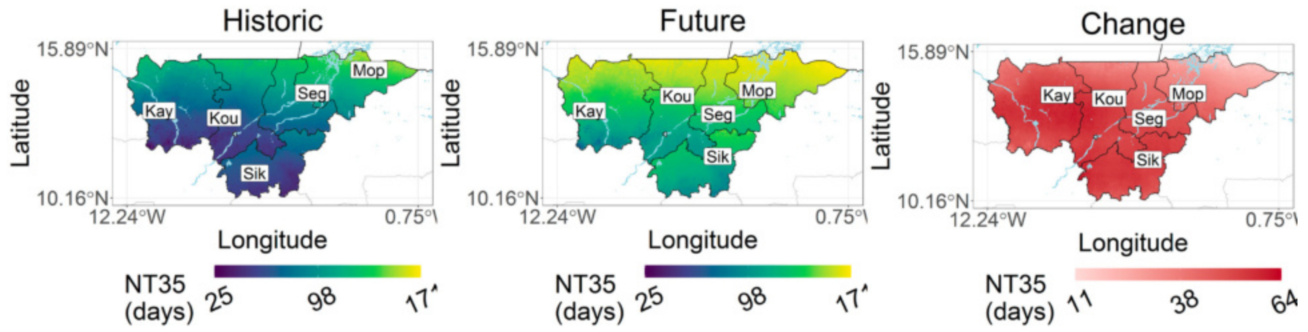


Figure 6. Historical (left), future projected (center) and projected change (right) for the total number of days with maximum temperature greater or equal to 35°C in the year (average of last 30 years) for Koulikoro, Sikasso, Kayes, Ségou, and Mopti Zones of Mali.



5.3. Crop suitability analysis

For our crop suitability analysis, we used the EcoCrop model (Ramirez-Villegas et al. 2011) to determine the suitable areas for crop production under current and future climate scenarios. EcoCrop has been used in numerous studies to conduct suitability assessments and understand the impacts of climate change on many crops. EcoCrop was our preferred model due to: i) ease of implementations and interpretation; ii) its comprehensive database of crop-specific parameters compared to process-based models that are hard to parameterize in data-scare regions; and iii) substantial agreement on projections of climate change impacts with other models. The analysis was based on worldclim v1.4 (Hijmans et al. 2005) for the historical and near current climate and an ensemble of 5 downscaled global climate models for future periods under Representative Concentration Pathway (RCP) 8.5 (Navarro-Racines et al. 2020).

Historically, from 1960-90, the highest suitability (80-100%) for rice area production is mainly in Sikasso (75%), followed by Kayes and Koulikoro, which account for 0-25 % of the highly suitable production area. Mopti region has been generally unsuitable (0%) for rice production while Segou show no suitability in 75% of its area to poor suitability (0-40%) in 25 % of its area which will shift to no suitability in the 2050s (Figure 7). **As we progress to 2030s and 2050s, the analysis highlights up to a 20% decrease in suitable areas for rice production in Sikasso, Kayes, and Koulikoro.**

Based on historical crop and climate data, potato production suitability analysis highlights that the selected regions are generally less suitable and suitability will decrease in the future (Figure 8). The suitability analysis also highlights new crops that would be suitable for these regions. Pearl millet, for example, is a new crop that would be highly suitable in Mopti and is expected to remain suitable in the 2030s and 2050s. Cowpeas, sesame, and sorghum would also be highly suitable across the whole of Sikasso and would maintain productivity even in the future.

In the 2030s and 2050s, due to changes in precipitation patterns and temperatures, we expect lower suitability and no suitability for mangoes in some areas (Figure 9). Sikasso region (100%) has historically had the highest suitability for mango production areas followed by Kayes (80%), Koulikoro (70%), Segou (65%) and Mopti (10%). Conversely, in Mopti, where current suitability is low, we expect new growing areas to emerge (10-20%). Mango production suitability areas will decrease significantly (>50%) in Sikasso, Kayes, Koulikoro, and Segou by 2030s and 2050s.

Figure 7. Left: Historical and future (scenario RCP 8.5, periods 2030 and 2050) suitability of African rice production in the Koulikoro, Sikasso, Kayes, Ségou, and Mopti Zones of Mali. Right: Suitability change of African rice production

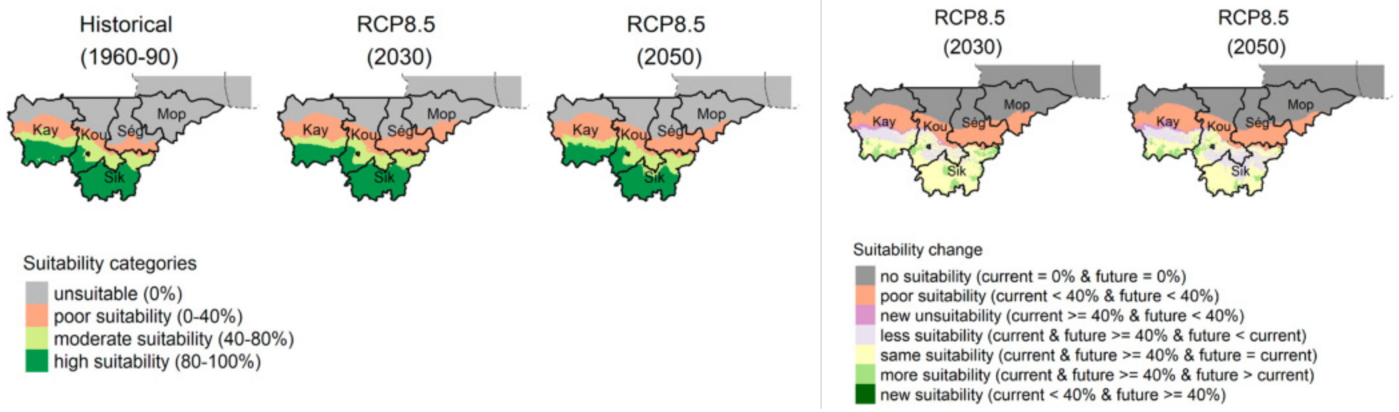


Figure 8. Left: Historical and future (scenario RCP 8.5, periods 2030 and 2050) suitability of heat tolerant potato production in the Koulikoro, Sikasso, Kayes, Ségou, and Mopti Zones of Mali. Right: Suitability change of heat tolerant potato production

