SCALING UP SMALL-SCALE IRRIGATION TECHNOLOGIES FOR IMPROVING FOOD SECURITY IN SUB-SAHARAN AFRICA

FINAL REPORT

Funding Agency

The OPEC Fund for International Development (OFID)

OPEC FUND
for International Development

Project Coordinator

International Center for Biosaline Agriculture (ICBA)

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This study has been possible with the generous financial support of the OPEC Fund for International Development (OFID) within the ICBA-led project on "Scaling up small-scale irrigation technologies for improving food security in sub-Saharan Africa (SSA). This report is based on a comprehensive four-year project implemented in four SSA countries: Burkina Faso, Mali, Niger, and Senegal. This project was executed with the collaboration of the national partners in each country. This report presents the current situation of the land and water productivity in the target countries. It discusses the potential role of small-scale irrigation technologies in improving agricultural productivity to improve food security and the livelihoods of the smallholder farming communities. The technical, institutional, and policy constraints and limitations in the wide-scale adoption of small-scale irrigation technologies and potential interventions are also discussed.

This project was led by the International Center for Biosaline Agriculture (ICBA), Dubai, and implemented in collaboration with the Ministries of Agriculture of four target countries. The project team is thankful to Dr. Tarifa A. Alzaabi, Acting Director-General, ICBA, for her overall leadership and Ms. Seta Tutundjian, Director Programs, ICBA, for her guidance during the project execution. The project team is also thankful to the Heads of partner organizations in Burkina Faso, Mali, Niger, and Senegal for extending technical and logistical support to complete this project successfully. The hardwork and dedication of the research and field staff in all partner countries are highly appreciated.

Acronyms

BCR	=	Benefit-Cost Ratio
CAADP	=	Comprehensive African Agricultural Development Program
DIPAC	=	Development of Private Irrigation and Related Activities
FAO	=	Food and Agricultural Organization of the United Nations
FFDs	=	Farmer Field Days
FFSs	=	Farmer Field Schools
GDP	=	Gross Domestic Product
ICBA	=	International Center for Biosaline Agriculture
IER	=	Institut d'Economie Rurale
INERA	=	Institut de l'Environnement et de Recherches Agricoles
IFPRI	=	International Food Policy Research Institute
INRAN	=	Institut National de la Recherche Agronomique du Niger
IPM	=	Integrated Pest Management
IPTRID	=	Intern'l Program for Technology and Research in Irrigation and Drainage
IWMI	=	International Water Management Institute
IsDB	=	Islamic Development Bank
ISRA	=	Institut Senegalais de Recherches Agricoles
NEPAD	=	New Program for Agricultural Development (
NGOs	=	Non-Governmental Organizations
OFID	=	The OPEC Fund for International Deelopment
RDS	=	Rural Development Services
SSA	=	sub-Saharan Africa
SSI	=	Small Scale Irrigation

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Forward

For millions of poor farm families in Sub-Saharan Africa (SSA), access to irrigation water is a dividing line between poverty and prosperity. Despite ample water resources, only 2% of the total renewable water resources are used for irrigation due to a lack of water infrastructure. Food production is entirely rain-fed, with irrigation playing a minor role. Only 4% of the region's total cultivated area is irrigated compared to 37% in Asia and 14% in Latin America. Thus, Africa is far from realizing its irrigation potential, estimated at 42.5 million ha. Helping farmers to access irrigation water by developing small-scale irrigation can enable them to boost agricultural production, achieve food security, and nutritional health.

It is now realized that small, motorized pumps could expand irrigation by 30 million ha in SSA (a four-fold increase over the current area) and improve food security for some 185 million people. Therefore, scaling up small-scale irrigation technologies (SSI) (with cheaper access to energy) should top SSA priorities. Over the last decade, ICBA has worked in SSA to identify the cost-effective small-scale irrigation technologies that are suitable for the local conditions and accepted by farmers. However, wide-scale adoption of these technologies by smallholder farmers remained a challenge due to high costs and lack of technical support. This project has explored the technical and policy options to support scaling-up these technologies to smallholder farmers in the target countries.

It gives me immense pleasure to present the achievements of the project "Scaling-up small-scale irrigation technologies to improve food security in sub-Saharan Africa". The project has been implemented from 2016-20 in four West African countries including Burkina Faso, Mali, Niger, and Senegal. The project has evaluated technical and economic performance of different SSI technologies and solar pumps against the existing irrigation practices. The crop water requirements and irrigation schedules for potential vegetables grown in different regions of the target countries have been estimated. Several farmer field days and capacity building activities were carried out to educate farmers and extension workers on different aspects of on-farm water management strategies. The project has reviewed the technical, institutional and policy constraints for the adoption of SSI technologies. The potential policy interventions to enable scaling-up of SSI technologies have also been suggested.

I would like to take this opportunity to express my sincere gratitude to the OPEC Fund for International Development (OFID) for their generous grant for this project. I hope that our genuine partnership with OFID will continue to realize our shared vision of ensuring food security and improved livelihood in SSA and other regions. The support, and collaborative efforts we received from our country partners in actualizing the project plans are highly commendable. I acclaim the commitment of ICBA's professional and support staff involved in this project. I believe that the findings of this project will be useful for the farmers, scientists, and policymakers in improving agricultural productivity and reducing poverty in SSA.

Dr. Tarifa A. Al-Zaabi
Acting Director General

Executive summary

This report presents the outcome of the OFID-funded project "*Scaling up small-scale irrigation technologies to improve food security in Sub-Saharan Africa.*" The project was implemented between 2016-20 in four West African countries (i.e., Burkina Faso, Niger, Mali, and Senegal). The activities carried out for this project mainly focused on:

- Collect data on available water resources, irrigation methods, irrigation potential, and potential cropping patterns
- Evaluate technical and economic efficiency of newly introduced small-scale irrigation technologies (SSI) and solar pumps to grow vegetables on farmer fields
- Estimate crop water requirements and irrigation schedules for different vegetables grown in these countries
- Organize training for farmers, irrigation technicians, and extension workers about irrigation systems and on-farm irrigation practices
- Establish Farmer Field Schools to disseminate information about SSI technologies and water and crop management practices to larger farming communities
- Review technical, institutional, and policy constraints to adopt SSI technologies in these countries and suggest possible interventions

During the project, SSI technologies (i.e., drip, sprinkler, and Californian systems) were introduced in three to four selected sites in each country. A solar pump was installed at one site in each country to extract water from river streams or groundwater. Vegetables were grown on all sites. The performance of these systems was compared with the traditional bucket, drip, sprinkler, and gravity irrigation methods.

The results revealed that the total water used for tomato crops under bucket and gravity irrigation systems was 50% and 8.5% higher than the Californian system, respectively. The tomato yield under the Californian systems was 18% higher than the gravity method. The water productivity of the bucket method was 54% higher than the gravity method, whereas it was 18% lower than the Californian system. The water productivity of drip, sprinkler, and Californian irrigation systems was almost double that of the bucket method. The highest water-saving and yield gains were obtained under drip irrigation. The drip system produced a 38% higher yield and used 20% less water than the bucket method. Similarly, the Californian system had a 28% higher yield and saved 34% water than the bucket method for the onion crop. In the case of sprinkler systems, water-saving was the highest (51%) compared to the bucket method; however, potato yield was comparable. The economic productivity was highest (3.87 $\$/m^3$) for tomatoes under the drip system. The economic productivity of the bucket method was less than half of the drip, sprinkler, and Californian irrigation systems.

In all countries, the Californian and drip irrigation systems performed significantly better in improving water use efficiency and crop yields than furrow and bucket methods. On average, Californian and drip systems' economic and water productivity was two to three times higher than the conventional irrigation systems. Farmers showed great interest in these systems and were ready to adopt them to increase their agricultural productivity and save water. However, the initial investment in drip systems (2000–4000 US$/ha) and operational and maintenance costs were a matter of grave concern for them. Farmers showed interest in the Californian System due to its low cost of installation (US$ 600-1000/ha), and cost-effective operation and maintenance, in addition to significant water saving. Therefore, farmers are looking for financial support to adopt the Californian system. Farmers were also keen to get improved vegetable seeds and market access to maximize their economic returns. This will enable them to extend these technologies to more areas using their financial resources.

The crop water requirements and irrigation schedules for the major vegetable crops grown in different regions of the target countries were calculated. Farmers and extension workers were trained to estimate the crop water requirements and to irrigate their lands according to crop water demand. This can save more than 15% water and energy, increase net profit, and enhance livelihood and food security. In each country, 30-50 farmers (primarily women) shared a solar-based Californian system. The women groups developed irrigation schedules to ensure equitable water distribution among water users. The women groups were also responsible for the maintenance of the irrigation system and solar pumps. The project team also helped women groups access local markets to get the actual value of their produce.

The economic analysis revealed that the benefit-cost ratio (BCR) of all irrigation systems (California, drip, and sprinkler) was more than one, implying that they lead to more benefits than costs. The BCR was highest in the drip system (2.579), followed by sprinkler (2.118) and the California system (2.086). The BCR analysis for cabbage shows that the total expenses for the bucket method (US$ 1170) were 21% higher than the Californian system (US$ 920). The net margin under the Californian system was about US$ 9,920 compared to US$ 2,725 for the bucket method. The net margin per kg was US$ 0.32 for the Californian system compared to US$ 0.21 for the bucket method. This indicates that farmers can earn up to three times more profit for vegetables grown with the Californian system. In addition, they are relieved of the hassle of operation and maintenance of diesel pumps.

The solar pump for water lifting can reduce production costs and improve food security and farmers' income. However, because of extreme poverty, these pumps are out of the reach of smallholder farmers. The average price of a motor pump is US$ 168 compared to US$ 2,837 for a 2.3 m^3/h solar pump. The solar pump remains a technology currently inaccessible to farmers. Therefore, government support would be needed to accelerate the adoption of solar pumps. The local production of solar pumps may help in reducing costs. For this purpose, the involvement of the private sector should be encouraged.

During the project's life, 920 extension workers and irrigation experts were trained in the target countries. For the training of farmers, 20 farmer field days (FFDs) were organized at regular intervals. Farmers of the neighboring villages attended these FFDs. to get first-hand information about these technologies. During the field demonstration, 11,475 farmers visited trial sites. The impact survey showed that the Californian system was adopted at more than 50,000 ha in all four countries. This coverage may be higher as we surveyed only the limited area in each country. In addition, eighteen brainstorming sessions were organized with the relevant stakeholders and policymakers to discuss potential policy interventions for scaling up SSI technologies. Two MSc students were supported through this project. Seven training and extension materials were developed in local languages for the benefit of farmers.

The main constraints related to the development of small-scale irrigation and agricultural water management in the target countries were found to be:

- High cost and accessibility of equipment in local markets
- Limited availability of surface water and groundwater
- Existing land-tenure laws discourage smallholder farmers from investing in irrigation technologies. Land-tenure problems are different in different countries
- Limited access to rural markets, credit, and maintenance services.
- Inadequate planning and monitoring capabilities of the responsible organizations due to understaffing and low levels of training, logistical problems, and low salaries.
- High transaction costs, fewer market opportunities, and inadequate consultation between public and private actors
- Lack of coordination at the national and regional levels to solve the problems of jurisdictional conflict and the lack of integration of support into land development.
- Lack of knowledge of farmers on irrigation technologies and farming techniques

The discussions during the brainstorming sessions revealed that the strategic approach for developing smallholder irrigation could be strengthened by:

- the inclusion and accountability of all public and private actors involved in the development of irrigated agriculture. These include producers, suppliers, processors, transporters, distributors, research, extension institutions, and funding institutions.
- valuing the comparative advantages of regions where smallholder irrigation has a high potential through the implementation of agricultural investment plans.
- promoting processing and marketing sectors and attracting private investments and creating cross-sectoral interactions with NGOs and government financial institutes.
- systematic consideration of gender and good governance in all interventions.

The small-scale irrigation technologies are irreplaceable for developing high-value crops. As such, it deserves to be supported by development projects. Even if it is poorly organized, the management of a private irrigation support project by a private association is no worse than management by a service State. On the contrary, state control can be exercised without influencing the direction of the day-to-day project. It is easy to promote simple technologies (manual drilling, treadle pumps, solar pumps) without credit if the methodology of NGOs used to launch the spread of treadle pumps in Africa is followed.

In addition, only technically proven products should be sold in the market. The cost of the equipment should be affordable and should not be directly subsidized to ensure that the sale continues after the project. The equipment must be sold primarily to individual farmers or small groups. We need to use local builders and work with the private sector responsible for providing maintenance and after-sales service. There is a need to introduce a well-defined monitoring and mitigation system to address environmental impacts of irrigation on depletion of water tables and pollution of minor aquifers. The development of smallholder irrigation must include a social dimension by providing the needs of the poor and women. Support for women could be done by promoting the post-harvest activities they most often do.

1. Background

The agricultural sector contributes, on average, 30% of GDP and 67% of employment in Sub-Saharan Africa (SSA) countries and accelerating its growth has been a high priority in the region (FARA, 2003). Some 80% of people in this region live in rural areas and 70% depend on agriculture for their livelihoods (Murrey and Sally, 2008). More than 200 million people are malnourished, one-third of whom were children (Murrey and Sally, 2008; World Bank, 2015). In SSA, yields are on average a quarter of those in other parts of the world, soil fertility has declined and agricultural productivity per capita has steadily fallen since 1961 while it has risen everywhere else (Bunting, 2008). Therefore, the development of the agricultural sector is central to combating hunger, reducing poverty, and achieving economic growth. However, this cannot be achieved without ensuring substantial land and water development (FAO, 2011). Most irrigated areas depend on groundwater or run-off-river pumping systems. Therefore, transportation of water from the source to farmer fields is the major bottleneck in improving agricultural productivity.

In Sub-Saharan African countries, lack of access to irrigation water is considered as the primary reason for agricultural development. For many, the long dry season is a trying time of one meal a day. One key strategy that could contribute to poverty alleviation and improvement in food insecurity is assisting the poor farmers in accessing irrigation water. This project aims to scale up tested and socially accepted low-cost small-scale irrigation technologies in SSA to boost agricultural production and achieve food security. Adoption of these irrigation technologies will enable farmers to irrigate their small plots to boost crop harvests, family incomes, and nutritional health in the deepest pockets of hunger in SSA.

In Sub-Saharan Africa, only 3% of its total water resources are used for irrigation compared to 33% for South and Southeast Asia (You et al., 2011). Food production in the region is entirely rain-fed, with irrigation playing a minor role. Only 4% (6 million ha) of the region’s total cultivated area is irrigated compared to 37% in Asia and 14% in Latin America. Thus, Africa is far from achieving its irrigation potential, estimated at 42.5 million ha (FAO, 2015).

The available groundwater resources in SSA are 100 times those of renewable surface water. But farmers often hold back from investing in groundwater irrigation because of the high drilling costs and lack of information about groundwater availability (Kadigi et al., 2012). Furthermore, the hydrology and aquifer characteristics of the area allow only low-yielding boreholes mainly operated by hand pumps. Therefore, extracted groundwater quantities are too low to support surface irrigation practices. Thus, irrigation techniques such as drip and sprinkle can help increase the productivity of smallholder farmers in SSA (Svendsen, 2009).

The impact of climate change on crop yields and the social and economic repercussions is another significant concern especially considering the region’s high dependence on rainfed agriculture. As a result, several development initiatives in SSA have focused on introducing irrigation systems in local farming systems to develop the resilience of the agricultural sector towards the escalating climate change.

1.1 Why to focus on small-scale irrigation in SSA?

Except in North Africa, Madagascar, and South Africa, irrigation development potential has not been effectively tapped in Africa. Though SSA has a rich water endowment, only 4% of its cropland is irrigated. Some 43 million hectares (Mha) of land are suitable for irrigation, but only 7.3 million ha are irrigated. Studies have shown that small, motorized pumps could expand irrigation by 30 Mha in SSA (a four-fold increase over the current area), generate annual net revenues of $22 billion, and improve food security and incomes for some 185 million people (IWMI, 2005; IFPRI, 2012). Therefore, scaling up small-scale irrigation (SSI) systems (with cheaper and sustainable access to energy) should top SSA priorities. With targeted investments and policies to expand SSI, the problems of hunger, poverty and malnutrition can be addressed (Burney and Naylor, 2012).

Until recently, irrigated agriculture was mainly state-sponsored. The performance of state-managed irrigation schemes has been far below expectations, and many of them have become non-functional due to poor operation and maintenance. Over 30% of the state-managed irrigation schemes in SSA have completed 20 years of life, and their rehabilitation is becoming increasingly a pressing issue for national governments (World Bank, 2008; Venot et al., 2013). The performance of most of the irrigation schemes in South Africa has been rated as poor with little sustainability. In Mozambique, smallholder irrigation schemes are found in every district but are either abandoned or partly utilized (FAO, 2015). In Zambia, Niger, Tanzania, Mali, and Somalia, most irrigation schemes operate below economic potential despite water management policies as they lack institutional mechanisms to manage water and irrigation infrastructure (Bangwe and van Koppen, 2012). By contrast, decentralized small irrigation systems designed to serve a single or community farm – are better compatible with local conditions. The small-scale irrigation schemes are preferred due to the following benefits:

- Lower initial investment, operational, and maintenance costs
- Easy accessibility to remote farms and better control on water
- Less negative environmental impacts
- Increased resilience for droughts and seasonal water shortages

Despite these advantages, farmers' adoption of small-scale irrigation systems remains a challenge due to high initial investments (pumps and motors) and operational costs. The availability of electricity and fuel in villages is another problem. For many smallholders, the price of diesel or electric pumps (40% of the total production cost) is not affordable (Qureshi and Shoaib, 2016). Therefore, the potential of solar pumps needs to be explored. Few NGOs have done useful work in northern Benin–a region with no electricity and groundwater too deep to access with manually operated treadle pumps – solar-powered pumps are used to manage drip irrigation systems. These projects have improved household food security. In addition to energizing irrigation pumps, solar systems can energize household lamps and fans, bringing a revolution in their lives as children will have better conditions for education. These developments could assist in poverty reduction (Hanjra et al., 2009). National governments, NGOs, and international donors should provide credit facilities in easy conditions for farmers to install small-scale irrigation systems (Amjath-Babu et al., 2016).

1.2 Lessons learned from previous ICBA managed project in SSA

In 2011, ICBA launched a project in SSA with the funding of the Islamic Development Bank (IsDB). Covering seven countries, namely Burkina Faso, Gambia, Mali, Mauritania, Niger, Nigeria, and Senegal, the main objective of this 4-year project was to identify the most cost-effective SSI technologies for smallholder farmers that are suitable for the local conditions and accepted by farmers. The tested technologies include drip and sprinkler system, Californian system, and gravity/pump system.

The project results indicate that these technologies perform better in terms of efficient water use and increased crop production. The water used by drip irrigation was one-third of the conventional gravity irrigation system used by most farmers in this region. On average, the Californian system uses 15-20% less water than flooding irrigation systems, producing about 10-15% more crop yields. Reduced water application to different crops directly increases farmers' incomes as it reduces the cost of irrigation (less fuel used). This clearly shows that these irrigation technologies are most suited for saving water and reducing irrigation costs.

Despite these advantages, the large-scale adoption of small-scale irrigation technologies by smallholder farmers remains a challenge. These challenges are related to low expertise, knowledge, and capacity to develop and manage irrigation systems. Initial investment costs for installing these technologies (pumps and motors) and the operational costs (fuel and O&M costs) are considered the major problems in adopting these innovative irrigation technologies by smallholder farmers. The cost of drip system is US$ 2000–4000 per ha and US$ 600-1000 per ha for the Californian system. These initial investments and operational and maintenance costs of these systems are a matter of concern for smallholder farmers.