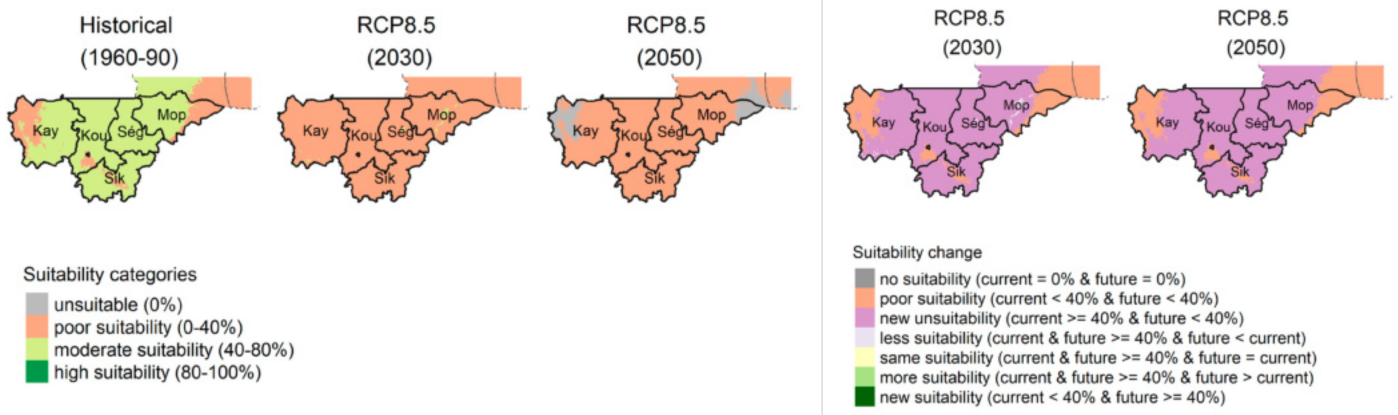
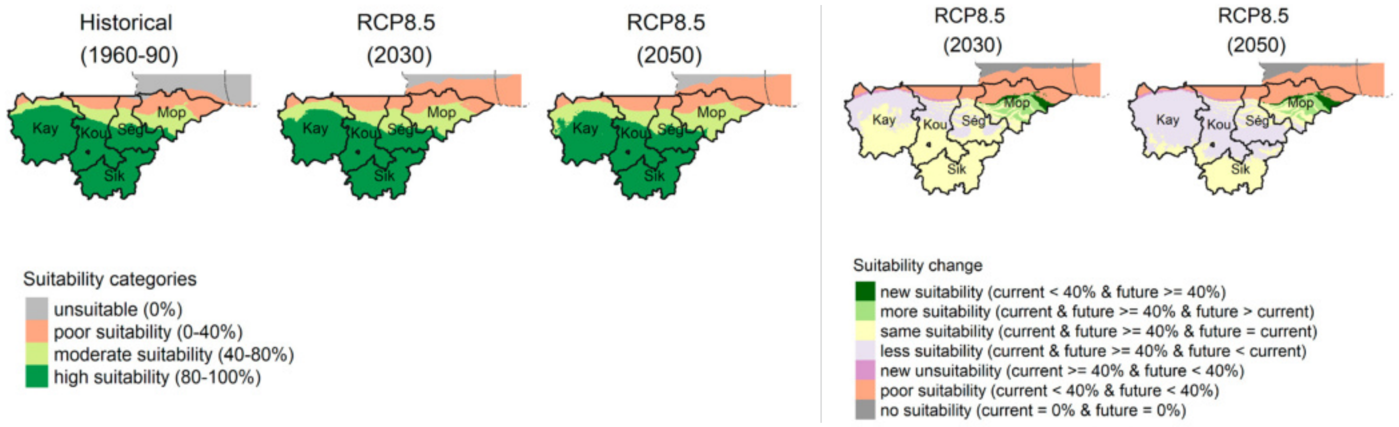


Figure 9. Historical and future (scenario RCP 8.5, periods 2030 and 2050) suitability of mango production in the Koulikoro, Sikasso, Kayes, Ségou, and Mopti Zones of Mali. Right: Suitability change of mango production



5.4. Climate vulnerabilities across agriculture value chain commodities

5.4.1. Rice

Reduced rainfall negatively impacts rice production. Seeds are damaged and land preparation is more challenging as the soils become difficult to plough. The cropping season starts late, reducing productivity. High breakage and wilting of the crop reduces the quantity, as measured in tons/ha, and quality of rice grains, especially their uniformity in size, shape, and color. Accordingly, the market value of the rice decreases, and farmers lose income.

It is impossible to overstate the importance of soil fertility to the yield and quality of the rice crop. Soil degradation instigates the loss of nutrients, organic matter, and applied fertilizers, thus drastically impacting overall productivity. Moreover, low water retention causes poor seed germination, which leads to poor crop development. **Apart from the expected low yields and poor quality of the paddy, soil degradation increases the costs of production and processing considerably.**

At least 70% of small-scale producers are impacted by this hazard, especially women, who constitute the majority of rice producers. Many underlying factors contribute to the vulnerability of rice farmers and either complicate their recovery from climatic shocks or expose certain groups like women and youths to worse consequences. These include a lack of access to productive resources like land or capital, limited knowledge and practical skills due to low levels of training or a lack of training, geographical location where farmers in low lying areas are more flood prone, inadequate infrastructure such as storage facilities, and poor access to agro-weather information and services. Furthermore, weak organizations constrain farmers' ability to collectively market goods and fetch decent prices. Rice farmers are also vulnerable due to their low investment capacity for mechanization and manuring.

5.4.2. Potatoes

Temperature fluctuations negatively affect potato production due to reduced tuber growth and yield. At high temperatures, there is a risk of slow tuber growth and of incidences of pests like aphids and potato tuber moths or diseases like potato blight. On the other hand, low temperatures bring the risk of frost, which can lead to tuber damage. Soils at high temperatures also cause seeds to rot and reduce their germination rate. Fluctuating temperatures increase the costs of input supplies such as seeds and fertilisers. Since men are mostly involved at the input stage, they are impacted the most. Additionally, due to isolated pockets of local seed production in Segou and Mopti, shortage of multiplication sites and lack of qualified personnel and cold chambers, national demand goes unmet. Poor quality as regards tuber shape and size and low quantity in together result in high storage costs and decreased incomes in the market.

Rainfall variability affects water availability for potato production. On one hand, potatoes are sensitive to soil water deficits during germination; on the other, they are also affected by excessive water through physiological damage to their tubers and increased incidence of pest and diseases. Input supply is moderately affected by rainfall variability. Despite low reserves of local seed and the decreasing quantity and quality of organic fertiliser in the five regions under study, farmers use local knowledge to adapt where necessary. Local knowledge and practices entail using mineral fertilizers in place of organic, uprooting and burning diseased plants instead of insecticide application and use of their own saved seeds instead of new and improved seed varieties. Poor water availability also leads to uncertainty about the start and length of growing seasons, decreasing productivity. These issues ramify to other stages in the value chain, where the lesser number and weight of tubers compromises their market value. Other quality traits such as protein and carbohydrate content as well as flavor and texture are also affected. This translates to low supply in the markets and low incomes for the producers. This marked demand is met through imports since there are cheaper and readily available.