1.3 Low water use efficiency in agriculture

Sub-Saharan African (SSA) countries are characterized by low yield levels and poor water use efficiencies. Water use efficiencies are only 22-25%, which is half of the world average of 45% (Kadigi, 2012). The increased water productivity can be achieved by introducing agronomic, engineering, and management technologies such as changing crop varieties, crop substitution, deficit, supplemental or precision irrigation ((Kijne et al., 2003). In most of the irrigated areas of SSA, the irrigation water application is irrelevant to the actual crop water requirement. Farmers are mainly unaware of the concepts of '*usual*' or '*optimum*' depth of irrigation application. Their perception about good irrigation is the depth of irrigation applied to the field regardless of soil moisture deficiency and the age and conditions of the crop. As a result, the applied irrigation amounts are higher than the actual crop water requirement (Qureshi and Shoaib, 2016). This suggests that farmers need to be educated regarding improved water management practices and water-saving strategies. The on-farm field losses can be reduced by adopting innovative irrigation technologies such as drip and sprinkler systems. Farmers also need to be educated on actual crop water requirements, suitable irrigation schedules, and the adoption of best cultural practices for principal crops grown in these areas. Despite the higher potential for drip irrigation, its adoption is low in SSA. With proper marketing and technical support, farmers' access to drip systems can be increased (Maisiri et al., 2005).

The water-use efficiency can be improved by adopting water-saving techniques (e.g., drip and sprinkler systems) and soil and crop management practices such as leaving crop residues on the soil surface and planting cover crops (Howell, 2001; Kijne et al., 2003). However, with the increasing water scarcity resulting from the growing population and shrinking water resources, increasing the productivity of the existing water resources deserves much attention as well. Increasing water productivity means producing the exact yield with fewer water resources or obtaining higher crop yields with the same water resources (Zwart and Bastiaanssen, 2004). In a broader sense, it reflects the objectives of producing more food, income, livelihood, and ecological benefits at less social and environmental cost per unit of water consumed.

1.4 Constraints and limitations for irrigation development in SSA

The main constraints related to agricultural water development and management are: (i) lack of a coherent and efficient mechanism for synergizing irrigated agricultural and water development between agriculture and other water sectors, (ii) planning developments according to administrative redistricting does not consider watershed boundaries. In addition, the low involvement of credit institutions in the financing, the high dependence on grants and other support from the State, the low participation of private developers in the financing of developments, and the weakness of the human and material resources of the decentralized services for the proper technical supervision of producers are considered major constraints for the development of SSI in sub-Saharan African countries.

The constraints in the development of irrigation in SSA can be categorized as follows:

Environmental factors

- Water shortage and poor water quality due to heavy sedimentation
- Land degradation (low soil fertility, soil salinity, lack of irrigation infrastructure, etc.).
- Poor on-farm irrigation practices resulting in water logging and soil salinization.

The capacity of the farmers

- Low level of expertise, knowledge, and capacity to develop irrigation systems.
- Lack of financial resources of most farmers and the relatively high investment costs involved in developing and maintaining irrigation schemes.
- Ineffective cultivation practices and unsuitable crop varieties (i.e., vegetables such potatoes, onions, peppers etc.) assuring high yields and market values

Government policy; institutional and legal support

- Higher-level neglect in development irrigation schemes for smallholder farmers.
- Poor institutional arrangements to support farmers in irrigation development
- A land tenure system does not encourage farmers to invest permanently in their plots and make improvements to obtain credits for further development.
- Farmer’s limited access to financial services – credit and insurance
- Farmer’s access to local and regional markets

2. The Project

One of the significant outcomes of the IsDB-funded project in SSA implemented by ICBA was that there is a need to scale up recommended SSI technologies to other parts and countries of the region. To reduce the operational costs, the introduction of solar pump irrigation systems was suggested. For large-scale adoption of these technologies, farmers suggested improving accessibility to equipment and materials, providing financial support from the government and/or NGOs, reducing the cost of equipment, access to credit from financial institutions, training, and organizing farmers, and supplying inputs at a subsidized price (Qureshi and Shoaib, 2016). ICBA took the lead in securing funding for the second phase of the project because of its understanding of local issues and strong association with the region's local NARS and farming communities.

In 2016, the OPEC Fund for International Development (OFID) provided a grant to ICBA to launch the second phase of this project with particular emphasis on expanding low cost and water-efficient irrigation technologies and addressing related constraints and limitations for large scale adoption by smallholder farmers in the four countries: Burkina Faso, Niger, Mali, and Senegal. These countries have the most considerable potential for small-scale irrigation (SSI) investments. This project aimed to scale up tested SSI technologies and introduce the best on-farm water and crop management practices to smallholder farmers to increase agricultural productivity and food security. The project also introduced solar systems as a sustainable source of energy to run irrigation pumps.

2.1 Objectives

The specific objectives of this project were:

- Review existing availability and use of SSI technologies by farmers in the target countries. This information is necessary to understand the dynamics of SSI before taking up scaling-up issues.
- Identify and map potential areas where the introduction of SSI technologies will be economically viable, technically suitable, and socially adaptable. Potential regions will be mapped using data on access to irrigation water, cropping patterns, and the economic conditions of the farmers in different regions of each target country.
- Demonstrate the use of solar systems for small-scale irrigation technologies for vegetable crops at selected farmer fields for exchanging experiences.
- Demonstrate suitable cultivation practices for vegetable crops, including optimum sowing date, plant density and improved varieties, fertilization, and pest control.
- Estimate crop water requirements and irrigation schedules for the vegetable grown in the target areas. This is linked to the water demand management strategy.
- Enhance the capacity of farmers to develop, maintain and operate SSI technologies using local knowledge and expertise to reduce costs and increase sustainability.
- Assess institutional, socio-economic, and financial constraints and develop mechanisms to overcome these issues to facilitate farmers for large-scale adoption.
- Develop policy guidelines to accelerate expansion of SSI in target countries.

2.2 The target groups

The project will directly target about 2,000 resource-poor smallholder farmers of Niger, Mali, Senegal, and Burkina Faso who has the potential of enhancing their agricultural productivity but are constrained by the access to irrigation water. The project outputs are expected to impact about 10,000 farmers indirectly. Despite having potential and capabilities, these farmers are not getting the needed knowledge about these irrigation technologies due to weak extension services and a lack of adequate knowledge about these technologies. Therefore, there is a need to enhance their capacity and skills to educate farmers in these technologies. *The project will train about 40 project staff and 60 extension workers in each target country to develop, operate, and maintain different SSI technologies.* The project will assist local farmers in the operation and maintenance of solar-based irrigation systems.

Farmers are reluctant to invest in SSI technologies because they are not getting reasonable prices for the produce. Group marketing is not practiced in most cases, and this situation favors merchants and traders who fix prices to their advantage. Crop diversification is also not practiced, which often results in low prices. Therefore, any improvement in small-scale irrigation should include applying irrigation technology, market analysis, extension, support systems, etc. The Project Team will work with local market players to develop effective linkages between farmers and buyers so that farmers can earn good profits, which will enable them to build and maintain these irrigation technologies.

Analysis of socio-economic data of the IDB-funded project reveals that the profitability of growing traditional vegetables using small-scale irrigation technologies in these countries is relatively low due to high production costs. On average, farmers earn US$ 1000-1500 per ha from the production of vegetables. Fertilizer and fuel costs are the leading production cost elements. Fuel and fertilizer make up 25% and 30% of the total costs, respectively. The primary threat to the enterprises' profitability was the fluctuation in farm gate crop prices. The introduction of solar pumps for SSI schemes could help in increasing the productivity of smallholder farmers. Adoption of these technologies will improve the production of high-quality crops. In addition, these technological interventions can positively affect livelihoods by alleviating food insecurity, generating income, and enhancing human health.

2.3 Implementation strategy, approach, and methodology

The project will adopt a participatory approach to work with smallholder farmers to adopt small-scale irrigation technologies in the target countries. The project team will jointly select and implement the best management practices and technologies for different agro-ecological zones in each country. Smallholder farmers (especially women and young farmers) will be involved to motivate farming communities. The main components of this strategy will be:

- ***Identification of key stakeholders* -** for the execution of the project. This will include farmers, extension workers and irrigation experts from the government institutes.
- ***Site selection -*** for the field demonstration of tested irrigation technologies in most vulnerable areas in Burkina Faso, Mali, Niger, and Senegal.

- ***Awareness campaign* –** to highlight benefits of the SSI technologies to farmers, extension workers, and irrigation technicians. The involvement of government officials and decision-makers in seminars and workshops will create awareness at the highest policy level about the new approaches to irrigation management.
- ***Technology transfer* -** introduce small-scale irrigation technologies, solar systems, and on-farm water management practices through farmer-to-farmer peer interaction, extension workers, and irrigation departments of target countries.
- ***Capacity building* –** to enhance skills of farmers and technical staff of extension departments on small-scale irrigation technologies and best soil and water management practices for improved efficiency, productivity, and sustainability.

This project strategy would first diagnose the issues related to SSI irrigation technologies in the target countries and then develop long-term strategies for introducing these technologies to smallholder farmers, considering all limitations and constraints.

This project will work to provide concrete answers to the following questions:

- How to increase farmers' knowledge and technical skills to access irrigation technology and operate and maintain them within their available resources?
- How to reduce production costs using small-scale irrigation technologies? The possibility of using solar pumps need also be evaluated.
- How to cultivate crops and choose the optimum date of sowing, density and suitable varieties, and appropriate fertilization and pest control practices?
- How to financially support poor farmers (loans, credits, etc.), and develop workable cost recovery schemes for smallholder farmers?
- How to improve the accessibility of producers to local and regional markets to ensure good returns and improve their incomes and livelihoods?
- What policies and government incentives are required to promote the adoption of these irrigation technologies among the smallholder farming communities?
- How to empower women to play a key role in decision-making in water management to ensure household food security?