Many youths are actively engaged in the on-farm production, postharvest, and processing stages, while women oversee marketing activities. Youth potato farmers are both socially disadvantaged and economically vulnerable. **These setbacks exacerbate their vulnerability to challenges like high production costs and poor access to agricultural credit facilities and agro-information services.** These factors diminish their ability to respond to or recover from climate hazards.

Even for experienced farmers, access to good-quality seeds and fertilizers is limited by high prices and weak advisory support. Furthermore, potato farmers face conservation issues with significant postharvest losses. Other actors affected include seed producers and small potato vendors, who risk severe losses because of climate hazards.

5.4.3. Mangoes

While warmer areas are conducive for mango production, extreme temperatures can decrease yields. At very high temperatures, their germination rate slows, and grown seedlings dry out. Leaves and flowers burn out, which interferes in fruit setting and maturation. High temperatures can result in shriveled fruits that are of poor quality, hence poor market value. This translates to increased production costs and reduced incomes. Farmers in the Bamako and Koulikoro regions are most affected by these consequences of climate hazards.

Changing precipitation patterns significantly disrupt the production cycle of mangoes. The start and length of growing seasons become uncertain, so planting materials such as grafted seedlings may dry out. Drying out of the plant hampers flowering and fruiting, and completely disrupts crop development and consequent mango farming activities like harvesting, processing, storage, and marketing. Huge economic losses result. Sikasso is the worst-affected region.

Farmers of different genders and ages are disparately affected by climate shocks due to different involvement in mango production. In particular, men suffer the costs of a dearth of planting materials and poor mastery of GAPs because they dominate the input and on-farm production stages. Agricultural information is vital for mango development. Low adoption of Good Agriculture Practices (GAPs) and a lack of practical experience in mango orchards management results in poor mango productivity.

Inadequate productive resources, especially financial constraints, also prevents them from investing in CSA technologies like irrigation infrastructure. Women and young people are affected by low mango quantities and qualities as they dominate the postharvest, processing, and marketing. At the nursery stage, youth engagement is limited due to insufficient skills and experience in activities such as grafting. The illiterate aging population are especially vulnerable to climate risks because of their diminished adaptive capacities. The high costs of clean planting materials, quality seeds, and processing and marketing mangoes also disadvantage many farmers.

6. ADAPTATION TO CLIMATE CHANGE AND VARIABILITY

KEY MESSAGES

- Farmers across the prioritized value chains are utilizing a variety of adaptation strategies to cope with climate change, including irrigation, organic and synthetic fertilizers, and/or improved crop varieties.
- Mali's Green Innovation Centres, the government, non-governmental organizations (NGOs), and farmer organizations are facilitating additional adaptation options
- Priority adaptations in rice includes SRI combined with bio fertiliser and deep placement of super-granulated urea (PPU).
- Priority adaptations for mangoes include good agricultural practices.
- Priority adaptations for potatoes includes locally produced tubers and solar pump irrigation.
- These innovations augmented productivity and reduced costs, and in almost all cases, the risk of economic losses was low.

6.1. On-farm adaptation strategies

Farmers have their own-farm adaptation strategies to face the impact of climate change on their production. For rice farmers, the main coping strategies are irrigation using a motor pump, re-sowing if the agricultural calendar allows, using short cycle varieties and contract farming. For rain fed crop systems including pluvial rice, the most commonly adopted strategies are the use of adapted, drought- or pest-tolerant crop varieties, early sowing, and the application of organic manure as fertilizer (Touré H. A. et al., 2016). Mango producers use motor pumps or drip irrigation to cope with the effects of climate change (Diallo et al., 2016). Farmers also practice intercropping with papaya trees and leave mangoes to drop at maturity.

The Green Innovation Centre has been promoting several innovations which have been tested and are currently being applied. For instance, rice farmers are implementing the system of rice intensification (SRI); engaging in urea deep fertilization to reduce the amount of fertilizer used; applying Fertinova, a biofertiliser containing high levels of natural organic matter, nitrate, phosphorus, potassium nutrients, and trace elements. Its granulated formula ensures nutrients are released slowly and efficiently at all stages of the crop lifecycle; and using locally produced Philippine seed drills, a form of sowing equipment for pre-germinated rice, with 6 rows. Seed drills support precision agriculture which enhances yields and improves ease of on farm activities like weeding, fertilisation and harvesting. To increase rice competitiveness in the markets they are promoting parboiling of rice. For potatoes, the Green Innovation Centre has been promoting the use of improved seeds, the cessation of dormancy, biological pest control, and modern irrigation systems with solar pumps, and new storage and processing options such as zero-energy cooling chambers and solar bubble dryers. Finally, the Green Innovation Centres are promoting seeds of high-yielding and sought-after varieties, integrated control of fruit flies, and organic certification of mangoes. Moreover, a transversal innovation has been proposed for the mango value chain: a matching grant facility for strengthening the transformation and expansion of the product range.

The Rizeries project, in addition, is promoting good rice harvesting techniques and good quality paddy from SRI packages, and enhancing farmers' incomes through contract farming. The state, small producers, and non-governmental organizations (NGOs) are promoting the use of short-cycle rice varieties, Semoir phillipin (Phillipine seed drill), 4-row seeders, and SRI technical packages. IPR/IFRA, the Direction Nationale de l'Agriculture (DNA), Le Projet d'Appui aux Filières Agricoles, the CIV, and the Groupement Interprofessionnel pour la valorisation de la Pomme de Terre are building farmers' capacities through formal training on good agricultural practices in potato handling, grading, packaging, and transportation. Many farmers have also been using equipment such as solar powered conservation boxes and cold rooms to ensure that potatoes keep well during storage. The use of short-cycle varieties is also common among farmers along with local seed production to supplement the demand for good-quality planting material. Microfinance institutions, DNA, CIV, DNGR, are also facilitating access to credit, linking farmers to markets, and promoting crop diversification as an adaptation strategy.

Farmer organizations and individual mango farmers are using improved varieties and employing GAPs like grafting, organic fertiliser application, pruning, and shading systems to improve the quality of mangoes and increase yields. Trackers, processing companies, and sellers are investing in proper infrastructure like cold chains to facilitate production of different mango products like juices, puree or chutney and increase market value.