2.4 Project activities

Output 1: Map areas most suited for the small-scale irrigation technologies

1.1 Collect baseline data on irrigation potential and irrigation methods used, current farming systems (crops, cropping pattern, crop yields, etc.) in target countries.
1.2 Analysis of data to develop GIS maps to identify potential irrigated areas for the introduction of small-scale irrigation technologies and to devise a long-term strategy for increasing land productivity after adopting irrigation technologies.
1.3 Identify suitable crops to be grown for the selected areas based on quantity and quality of available water, type, and fertility level of the land.
1.4 Analyze socio-economic, policy**,** and institutional constraints for scaling up small-scale irrigation technologies in the target areas. This will be done through formal and informal discussions with farmers, policy makers, NGOs, and relevant stakeholders.

Output 2: Appropriate irrigation technologies and practices are introduced

2.1 Select representative farms in different regions for establishing field trials of tested irrigation technologies and crops in collaboration with the national partners.
2.2 Introduce innovative irrigation technologies and solar pumps for different vegetable crops in the selected field trial areas of the target countries.
2.3 Develop technological packages to reach 10,000 farmers covering 25,000 ha through NARS, extension workers, and NGOs.
2.4 To scale-up promising irrigation technologies to 10,000 farmers by establishing linkages with extension workers and farming communities. During the process, a strategy addressing the long-term sustainability of these technologies will be developed.

Output 3: Selected irrigation technologies are adopted in 25,000 ha

3.1 Exchanging experiences and limitations associated with the working of irrigation technologies with different stakeholders of areas other than the project's target areas for possible scaling up. This will include discussions with local farmers, extension workers, and local manufacturers.
3.2 Estimate crop water requirements and irrigation schedules for potential crops grown in target areas as a part of water demand management strategy. The calculated water requirements for different crops will be disseminated to farmers using the national governments' extension network in each country. Farmers will also be educated on different water conservation strategies to improve water use efficiency.
3.3 Develop community and policy level guidelines for the scaling up and wide-scale adaptation of selected and tested irrigation technologies and schedules.
3.4 Prepare a position paper from a technical and policy perspective for large-scale adoption of irrigation technologies in all four target countries.

Output 4: Capacity and skills of farmers are enhanced to ensure sustainability

4.1 Management of data and knowledge generated under this project in different forms (archives, GIS, databank, etc.) for future use in development projects in these areas. This will be done by developing a comprehensive data management system.
4.2 Develop high-quality educational audios/videos in the local dialects for highlighting the benefits of tested irrigation technologies and water management practices for various crops. These videos will be made available in the public domain through the internet and accessible to all stakeholders.
4.3 Organize technical training for farmers, researchers, and extension workers regarding selected irrigation technologies and water management practices for different crops. This training will include irrigation-plant growth linkages, water requirements for crops, and strategies to increase water use efficiency for crop production.
4.4 Establish Farmer Field Schools (FFS) to educate farmers on new irrigation technologies and water and crop management practices. Special training will be organized for women because they are the significant contributors to small-scale irrigation in SSA. Based on the success and interest of the farming community, FFS will be transformed into Farmer Field Centers (FFCs), which can continue working after the conclusion of this project.

Output 5: Policies to adopt of SSI technologies are discussed with the policymakers

5.1 Develop learning tools and extension material for farmers and extension workers to disseminate project results and outcomes. We will develop project reports, technical reports, and training packages that can guide the establishment of new irrigation technologies under different soil, water, climate, and environmental conditions.
5.2 Organize multiple brainstorming sessions with different stakeholders and policymakers to prepare policy guidelines to facilitate the adoption of tested technologies and solicit their political and administrative support for scaling up project activities.
5.3 Organize at least one workshop in each country with leading academic professionals from universities to present the basics of sustainable agricultural production and develop a strategy for integrating these principles in the syllabus of farming schools.
5.4 Develop policy briefs at different stages of project implementation to keep various stakeholders aware of project progress and outcomes.

2.5 Outcomes and impacts

The project's primary outcome will be the introduction of promising irrigation technologies in the pilot sites. The long-term outcome will be new thinking and awareness of the gains possible from new irrigation technologies and on-farm water management approaches. This, will lead to the out-scaling of irrigation management strategies beyond the project area. The successful implementation of the above activities will increase agricultural lands' productivity, positively contributing to the country's economy and reducing rural poverty. The overall impact of the project will be a revitalized irrigated agriculture in four target countries. The move from output to outcomes and impact will be facilitated by the collaborative project design. This includes awareness creation of issues and prospects, the introduction of tested SSI technologies, and supporting extension services under changing conditions for scaling-up. Together this leads to a shared vision and action by those in the best position to act.

The project will directly engage 20,000 smallholder farmers who are constrained by access to irrigation water. The project will impact 50,000 farmers indirectly. Through farmer field schools, demonstration plots, access to extension material, awareness campaign, and informal meetings and training, these farmers will benefit.

2.6 Scaling up pathways

The critical element of this project is to "scale up' recommended SSI technologies to small-holder farmers. The farming communities will act as the champions of change and essential drivers of this process. During the demonstration stage of the project, opportunities and socio-economic constraints that may affect the scaling-up process will be critically evaluated, and a strategy will be developed to overcome these issues. Based on these discussions, the project team will develop a suitable outreach strategy for scaling up project intervention with key stakeholders. This strategy will include the development of partnerships and networks with the key players who can provide the required infrastructure, support, and leadership for going to scale from the beginning. These will include government agencies, extension services, NGOs, and top-level policy and decision-makers.

2.7 Socio-economic and environmental impacts

It is anticipated that the adoption of SSI technologies and alternate cropping patterns will help increase farm productivity, farmers' income and improve the livelihood of poor rural communities, especially women. Adopting these interventions will also be instrumental in reversing or reducing many social impacts of low productivity, low income, and poverty. Improvements in the productivity of irrigated crops will also contribute directly to poverty reduction by increasing the availability of fuel, wood, construction materials, wild foods, and medicinal plants. On the social side, improved crop yields and farm incomes will reduce migration to cities and help in stabilizing family structures.

2.8 Project partners

The project was implemented in collaboration with the national partners, which involves Ministries of Agriculture, Extension, Water Resources, Local NGOs, and companies dealing with the different irrigation technologies. In addition, local university students and professors were engaged in devising policy and capacity building of project staff, extension workers, and farmers. The following NARS were implementing partners in each country.

Country	Institutes
Burkina Faso	Institut de l'Environnement et de Recherches Agricoles (INERA)
Mali	Institut d'Economie Rurale (IER)
Niger	Institut National de la Recherche Agronomique du Niger (INRAN)
Senegal	Institut Senegalais de Recherches Agricoles (ISRA)

2.9 Project organization and management

ICBA was responsible for the overall management of the project. ICBA's Senior Scientist led the project. He monitored the project progress according to the agreed work plan. He will produce annual progress reports and coordinate meetings regularly with all the national partners in each country to discuss technical and management aspects of the project. Project Steering Committee (PSC), composed of all stakeholders, was established to provide overall guidance and support to the project. A Project Technical Committee (PTC) was constituted with representation from partners, donors, and ICBA scientists to discuss and review the project progress to ensure project achievements according to the work plan.

The project was integrated into ICBA's institute-wise project portfolio and was subject to the Quality Management System, which involves standardized documentation, reporting, monitoring, and evaluation of projects. The PL was responsible for monitoring the project funds and work plan and identifying any changes in the implementation plan if needed. ICBA's online accounting and time tracking system supported the project implementation. Quality control was further ensured through ICBA's internal set-up, with the Director of Programs, overall, in charge of the research program.

3. The Country Profiles

3.1 Burkina Faso

Burkina Faso is a Sahelian country with an area of 274,000 km². It has a population of 17.3 million with a growth rate of 3.1% per year. Agriculture occupies over 85% of the workforce and contributes nearly 33% of GDP and over 85% of export earnings (MAH, 2010). Despite more than 10% spending of the national budget every year on agriculture, income levels remain low. Agriculture is essentially subsistence farming dependent on rainfed crops and dominated by poorly equipped small farmers. About 88% of the cultivated area is dependent on the scanty nature of the rainfall and is therefore vulnerable to the vagaries of climate and cannot meet the food needs of the growing population (FAO, 2010). Rainfed cereals dominate agricultural production, and productivity is characterized by sizeable inter-annual rain fluctuations, resulting in persistent food insecurity and household poverty.

Since the 1960s, the dry season crops have been the primary asset for developing agricultural production in Burkina Faso. However, after the severe drought of 1970 in the CILSS countries, Burkina has made significant progress in the dry season crops. It first adopted fruit and vegetable crops and then integrated them with other food crops (cereals) to compensate for the chronic food deficits caused by climate hazards and other limiting factors. Since the adoption of the Strategic Framework for the Fight against Poverty in 2000, the dry season crops are deemed a strategic alternative to reduce food insecurity, increase household incomes, create jobs, and reduced poverty (CAPES, 2007).

Since the 1980s, irrigation has become a national priority in Burkina Faso. These attempts for efficient use in agriculture continued until 1990 when the country opted for the exclusive development of lowlands at the expense of large areas under irrigation. The emphasis on dry season crops reflects the adoption of a policy of sustainable development of irrigation as an operational program lighthouse Small Irrigation Project Villager (PPIV) pilot phase (2001-2004). Its objective is to increase cereals and legumes production during the dry season, using irrigation systems and low-cost and appropriate production technologies.

Burkina Faso has two main seasons: the dry season from October to March and the rainfall from May to September. The country has three main climatic zones (Figure 1).