6.2. Overall ranking of the adaptation strategies

The proposed adaptation strategies by Mali stakeholders offer options to address anticipated climate variability and are largely drawn from ongoing interventions across the selected value chains (Table 1). For example, to reduce drudgery, the risk of heat burns, and exposure to smoke, grain quality-enhancer, energy efficient and durable material (GEM) parboiling technology is an excellent adaptation option for rice farmers, especially women. To cope with rainfall deficits, good options include scaling up the use of rice hybrid varieties, SRI, and the sustainable rice platform (SRP). Plus, alternate wetting and drying for rice is an important crop management practice that can build the resilience of the rice production systems and farmers too. Introducing accessible services such as crop insurance and purchasing equipment for GEM or the hulling machine adapted to parboiled rice would also boost quality, thus increasing incomes. Advanced technologies such as drones can help control pests and disease as well as aid in the general management of large-scale rice farms. To link farmers to markets, rice trade fairs would serve as a great platform for consumers and small-scale producers to meet. In addition, the Green Innovation Centre in Mali proposed several adaptation options: alternating irrigation of wet rice fields, rice husk biochar production, early incorporation of rice straw or complete extraction, incorporation of manure, use of adapted varieties, combining fish culture with rice culture, and use of the digital tool RiceAdvice (Green Innovation Centre Mali, 2018).

Table 1. Specific practices within each practice group relevant to the focus value chains

PRACTICE GROUPS	RICE VALUE CHAIN	POTATO VALUE CHAIN	MANGO VALUE CHAIN
Climate services		• Increased access to agrometeorological information	• Extension services • Timely agro-weather information • Adaptation of crop calendars to updated weather information
Conservation agriculture	• No till	• Soil and water conservation • Agroecological cultivation • Associating potato production with that of other vegetable crops	
Disease & Integrated Pest Management		• Pest and disease management	
Fertilizer management	• Use of bio-fertilizer* • Rice husk biochar production • Early incorporation of rice straw or complete extraction		
Harvesting technique	• Combine harvester		
Improved processing	• Grain quality-enhancer, energy efficient and durable material (GEM) parboiling technology • Provision of equipment for GEM and hulling	• Facilitating access to solar energy	
Improved rice management	• System of rice intensification (SRI)* • Use of drones, e.g. for pest control and farm management; • Combining fish culture with rice culture • Sustainable rice platform (SRP) • Use of the digital tool RiceAdvice		
Land restoration	• Reforestation		
Manure management	• Incorporation of manure		
Organic inputs		• Organic farming	
Production best practices	• Capacity building*	• Training in Good Agriculture Practices*	• Improved access to production inputs • Use of Good Agriculture Practices*
Protected cultivation			• Greenhouse planting material and general production
Risk insurance	• Crop insurance		
Storage and post-harvest	• Storage silos	• Good potato conservation practices • Infrastructural facilities such as refrigerated storage • Improvement of the potato conservation system in the lowlands • Post-harvest management	• Use of adapted transportation like cold vehicles* • Advanced cold storage facilities
Tree management			• Installation of modern commercial orchards with high production density and total control of the production system • Training in proper orchard management practices
Variety improvement	• Use of adapted rice varieties* • Use of rice hybrid varieties*	• Use of climate resilient seed varieties, e.g. heat-resistant, drought-resistant, or rainy season potatoes • Use of locally produced tubers*	• Improved seed or planting material*

PRACTICE GROUPS	RICE VALUE CHAIN	POTATO VALUE CHAIN	MANGO VALUE CHAIN
Water management	• Improved crop management, e.g. alternate wetting and drying • Sprinkler irrigation • Alternating irrigation of wet rice fields	• Efficient irrigation systems • Promotion of measures for rational management of water and related infrastructure • Introduction of solar-pumped irrigation systems*	• Use of efficient irrigation systems, e.g. drip or micro-spray irrigation*
Marketing	• Rice trade fairs	• Adapted infrastructure with renewable energy • Training on good potato grading practices • Increased access to market information	• Linking farmers to markets
Finance		• Access to agriculture credit schemes	• Improved access to financial services such as credit schemes or small loans

*Denotes that this is the highest-ranked adaptation strategy for its respective value chain.

To be resilient, potato growers require access to agriculture credit schemes to enable them to acquire inputs such as certified seeds, fertilisers and pesticides. The farmers should also be supported to intensify potato production through training on good agriculture practices. Specifically, the use of climate resilient seed varieties, efficient irrigation systems, organic farming, soil and water conservation, pest and disease management and post-harvest management. Capacity building initiatives should also focus on enhancing producers' knowledge and skills at all stages of the value chain. These include increased access to agrometeorological and market information for informed decision making. With potato being an increasingly important cash crop for Malian farmers, infrastructural facilities such as refrigerated storages are important for potato conservation. These proposed adaptation strategies highlight potential areas to increase potato productivity however they need to be contextualized to specific regions and tailored to beneficiaries needs (Table 2).

Mango farmers' enhanced capacity to manage mango orchards requires them to have access to production inputs, financial services such as credit schemes or small loans, timely agro weather information and markets. Inputs like improved seed or planting material use should be promoted and augmented with training on proper orchard management practices. Extension services which are vital for transference of new technical knowledge and skills should be accessible and available to farmers. Greenhouse planting material production, use of efficient irrigation systems and advanced cold storage facilities are other proposed adaptation strategies (Table 2).

Table 2. Adapting to climate change: strategies across major value chain commodities

RICE	INPUT	ON-FARM	POST-HARVEST	MARKETING
Rainfall deficit	• Poor germination due to insufficient water • Dried out crops due to insufficient water • Production of poor-quality seed	• Late start of the cropping season • Lower productivity • Difficulty in plowing the soil • Decreased productivity • Presence of empty rice husks	• Poor-quality paddy • High breakage rate • Poor-quality final product	• Reduction in market value • Loss of income
Magnitude of impact	MODERATE	SEVERE	MODERATE	SEVERE
Farmers' current coping strategies	• SRI technical packages such as SRI plus deep placement of super-granulated urea (PPU) plus biofertilisers • Use of short cycle rice varieties • Use of tools like "Semoir phillipin" and 4-row seeder	• Agrometeorological information • SRI technical packages (SRI plus PPU plus biofertilisers) • Direct seeding • "Semoir phillipin" • 4 row seeder	• Good harvesting techniques • Awareness of the humidity level • Good-quality paddy from SRI package • Adapted packaging	• Capacity building • Contract farming
Other options to increase adaptive capacity	• Hybrid varieties	• Alternate wetting and drying • Sprinkler irrigation • Use of drones	• Use of GEM equipment • Storage silos	• SRI plus SRP
Soil degradation	• Loss of inputs through runoff • Poor germination • Decreased fertility • Low water retention (drier soil)	• Poor plant development • Sensitivity to lodging • Low yield • Difficulty working on soil • High cost of production	• Poor-quality paddy (after pouring) • Poor-quality final product • High cost of processing	• Reduced market value • Decreased income
Magnitude of impact	SEVERE	SEVERE	MODERATE	MODERATE
Farmers' current coping strategies	• Use of organic manure • Biofertiliser "PPU"	• Anti-erosion techniques • Pelleting machines • Landscaping systems with total water control	• Agro mill machinery-180 kg rice kit • Mini-rizeries	• Capacity building • Contract farming
Other options to increase adaptive capacity	• Improved, well-adapted varieties	• Reforestation • No tillage • Crop insurance • Combine harvester	• "GEM" equipment • Hulling machines adapted to parboiled rice • Use of "ER/EE"	• SRI plus SRP • Parboiled Rice Fair