- The Sudanian zone, with annual rainfall between 900 and 1100 mm.
- The Sahelian zone in the North, with annual rainfall below 600 mm.
- The Sudano- Sahelian zone, with rainfall between 600 and 900 mm.

High temperatures characterize the climate. The humidity increases southwards and ranges from a winter low of 12% to 45% to a rainy season-high of 68% to 96%. The harmattan, a dry east wind, brings with it spells of significant heat from March to May. The maximum temperature rises from 40°C to 48°C from May to October. The climate from November to March is dry, whereas temperatures in January range from 7°C to 13°C. The rainy season lasts for four months in the northeast to six months in the southwest (May – October).

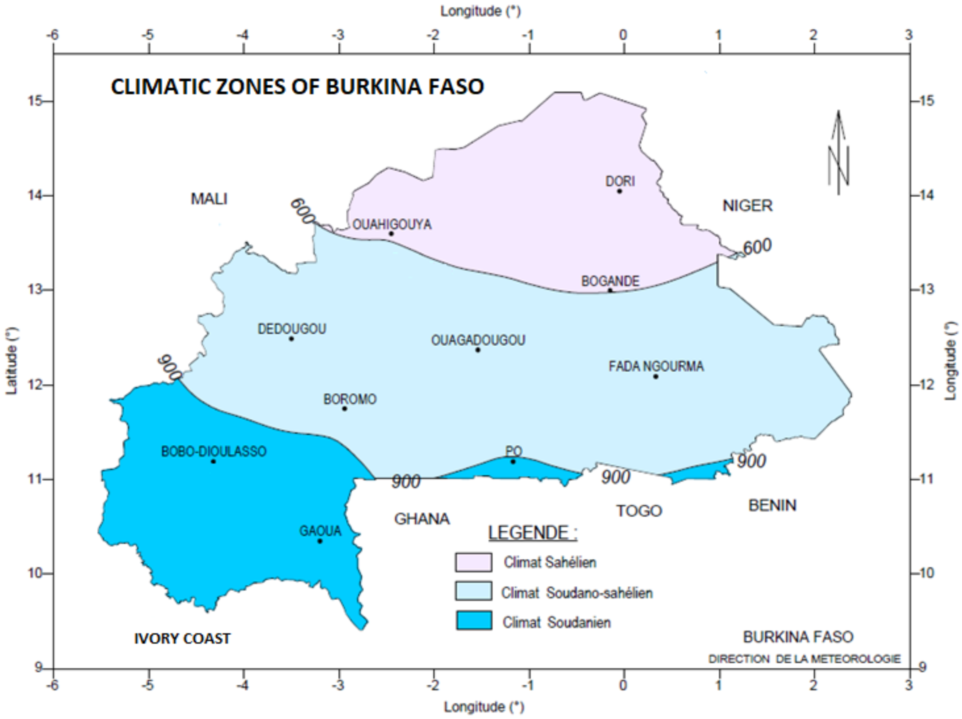


Figure 1. Agro-climatic zones of Burkina Faso

The annual evapotranspiration varies between 1854mm in the South to 2225mm in the North (MEE, 2001). From June to August, precipitation exceeds evapotranspiration causing wet and humid conditions. The highest rainfall months are July and August, followed by June and September. October to April is the most critical period as rainfall is almost negligible, and crop production is dependent on irrigation (Table 1).

Table 1. Average monthly climatic data for Burkina Faso

Months	Temperature (ºC)		Average Temp (°C)	Average Rainfall (mm)	Wet Days (>0.1mm)	Average Sunlight hr/ day	Relative Humidity (%)	Wind Speed (Beaufort)
	Min	Max						
January	16	35	24.5	0	0	8.3	19	2
February	20	32	28.5	2	1	8.9	19	2
March	23	40	32	13	2	9.1	20	2
April	26	39	33	16	3	8.3	28	2
May	26	38	32	83	6	8.5	40	2
June	24	36	30	122	9	8	49	2
July	23	33	28	203	11	7.3	62	2
August	22	31	26.5	280	14	5.7	67	2
September	23	32	28	144	10	7.1	60	1
October	23	35	29	33	4	9.3	44	2
November	22	36	29	1	1	9.4	30	1
December	17	35	26	0	1	9	23	1

Surface water resources

Burkina Faso is divided into 13 regions which are pathways of 3 international river basins i.e., Volta, Niger, and Comoé. These three basins are feeding four national basins i.e., the Nakanbé, the Volta, the Niger, and the Comoé (Figure 2). These four basins are further divided into 17 national sub-basins.

- Comoé: This basin is essential for agricultural activities. The land surface of the basin is 4980 ha irrigated, and 1880 ha managed shallows.
- Mouhoun: This basin covers 5360 ha 3315 ha of various shallows managed to Sourou, Kou Valley, and Banzon. The managed Shallows are about 2090 ha.
- Nakambé: This basin covers 2620 ha, 1000 ha for Bagré (hydroelectric and hydro agricultural barrage). Shallows managed to cover almost 2175 ha.
- Niger: The Niger is the smallest of all basins. The managed irrigation area under this basin is low. The most critical irrigated areas are Dakiri (120 ha) and Liligouri (60 ha). Shallows managed areas are approximately 660 ha.

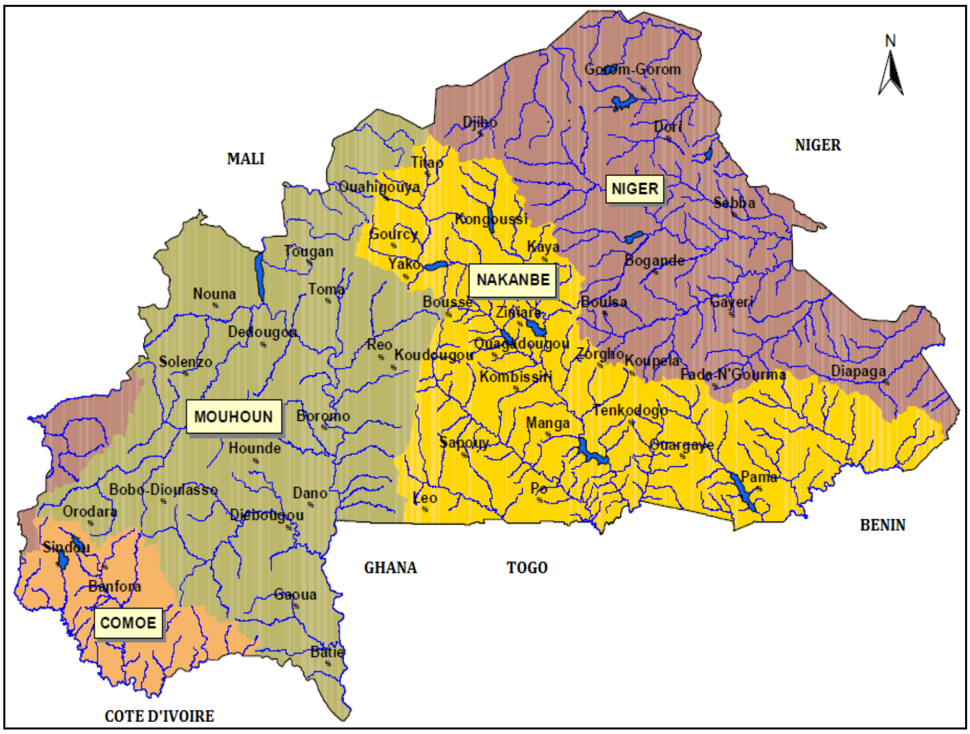


Figure 2. National Basins of Burkina Faso

Despite their substantial interannual variability, the four national basins are the country's primary source of surface water. The annual surface water availability is 8 billion m^3 (Bm^3) (FAO, 2010). It currently has more than 1200 water storage (dams, lakes, ponds, sills, and Boulis/artificial lakes,) for multiple uses such as irrigation, livestock, domestic, fishing, etc. The total water storage capacity is 5 Bm^3billion m^3. The distribution of basins in Burkina Faso is given in Table 2. The quantity of water leaving Burkina is estimated as 7.5 Bm^3. The annual total volume stored is 2.66 Bm^3. Based on the past 30 years (1970-1999) data, Burkina Faso has an annual potential of 8.6 Bm^3 surface water (Table 2).

Table 2. Distribution of basins in Burkina Faso (*Source: MEE, 2001*)

International basin	National basin	National Sub-basin	Surface area (km²)	Percentage
COMOE	*COMOE*	Comoé - Léraba	17 590	6
NIGER	*NIGER*	-	83 442	30
		Beli	15 382	
		Gorouol	7 748	
		Dargol	1 709	
		Faga	24 519	
		Sirba - Gouroubi	11 946	
		Bonsoaga	7 231	
		Dyamangou	3 759	
		Tapoa - Mekrou	5 707	
		Banifing	5 441	
VOLTA			172 968	30
	NAKANBE	-	*81 932*	
		Pendjari - Kompienga	21 595	
		Nakanbé	41 407	
		Nazinon	11 370	
		Sissili	7 559	
	MOUHOUN	-	***91 036***	33
		Mouhoun supérieur	20 978	
		Mouhoun inférieur	54 802	
		Sourou	15 256	
BURKINA FASO			274,000	100

Table 3. Water storages in Burkina Faso

Region	Dams	Pond	Boulis/artificial lakes	Lakes	Sills
Cascades	20	2	6	3	2
Centre	84	1	3	0	1
Centre-Est	68	5	2	4	1
Centre-Nord	82	10	12	4	0
Centre-Ouest	171	2	49	0	4
Centre-Sud	103	1	5	0	0
Est	63	5	3	2	0
Hauts-Basins	34	10	1	2	0
Boucle du Mouhoun	49	2	3	0	0
Nord	93	1	22	0	1
Plateau Central	84	2	18	0	1
Sahel	38	28	53	1	0
Sud-ouest	37	4	2	2	2
Total	*926*	*73*	*179*	*18*	*12*

Groundwater resources

The groundwater resources are estimated at 113.5 Bm^3 in two major geological zones of the country (FAO, 2010). These include:

- *Crystallin zone* (82% of the territory). Flows in boreholes are low (0.5 to 20 m^3/h).
- *Sedimentary zone* (18% of the territory) is in a band from south-west to north and in South-East.