POTATOES	INPUT	ON-FARM	POST-HARVEST	MARKETING
Temperature deviation and amplitude	• High dependence on imports • Isolated pockets of local seed production • Inadequate local seed production • Decreased quantity and quality of organic fertilizer	• Decreased productivity • National demand unmet • Small size of potatoes • Shortened production period	• High decay rate • High storage costs • Decreased income	• Low market value of the local potato • Heavy dependence on imports of ware potatoes
Magnitude of impact	MODERATE	SEVERE	SEVERE	MINOR
Farmers' current coping strategies	• Use of short-cycle varieties • Promotion of local seed potato production	• Promotion of good agricultural practices at production and postharvest stages • Facilitating access to credit • Promotion of diversification and rotation measures	• Enhanced conservation boxes with solar energy • Realization of cold rooms	• Training on good potato handling practices, grading, and transportation • Facilitating access to credit
Other options to increase adaptive capacity	• Introduction of, e.g., heat-resistant varieties adapted to climatic conditions • Introduction of seed varieties for rainy season potatoes	• Expansion of production in other areas • Promotion of organic and agro-ecological cultivation and good practices • Associating potato production with that of other vegetable crops	• Facilitating access to solar energy • Good potato conservation practices	• Adapted infrastructure with renewable energy
Excess and lack of water	• Isolated pocket of local seed production • National needs unmet by local seed protection • Decreased quantity and quality of organic fertilizer	• Decreased productivity • Reduced quality of potatoes due to disease • Potato production only possible in Sikasso, Segou, and Mopti	• High decay rate • Loss of produce in flood or drought conditions	• Low market value of the local potato • Dependence on potato imports
Magnitude of impact	MODERATE	SEVERE	SEVERE	MINOR
Farmers' current coping strategies	• Watering with solar-powered irrigation motor pumps	• Development of lowland and market gardening perimeters	• Waterproof storage facilities	• Good practices for sorting, solar preservation, and market quality
Other options to increase adaptive capacity	• Introduction of solar-pumped irrigation system • Agrometeorological information	• Promotion of measures for rational management of water and related infrastructures • Introduction of varieties adapted to climatic conditions, like heat- and drought-resistant varieties	• Improvement of the potato conservation system in the lowlands	• Training on good potato grading practices

MANGOES	INPUT	ON-FARM	POST-HARVEST	MARKETING
Extreme temperatures	• Burned leaves of seedlings • Low germination rate	• Dried out flowers • Low fruit set • Dried out fruits • Tree death due to overheated roots • Disruption of fruit maturity	• Dehydration • Early maturation • High energy costs for storage • Economic loss	• Early maturation • High energy costs • Economic loss
Magnitude of impact	MAJOR	SEVERE	MODERATE	MAJOR
Farmers' current coping strategies	• Good production practices: seedlings, shading system, living fence, etc	• Mulching • Organic fertilization • Pruning • High-density orchards • Agricultural diversification in orchards	• Using mango leaves in the crate	• Storage in aerated areas
Other options to increase adaptive capacity	• Drip irrigation	• Drip and micro-spray irrigation	• Use of adapted transportation like cold vehicles	• Storage centres with modern cooling or solar systems
Precipitation patterns	• Loss of the graft	• Delayed flowering • Diseases or stress and disruption of the production cycle • Erosion and loss of soil fertility • Irregularity in production	• Disruption of harvesting time • Economic loss	• Economic loss
Magnitude of impact	MAJOR	SEVERE	MAJOR	MAJOR
Farmers' current coping strategies	• Installation of straw sheds	• Anti-Erosion Control • Organic fertiliser • Surface water harvesting	• Monitoring weather information • Protection with tarpaulins	-
Other options to increase adaptive capacity	• Greenhouse production	• Installation of modern commercial orchards with high production density and total control of the production system	• Adaptation of crop calendars to usable weather information	• Linking farmers to markets

Stakeholder assessment of promising adaptation strategies

To prioritize the most promising adaptation options for climate hazards in each value chain, stakeholders identified five criteria: economic profitability, attenuation, adaptation, social impact, and ease of scaling up and out. They used these factors to score each adaptation strategy on a scale of 1 to 5, where 5 represents highest impact. The sum of the scores was used to rank the adaptation options. For rice, the most promising, highest-scoring adaptation options were as follows: focusing on productivity and farmers' resilience, e.g. using SRI technical packages; adoption of improved rice varieties; and capacity building efforts. Similarly, in potato and mango production, there was strong advocacy for adoption of improved varieties and use of GAPs. In the mango value chain, improvement of postharvest, processing, and storage by investing in cold vehicles was prioritised.

6.3. Cost benefit analysis of the prioritized adaptation strategies

CBA analysis for the prioritized innovations for mango, potato and rice value chain in Mali. Cost and benefit analysis (CBA) is critical when making investment decisions, including those associated with Climate-Smart agricultural (CSA) practices. This is because CBA allows for the comparison of costs and returns associated with a given CSA practice when compared to those that are already existing (also referred to as business as usual (BAU) or conventional practice) (Ng'ang'a et al., 2017). In CBA, three CBA indicators, the Net Present Value (NPV), Internal Rate of Return (IRR), and payback period are used to show the profitability associated with an improved practice or innovation. The NPV measures the incremental flow of net benefits from the innovation over its lifecycle, while the IRR is the discount rate that equates NPV to 0. A higher IRR indicates that innovation is profitable. The payback period is the number of years it takes to recoup the initial capital invested. CBA was conducted for the highest-ranked innovation in the mango, potatoes and rice value chains in Mali. In the case of mango and rice value chains, the use of good agricultural practice and use of a system of rice intensification combined with bio-fertilizer were the prioritized innovations respectively. In the case of the potato value chain, the use of locally produced tubers and irrigation with the solar pump was prioritized. The use of locally produced tubers in the potato value chain was prioritized due to its ability to resist drought and produce superior yield even with a low amount of rainfall. The use of good agricultural practices, the use of rice intensification and the use of irrigation for mango, rice and potato value chains respectively were prioritized because they result in superior yield compared to the BAU. Except for irrigation with a solar pump that had a lifecycle of 6 years, all the innovations under consideration had a lifecycle of 10 years.

The use of good agricultural practices in the mango value chain, the use of irrigation using a solar pump for potato production, the use of locally produced potato tubers and rice intensification requires about 321%, 123%, 243% and 19% more installation capital respectively compared to the BAU (Table 3). All the four innovations require between 3 and 37% more maintenance cost compared to the BAU (Table 3). The use of locally produced tubers and rice intensification requires about 83% and 64% more capital for operation activities respectively compared to BAU (Table 3). The main benefits emanating from the use of agricultural practices in the mango value chain, the use of irrigation using a solar pump, the use of locally produced tubers, and rice intensification was as a result of increase in yield per unit hectare when compared with the BAU. The results in Figure 10 shows that the use of good agricultural practices in the mango value chain, the use of irrigation using a solar pump, the use locally produced tubers and rice innovations increases the yield by about 200%, 25%, 25% and 100% respectively.

The NPV associated with the use of good agricultural practices in the mango value chain, the use of irrigation using solar power pump in the case of the potatoes value chain, the use of locally produced potatoes tuber and the use of intensification in rice was US$ 15,599, US$ 28,449, US23,581 and US$ 10,665 per hectare respectively (Table 4). Summary information on profitability associated with the adoption of the innovations (good agricultural practices, irrigation using solar pump, use of locally produced tubers and the use of system intensification) in mango, potato and rice value chains). The IRRs associated with these four innovations were 84%, 62%, 38% and 244% all of which are higher than the prevailing discount rate of 13.5%. The payback period associated with the use of good agricultural practices in the mango value chain, the use of irrigation using solar power pump in the potato value chain, the use of locally produced potatoes tuber and the use of rice intensification was 3, 5, 6 and 1 year(s) respectively. Payback period refers to the time needed to repay the initial investment. A longer payback act as a barrier for adoption and scaling up of innovations.

The risk associated with the adoption of four innovations were modelled using the Monte Carlo simulation (at n=10,000 simulations). The result showing the probability of making unprofitable returns after investing in the use of the four innovations is summarized in column 6 in Table 4. The result shows that the risk associated with implementing the use of good agricultural practices in the mango value chain, the use of irrigation using solar power pump in the potato value chain, the use of locally produced potatoes tuber and the use of rice intensification, given the characteristics of the cumulative density function of expressing the probability of the NPV of being less than or equal to the costs (i.e. implementation, maintenance and operation costs) of adopting the innovation is 1%, 3%, 20%, and 10% respectively (Table 4). The results show that the use of good agricultural practices in the mango value chain and the use of irrigation using solar power pump in the potato value chain are both profitable, have a relatively short payback, and both of these innovations have a negligible probability of losing invested capital (Table 4). The use of locally produced potatoes tuber and the use of rice intensification are also profitable, have high IRR but they have a longer payback period and carries a moderate amount (ranging between of 10 and 20%) of risks. In the latter two innovations, the moderate risk could be attributed to the large operation costs (Table 4), however, all these innovations constitute a promising basket of innovations that should be promoted for upscaling in Mali.

Table 3. Summary Information on Installation cost for business as usual (BAU) and the innovations (good agricultural practices, irrigation using solar pump, use of locally produced tubers and the use of system intensification) in mango, potato and rice value chain

VALUE CHAIN	INNOVATION	INSTALLATION COSTS (US $ /HA)			MAINTENANCE COSTS (US$/HA)			OPERATION COST (US$/HA)		
		BAU	IMPROVED SEED VARIETY	*% CHANGE IN COST*	BAU	IMPROVED SEED VARIETY	*% CHANGE IN COST*	BAU	IMPROVED SEED VARIETY	*% CHANGE IN COST*
MANGO	**The use of good agricultural practices**	704	2,961	*+321*	6,615	9,432	*+37*	0	0	*N/a*
POTATO	**The use of irrigation using solar pump**	10,226	22,781	*+123*	134,415	138,150	*+3*	9,600	9,600	*0*
	The use of locally produced tubers	4,667	16,003	*+243*	38,186	50,094	*+31*	2,830	5,180	*+83*
RICE	**The use of system of rice intensification**	2,908	3,452	*+19*	14,148	15,357	*+9*	4,220	6,940	*+64*

Figure 10. Yield for Business as usual versus the adoption of the innovations (good agricultural practices, irrigation using solar pump, use of locally produced tubers and the use of system intensification) in mango, potato and rice value chains respectively in Mali

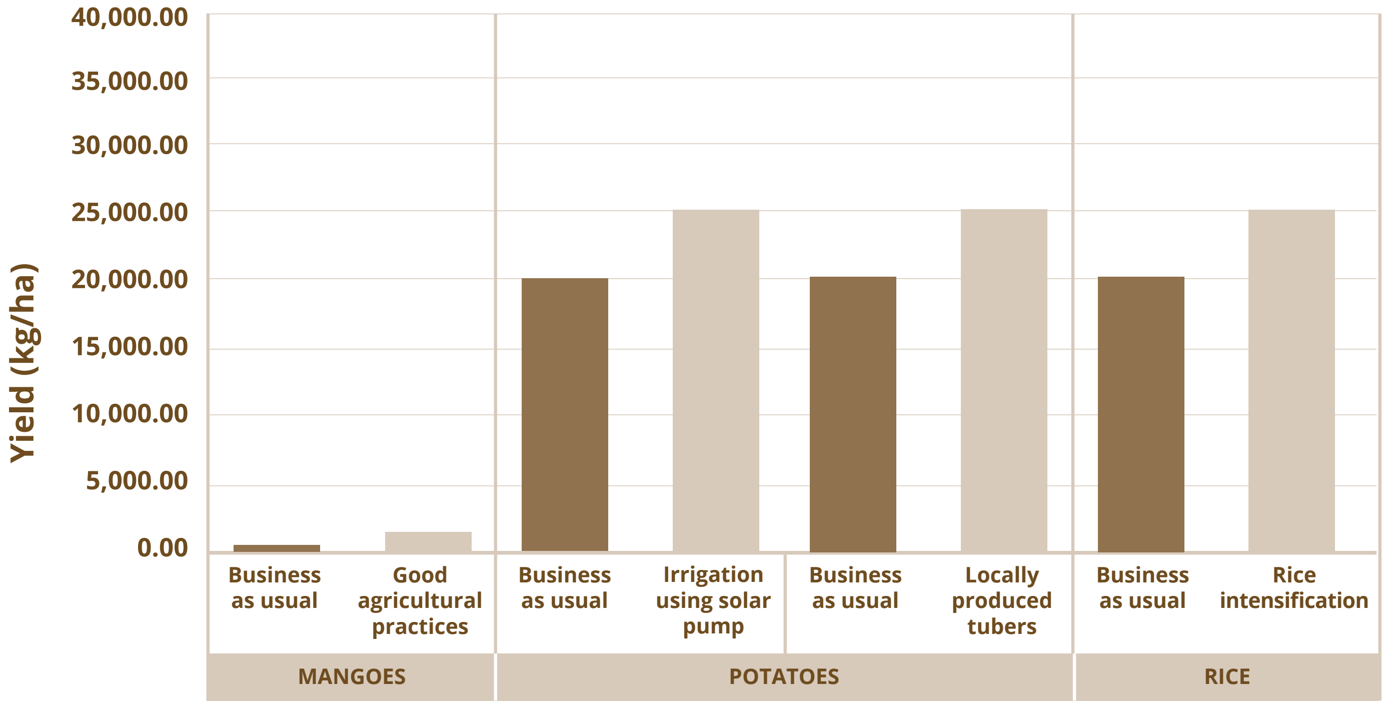


Table 4. Summary information on profitability associated with the adoption of the innovations (good agricultural practices, irrigation using solar pump, use of locally produced tubers and the use of system intensification) in mango, potato and rice value chains