The accessibility to groundwater is limited due to drilling costs and a lack of machinery and technical expertise. Therefore, farmers prefer to use surface water. As is being practiced in many other countries such as India and Pakistan, the "community wells" are not common in Burkina Faso. Farmers share wells' installation and operational costs in the community wells and collectively use groundwater for irrigation. In Burkina Faso, groundwater is mainly used for domestic purposes because groundwater quality is generally reasonable.

Water demand in Burkina Faso

The total water demand of Burkina Faso is estimated at 2500 million m^3 per year, of which 80% comes from hydroelectric units. About 95% of hydroelectric demand is met by Nakanbé basin (MEE, 2001). The water demand is estimated at 505 million m^3/year. Three main water use sectors are irrigation (64%), domestic use (21%), and livestock (14%) (MEE, 2001).

Distribution of vegetable cropped areas

Vegetables are grown in all 13 administrative regions of Burkina Faso (Figure 3). These include Nord, Centre-Nord, and Hauts-Bassins regions due to their importance for dry season crop production. There are 4,844 vegetable crop sites. The Nord, Hauts-Basins, and Centre-Sud regions each have more than 10% of vegetable crops sites. The vegetables are grown mainly in the dry season. The onion bulb is cultivated on 11,449 ha (41% of the total vegetable cropped area). The main 5 regions for onion bulb include: the Nord (3,134 ha), the Centre Ouest (1,662 ha), the Hauts-Bassins (1,423 ha), the Centre Nord (1,165 ha) and the Boucle du Mouhoun (1,039 ha). The area cultivated with tomatoes is 5,224 ha (18.9%). This area of tomato is unevenly distributed in the 13 regions of the country. Thus, the Nord region alone has about 25% of the total area cultivated with tomatoes.

The cabbage area is 2,438 ha (8.8% of the total vegetable area). Lettuce is practiced on 2,116 ha (7.6%). The lettuce area is in the Centre region (1,272 ha). The Hauts Basins and the Boucle du Mouhoun register respectively 427 ha and 146 ha of lettuce.

The eggplant is cultivated in all regions on about 482 ha (1.7% of the vegetable area). The largest site is in the center-est part (85 ha). The cultivation of local eggplant is very little practiced in the Est (1.02 ha). Approximately 2.4% of the national vegetable area, or 666 ha, was sown for leaf onion production. More than 100 ha, or more than 15% of the national area, were cultivated for leaf onions in South-Central and Eastern regions. Apart from East Central (82 ha) and Central (70 ha), the other areas grow less than 50 ha of leaf onions.

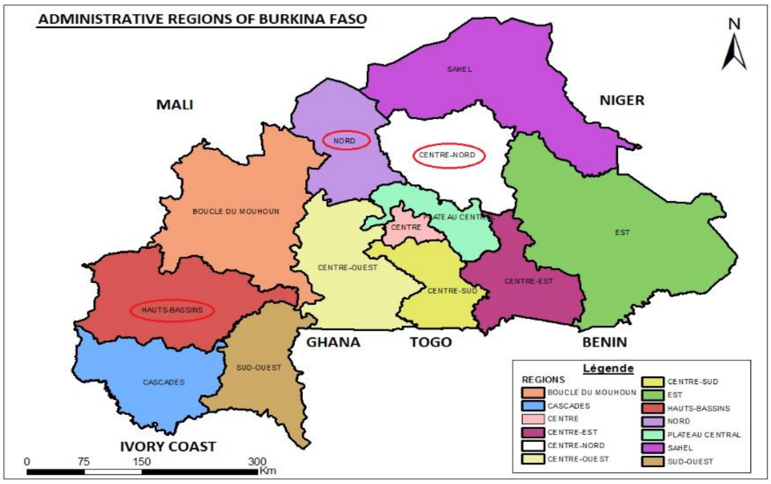
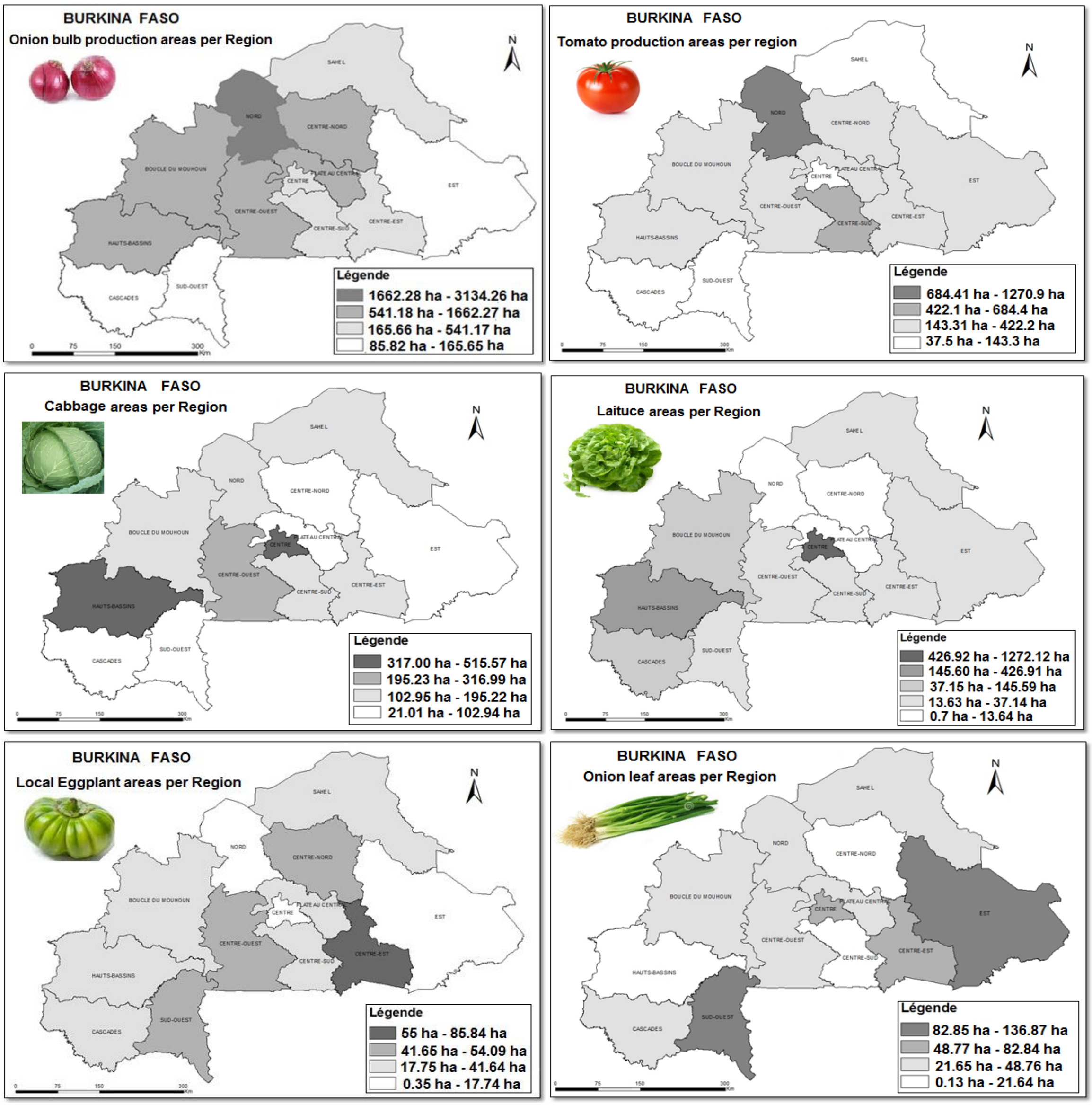


Figure 3. Main vegetables grown regions of Burkina Faso



Irrigation methods used in Burkina Faso

In Burkina Faso, more than 76% of the farmers lift irrigation water manually (Figure 4). The motor pumps are used only by 15% of the farmers, whereas the rest use pedal pumps (6%) and gravity methods (3%). The manual irrigation mode is standard in all regions except the Centre-Nord, where the motor pump model is dominant. Most motor pumps are small (up to 10 hp) and have limited suction capacity. The highest rate of motor pump use is in the Centre Nord (63%) and the Centre (31.8%) regions, whereas the center-est area has the lowest rate of motor pump use (1.0%) (Figure 5). The amount of water lifted through the manual devices is low and cannot irrigate large areas. Women mainly do this job as male family members go to towns to do off-farm employment. For women, manual irrigation is a tiring job as they must perform other household activities.

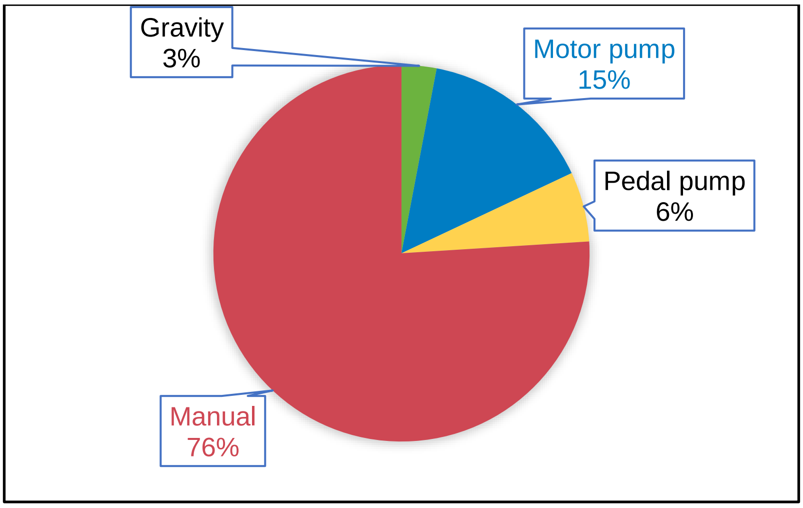


Figure 4. Percentage of farmers using different irrigation systems.