VALUE CHAIN	INNOVATION	PROFITABILITY INDICATORS			
		NPV IN US$	IRR IN (%)	PAYBACK PERIOD (YEARS)	RISKINESS OF INVESTMENT
Mango	Good agricultural practices	15,599	84 (>r)	3	Farmers has a negligible (less than 1% probability) of losing the money
Potato	Use of locally produced tubers	28,449	62 (>r)	5	The likelihood of losing money invested is less than 3%
Potato	Irrigation with Solar pumps	23,581	38 (>r)	6	This practice has about 20% probability that the farmers will lose
Rice	System of rice intensification	10,665	244 (>r)	1	Farmers has a (10% probability) of losing the money

NB: >r implies that the practice is privately profitable

CBA is important for evaluating innovations, especially when investment decision needs to be made. Despite the strength and limitation (i.e., potential inaccuracies when identifying and quantifying costs and benefits for a given innovation) associated with CBA methodology, CBA is very critical for planning purposes, targeting future investment and also for identifying potential barriers for scaling up of innovations. The use of good agricultural practices in the mango value chain, the use of irrigation using solar power pump in the potato value chain, the use of locally produced potatoes tuber and the use of rice intensification are all ‘no-regret options’, implying that they will yield economic benefits now and in the future and are, therefore, important for strengthening future household resilience. All the studied innovations are profitable, have a high IRR, relatively short payback period, and carries a relatively lower amount of risks, especially the use of good agricultural practices in the mango value chain and the use of irrigation using solar power pump in the potato value chain. Despite the 10% and 20% level of risks associated with the use of locally produced potatoes tuber and the use of rice intensification respectively, they are still profitable and have a high IRR. These could explain why the use of good agricultural practices in the mango value chain, the use of irrigation using solar power pump in the potato value chain, the use of locally produced potatoes tuber and the use of rice intensification emerged as a strong choice for stakeholders during the prioritization process in Mali. When implementation, maintenance and operation costs are considered, all these innovations requires considerable capital meaning that if this innovation is promoted (since they are profitable and therefore makes an economic sense to be promoted) for scaling up, sufficient financial support needs to be provided to ensure that they yield a desirable outcome for a majority of smallholder farmers in Mali.

7. SYNTHESIS AND RECOMMENDATIONS

There are many potential adaptation strategies and options presented in this profile through discussion with different stakeholders. They offer options to reduce the impact of risks and build capacities of agricultural systems as well as individual farmers. To develop climate-smart practices for the rice, mango, and potato value chains, more information about climate risks and vulnerabilities is required to identify specific needs and priorities to determine appropriate options in the selected regions. For instance, sensitivity to the perceptions of farmers will allow for better understanding of climate realities at farm level, which is essential for climate adaptation planning, policy formulation, and project implementation. Additionally, linking climate data to farmers' perceptions or local knowledge will increase adoption of identified strategies.

Cited as major constraints across all prioritised value chains, lack of skills and knowledge by both farmers and extension service providers impedes broad agriculture development. Therefore, constant training and retraining of farmers is requisite to enable them remain current in agriculture knowledge and skills. Farmers should collaborate with extension service providers in designing, testing, and implementing new technologies.

Going forward, a variety of opportunities for collaboration, funding, and synergies exist for these practices (Table 5). Policy frameworks broadly relevant to climate-adaptive programming include Mali's Nationally Determined Contributions, the National Program for Adaptation Actions (NAPA), the National Climate Change Policy (PNCC), the National Climate Change Strategy (SNCC), the National Climate Action Plan (PANC), and Agricultural Orientation Law (LOA). Several organizations are well positioned to offer general support across all potential activities, including:

- Mali's National Climate Change Committee (CNCC)
- Mali's Environment and Sustainable Development Agency (AEDD)
- The Ministries of Agriculture, Environment and Sanitation, Livestock and Fisheries, Planning and Spatial Planning, and Energy and Water
- The National Directorate for Meteorology (DNM)
- German Agency for International Cooperation (GIZ)
- The United States Agency for International Development (USAID)
- The Netherlands Development Organization
- The Food and Agriculture Organization of the United Nations
- Institute of Rural Economy (IER) and IPR-IFRA of Katibougou

Table 5. Practice-group specific potential strategies and considerations for advancing CSA at scale

PRACTICE GROUP	PARTNERSHIPS	BARRIERS	EXISTING AND POTENTIAL FUNDING	SYNERGIES
Climate services	• Malian National Directorate for Meteorology (DNM)	**Farm level barriers:**** • Confidence in weather forecasts **Institutional barriers:** • Low access to information and extension services	• Public and private interests with good blended finance potential	• Supports efficiency and planning in input provision, production, postharvest transport and processing, and marketing
Conservation agriculture	• Competitiveness and Agricultural Diversification Program (PCDA)	**Farm level barriers:** • Considerable capital required **Institutional barriers:**** • Weak land tenure security • Inconsistent extension services • Poor financial service availability • Limited land tenure	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Improved soil fertility improves harvest yields, water retention, and climate resiliency. This in turn supports improved water management and robust, stable markets
Disease & Integrated Pest Management		**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:**** • Inconsistent extension services • Poor financial service availability	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports both productivity and environmental/ land restoration goals
Improved rice management	• Office du Niger • Ségou Rice Office (ORS) • Office Riz Mopti (ORM) • The société coopérative artisanale des forgerons de l'office du Niger (SOCAFON)	**Farm level barriers:** • Considerable capital required, creating some financial risk versus business-as-usual **Institutional barriers:**** • Weak land tenure security • Inconsistent extension services • Poor financial service availability • Poor insurance availability	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Optimized harvesting enables improved processing and storage