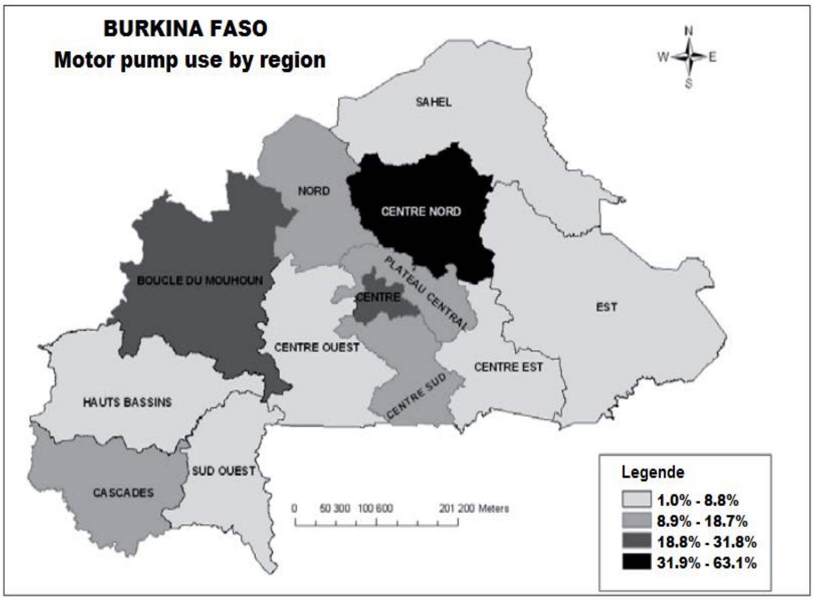


Figure 5. Use of motor pumps in different regions of Burkina Faso

3.2 Mali

Mali has an agriculture-based economy, which accounts for 36% of GDP and is the main source of income for at least 80% of the population. In addition, the sector contributes about 40% of export earnings. Mali's population is estimated at 14.5 million with an average density of 11.7 inhabitants/km², which varies from 20 in the South (regions, Koulouri, Keyes, Segou, Sikasso, Mopti, Gao) and less than one inhabitant/km² in the north (Tombouctou and Kidal regions). The average annual growth rate of GDP over the past decade is 5%, and the rate of population growth for the same period was 3.6%, with per capita GDP of US$ 693.

In Mali, agriculture is mainly dependent on rainfall, although the country has land and water resources adequate for the development of irrigated agriculture. The Malian government has tried to expand the country's irrigation infrastructure to improve agricultural production. Before the year 2008, Dougabougou and Siribala was the largest sugarcane plantation area. Currently, the government is implementing a national program to ensure food security for smallholder farmers targeting small-scale irrigation systems.

The types of irrigation technologies practiced in Mali are drip irrigation, Californian system, sprinkling system, and gravity system. Drip irrigation is used to grow tomatoes, onion, shallot (Allium fistulosum), bananas, papaya, and oranges. Sprinkler systems are used for commercial farms to produce high-value crops such as fruit trees, coffee, sugarcane, and horticultural crops. The Californian irrigation system is a network of PVC pipelines buried in the soil that decreases infiltration. It routes water on a parcel moved away from the pumping source or having an irregular topography and follows the triage and row-level without adding or manipulating hoses. Water is lifted from the surface or the underground water source and distributed to plants through furrows.

Mali has a great diversity in climate, hydrology, hydrogeological, and soil conditions, making it suitable for irrigated agriculture (DNGR, 2016). In general, 98% of water needs in Mali are covered by surface water. The exploitation of groundwater for irrigated agriculture is very low, whereas the potential of groundwater exploitation is enormous (2700 Bm^3 of static reserves with an annual renewal rate of 66 Bm^3). Currently, groundwater resources are mainly used for market gardening. In recent years, the various projects, and programs for the fight against poverty and food self-sufficiency have focused on developing market gardening in rural areas as an income-generating activity. In the peri-urban areas of the major cities where groundwater is shallow, market gardening is practiced. The watercourses near dam areas that serve to recharge groundwater tables on a local scale also help develop market gardening. In addition, new techniques are emerging, among which we can cite the peri-urban private small and micro-perimeters and the oasis irrigation.

In these areas, 10,033 ha are managed by the National Proximity Irrigation Program (PNIP) from 2012-16, including 195 ha of market gardening. The rate of exploitation of market gardening is low in Koulikoro, high in Sikasso, and very high in Mopti. In Mali, 98% of water consumption needs are covered by surface water, and the groundwater exploitation is very limited, although groundwater potential is very high (2700 Bm^3 of static reserves with an annual renewal rate of 66 Bm^3).

The irrigation water for vegetable crops is supplied through canals, cemented large diameter wells, and shallow manual drilling. The water distribution for irrigation is done through gravity, pedal pumps, low power pumps, and rarely electric motor pumps with generators and solar. The water distribution techniques used at the farm include (i) gravity irrigation (the most common) to the water-spray ray with calabash, (ii) irrigation at the calabash or watering cane with manual water transport (iii) sprinkling with hose and watering cane, and finally the micro-irrigations systems (drip and sprinkler) that are struggling to put in place.

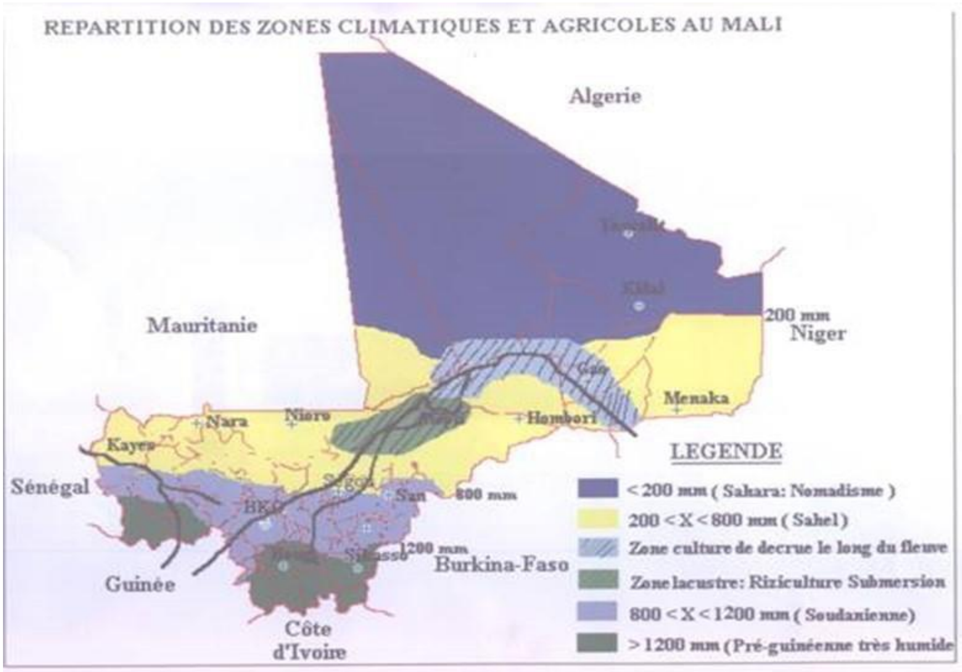


Figure 6. Agro-climatic zones in Mali

Figures 7-9 show the agricultural areas most suitable to produce crops and vegetables by promoting small-scale irrigation systems. These maps are developed with local partners. The general characterization of the three regions is in Table 4. A summary of suitable cropping patterns and the irrigation methods for these selected regions is given in Table 5. Table 5 also provides crop market gardening and appropriate irrigation technologies in the circles and agricultural areas of the three areas targeted by the ICBA project. Thus, all market gardening (leafy vegetables, fruit, bulb, and tuber crops) is cultivated in all three regions of Mali.

Gravity irrigation cannot solve the adverse effects of climate change and their impacts on reducing rainfall and the availability of surface water and groundwater. Therefore, micro-irrigation techniques (sprinkler, drip) supported by the Californian water delivery system need to be introduced as an alternative to expand small-scale irrigation to produce vegetable crops.