PRACTICE GROUP	PARTNERSHIPS	BARRIERS	EXISTING AND POTENTIAL FUNDING	SYNERGIES
Fertilizer management		**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:**** • Weak land tenure security • Inconsistent extension services • Poor financial service availability	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports climate resiliency and yields, maximizes cost efficiency of fertilizer inputs, and minimizes environmental impacts • Supports robust markets
Improved processing	• The société coopérative artisanale des forgerons de l'office du Niger (SOCAFON)	**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:** • Lack of training • Varietal impurity, which complicates rice processing • Suboptimal access to rice processing infrastructure	• High potential for private sector investing	• Best processing practices reduce losses in storage and in transport to market, thus stabilizing supplies
Harvesting technique		**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:**** • Inconsistent extension services • Poor financial service availability	• Primarily publicly funded through extension support, with possible private extension support options	• Optimized harvesting enables improved processing and storage
Land restoration		**Institutional barriers:**** • Cross-institutional coordination • Enforcement of regulation • Balancing livelihood priorities with environmental priorities	• Blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Enables robust environmental services to support climate resilient agriculture • Improved fertility supports productivity, and environmental services decrease livestock feed, fertilizer, and energy purchase requirements

PRACTICE GROUP	PARTNERSHIPS	BARRIERS	EXISTING AND POTENTIAL FUNDING	SYNERGIES
Manure management		**Farm level barriers:** • Labor-intensive, particularly in extensive systems **Institutional barriers:**** • Poor energy access creates competing needs for organic residues	• Blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports both productivity and environmental/ land restoration goals
Organic inputs	• CikelaJigi, Mali Yiriden and La Sikassoise	**Farm level barriers:** • Capital constraints • Knowledge gaps **Institutional barriers:** • Inadequate access to inputs • Low access to finance	• Blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports niche markets, including international markets, attracts finance, and supports conservation agriculture and land restoration
Production best practices	• Mango Interprofession (IFM)	**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:**** • Inconsistent extension services • Weak land tenure • Low energy access • Labor shortages • Weak finance services	• Blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports climate-resiliency and yields, thus improving market stability
Protected cultivation	• Mango Interprofession (IFM)	**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:**** • Inconsistent extension services • Weak land tenure • Low energy access • Labor shortages • Weak finance services	• High potential for private sector investing	• Supports robust yields, climate resiliency, and consistent harvests, thus stabilizing markets

PRACTICE GROUP	PARTNERSHIPS	BARRIERS	EXISTING AND POTENTIAL FUNDING	SYNERGIES
Risk insurance		**Farm level barriers:** • – **Institutional barriers:**[**] • Lack of service providers • Lack of infrastructure for efficient monitoring and reliable payouts	• Public and private interests with good blended finance potential	• De-risks changes toward unknown new production practices and continued production in the face of climate change
Storage and post-harvest	• Mango Interprofession (IFM) • Agro-processors like Comafruit and Mouna-Utrafle, middlemen, exporters, aggregators, and collectors	**Farm level barriers:**[**] • Capital constraints • Knowledge gaps **Institutional barriers:** • Suboptimal infrastructure, including inadequate access to good roads, cold storage, warehouses, and other conservation technologies	• High potential for private sector investing	• Reduces losses, thus increasing profits and supporting markets stability, particularly inter-seasonally
Tree management	• Mango Interprofession (IFM) • Mango collectors and exporters	**Farm level barriers:** • Financial constraints **Institutional barriers:** • Expensive initial production costs and investments required • High poverty rates • Low access to credit	• Blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Improved soil fertility improves harvest yields, water retention, and climate resiliency, this in turn supports improved water management and robust, stable markets
Variety improvement	• Direction Nationale de l'Agriculture (DNA) quality seed provision • Mango Interprofession (IFM) • Rice cooperatives, rice seed associations, and private rice seed suppliers • CikelaJigi, Mali Yiriden and La Sikassoise input suppliers	**Farm level barriers:** • Financial constraints • Considerable capital required • Some financial risk involved in adopting improved potato varieties **Institutional barriers:** • Inadequate access to inputs • Low access to finance • Domination of expensive, imported potato seeds from Europe • Need for increased training and more human resources to multiply potato seeds	• International research funding offers robust support • Diversification toward local and culturally important crops needed	• Climate-resilient varieties help stabilize harvest quantities, thus supporting stable markets
Water management	• Ministry of Energy and Water • Support Program for the Local Irrigation Sub-Sector (PASSIP) • Mango Interprofession (IFM)	**Farm level barriers:** • Financial constraints **Institutional barriers:** • Lack of access to training and technology • Reliance on labor-intensive potato irrigation practices, e.g. with gourds • Considerable capital required	• Public and private interests with good blended finance potential	• Effective water management reduces erosion and flooding to support productivity and land restoration efforts
Marketing	• Mango Interprofession (IFM) • Mango exporters like the Association Malienne des Exportateurs de Fruits et Légumes, the Association Professionnelle des Exportateurs de Fruits et Légumes • Mango packaging service providers, transporters, wholesalers, and retailers	**Farm level barriers:**[**] • Poor transportation networks to access markets • Dearth of pre-harvest and/or long-term contracts **Institutional barriers:** • Suboptimal rice processing, leading to breakage and lower rice prices • Underdeveloped rice marketing infrastructure • Lack of quality control for mangoes, which limits export	• High potential for private sector investing	• Reliable storage and processing systems support market stability and consumer confidence
Finance	• The Agricultural Development Policy (PDA) 2011-2020 and the National Agricultural Investment Program (PNISA) • Integrated Initiatives for Mali's Economic Growth (IICM) project funded by the United States Agency for International Development (USAID)	**Farm level barriers:** • - **Institutional barriers:** • High-risk nature of rice production, reducing access to finance • Price volatility of rice, reducing access to finance • Poor access to credit • Poor availability of farmer-targeted financial services, including loan, credit, savings, and warehouse receipts.[**]	• Blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Enable on-farm investments in soil fertility, optimized management techniques, and climate resiliency

** based on literature

Further, several barriers challenge the general implementation of climate-aware programming in Mali. The fragmented nature of the rice business leads to isolated, disharmonized initiatives that are contradictory and challenging to smallholder farmers. Gender norms, traditions, and land rights make it difficult for women to be equal partners in agriculture. The impoverished population is vulnerable to market volatility and consequent fluctuations in the prices of food and other agricultural inputs and outputs. Infrastructural constraints continue to hinder export growth, especially in light of Mali being a landlocked country, and the time required to clear land borders creates bottlenecks that delay shipments.

To boost smallholder farmers' incomes, there is a pressing need to improve market structures and access by linking farmers to ready markets. They should be encouraged to participate in training or sensitization fora that increase their products market competitiveness. Additionally, augmenting their access to financial services including lending, saving, and insurance is a value chain intervention that cushions against climate risks. Climate information services like early warning systems and participatory scenario planning empower farmers to understand risks and find suitable solutions.

Multi-stakeholder networks are a crucial modality to scale up climate adaptation strategies that might engage Mali's many implementing organizations, including the government, NGOs, the private sector, and civil societies. These networks will enable achievement of sustainable impact at scale by opening up new opportunities for collaboration; improving the coordination of activities; linking action across multiple scales from global to national to local; and facilitating knowledge-sharing and quick learning.

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