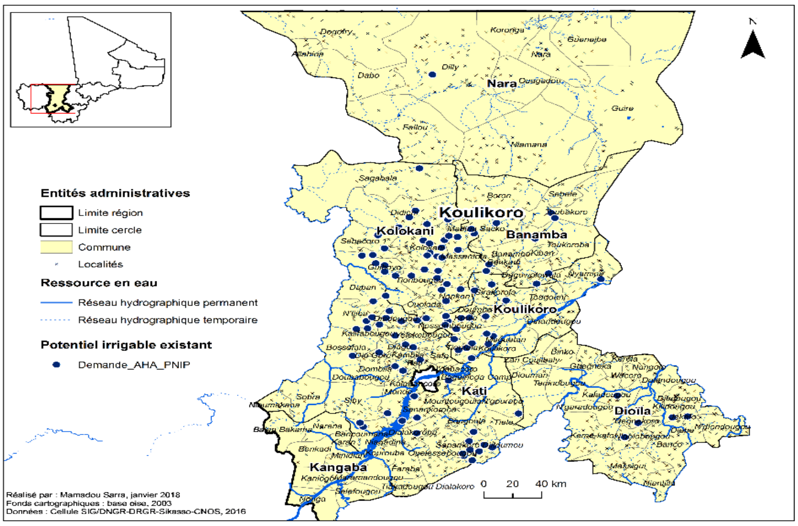


Figure 7. Potential irrigable sites in Koulikoro region

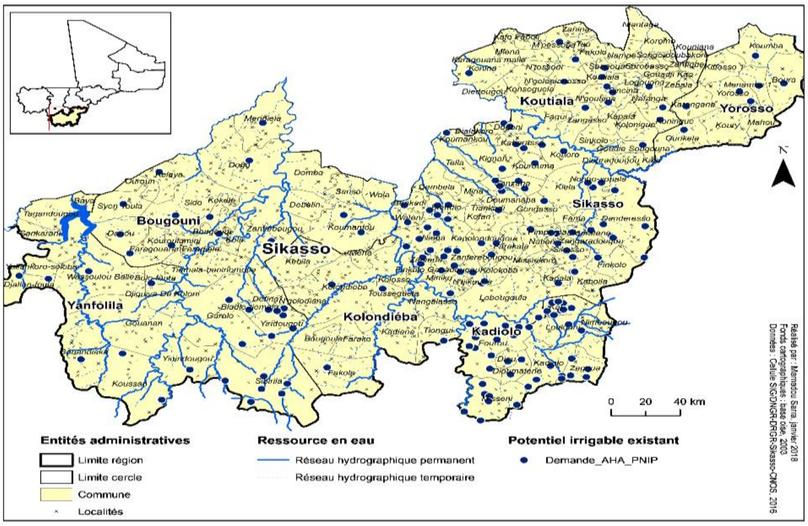


Figure 8. Potential irrigable sites in Sikasso region

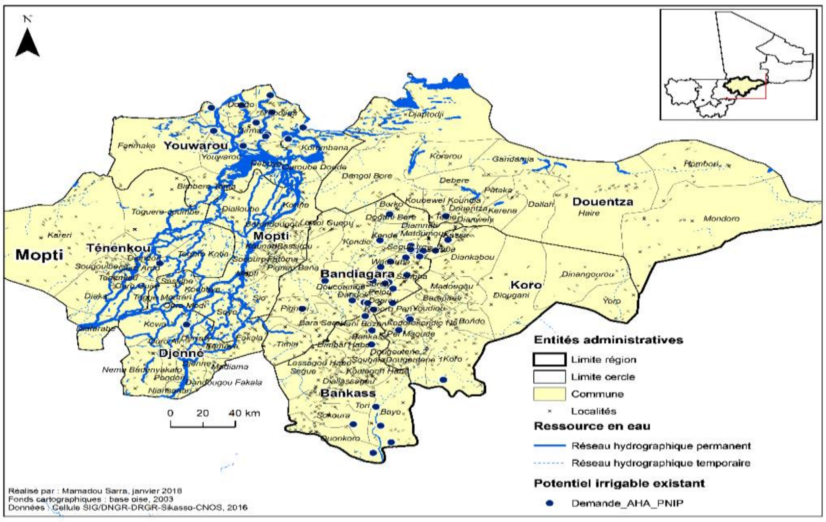


Figure 9. Potential irrigable sites in Mopti region.

Table 4. Characteristics of three potential sites in Mali

Characteristics	Regions		
	Koulikoro	Sikasso	Mopti
Areas (km^2)	90 910	71 790	79 017
Relief	Mount Manding at South	Mount Kouloum	Cliffs of Bandiagara and Mount Hombori
Surface water resources	Niger River, Baoulé, Sankarani, Bagoé, Baní and Bafing	Sankarani River, Bagoé, Baoulé, Banifing, Katiorniba	Niger River, Sourou, Diaka, Bara Issa, Koli Koli, Bani, Yamés, Dakadjan, Sense, Diallo, Wango, Oualado, Débo, Korientzé, Korarou, Aougoudou and Niangaye
Drilling done between 1992-2000	442	1624	1105
Productive drilling between 1992-2000	505	1390	506
Pumps made between 1992-2000	500	1776	863
Modern wells between 1992-2000	1165	389	1914
Water supply between 1992-2000	24	26	21
Major hydraulic infrastructures	Manicoura	Dam of Sélingué	Threshold of Djénné under construction
Areas potential suitable for irrigation (ha)	110 000	150 000	35 484
Area realized (ha) from 2015 by the National Proximity Irrigation Program (PNIP)	410	1 641	1 291
Area Developed in Small Market Perimeters (PPM) from 2012 to 2015 (ha) by PNIP	85	14	111
Area developed in lowlands and pools from 2012 to 2015 (ha) by the PNIP	873	5 054	1448
Area developed in PIV from 2012-15 by PNIP	0	40	2626
Area used for market gardening (ha)	20,53	9,3	98,23
Market gardening rate (%)	32	66	95
Water distribution techniques used at the plot or plant for market gardening	- gravity irrigation (the most widespread) to the line with sprinkling of water to the calabash. - irrigation with calabash or watering can with manual transport of water between water point and the plant, Spray with hose and watering cane, Californian micro-irrigations, drip and sprinkler.		
Water sources for market gardening	Surface waters (river, micro-dams, canals, ponds), Underground waters, rains		

Means of drainage from market garden crops	Gravity, pedal pumps, low-power pumps/motor pumps, electric pumps with generator and solar (rarely).		
Means of capture	- irrigation channels, Cemented large diameter wells, manual drilling at shallow depth.		
Number of operators (Farmers)	1491	997	4063
Average production yield in market gardening (PNIP and National) (t / ha)	18	14,41	19,71
Market gardening production (ton)	431	131,4	1505
No. AHA population requests registered by PNIP National Orientation and Monitoring Committee (CNOS) for Proximity Planning Program (PAP)	300	323	82
Populations in 2009 (RGPH)	2 418 305	2 625 919	2 037 000
Population earning from the rural sector (%)	80 to 84	66 to 80	84 to 87
Economic	agriculture, livestock, beekeeping, fishing	agriculture, livestock, fishing, forestry, mining	agro-sylvopastoral and halieutic, tourism, crafts

Table 5. Summary of cultivated crops and suitable irrigation technologies

Region	Agriculture Area	Crops	Suitable Irrigation Technologies
Koulikoro	Koulikoro, Banamba Dioïla, Kangaba, Kati, Kolokani, Nara, OHVN, OPIB Manicoura	-Vegetables with leaves (cabbage, lettuce etc. -Fruit vegetables (tomato, okra, cucumber, eggplant, etc. -Vegetables with bulb, tuber, root (shallot / onion, potato, carrot, etc.	Sprinkler, drip, Californian and gravity systems
Sikasso	Sikasso, Bougouni, Kadiolo, Kolondiéba, Koutiala, Yanfolila Yorosso	- Vegetables with leaves (cabbage, lettuce, etc. - Fruit vegetables (tomato, okra, cucumber, eggplant, etc. - Vegetables with bulb, tuber, root (shallot / onion, potato, carrot, etc.	Sprinkler, drip, Californian and gravity systems
Mopti	Bandiagara, Bankass, Djenné Douentza, Koro Mopti, Ténenkou Youwarou	- Vegetables with leaves (cabbage, lettuce, etc. - Fruit vegetables (tomato, okra, cucumber, eggplant, etc. - Vegetables with bulb, tuber, root (shallot / onion, potato, carrot, etc.	Sprinkler, drip, Californian and gravity systems

3.3 Niger

Niger covers an area of 1,26 million km^2. The national strategy for Irrigation (SNDI) development was developed in 2001 and updated in 2005 to expand its scope to Rural Development Strategy (RDS). Under this strategy, the Government abolished all public irrigation schemes, and it was decided that all such initiatives should be taken with the support of the private sector. Even with public investment, Niger irrigation must be supported and managed by private farmers to double its contribution to GDP by 2015. This strategy intends to double or even quadruple crop yields to increase rural farmers and lift them from chronic poverty. In addition to irrigation water delivery, there is a need to provide quality seed and other farm inputs. This project is well placed in the National Agenda of Niger because it focuses on improving access to small-scale irrigation systems to increase water use efficiency and crop productivity of smallholder farmers.

Niger is a Sahelian country belonging to the dry tropics. The rains are erratic and poorly distributed in time and space. Agriculture is mainly subsistence farming. Agriculture is the main economic activity and the first source of income for the rural population. Its contribution to the national GDP is significant. Millet and sorghum are the primary food crops. Each year, the planted area planted for these two crops increases while the yield remains low.

Since 1980, the government of Niger has adopted an agricultural policy that supports irrigated crops production and commercialization. Irrigated farming of vegetables (onion, pepper, and tomato) has become the main cash crop. The areas assigned to these crops are 48,000 ha, with an annual production of about 700,000 (MDA, 2013). Despite the importance of vegetables for the national economy, limited attention is paid to their winter production, resulting in their import. The problems related to irrigated agriculture in Niger are:

- Multi-crop orientation: millet, sorghum, cowpea, and other vegetable crops. Rice has traditionally grown along the river where irrigation water is available.
- Use of hand tools for agricultural activities – no mechanization.
- Use of poor-quality seed for crops and vegetables and low fertilizer use.

The climate of Niger is Sahelian type characterized by a long dry season from October to May and a rainy season from June to September. There is a significant variation in rainfall days from North to South, ranging from an annual rainfall between 100 mm and 700-800 mm. Niger has the following climatic zones.

- The Saharan zone (65% of the national territory) with less than 100 mm/year precipitation. The temperature average is about 35°C, and the climate is desert type.
- The Sahalo-Sahelian (12% of the national territory) region has an annual precipitation of 100 to 300 mm. The climate is sub- desert type.
- The Sahelian zone (13% of the total area) with a Sahelian area to the North, where annual rainfall ranges from 300-600 mm, and a Sudanese domain to the South.
- The Sahelo- Sudanian zone (10% of the total area), receives over 600 mm/year**.**
- The relationship between the ten years of wet and dry annual precipitation reaches 2.5 to the isohyets 500 mm/year and more than 3 to 200 mm/year.

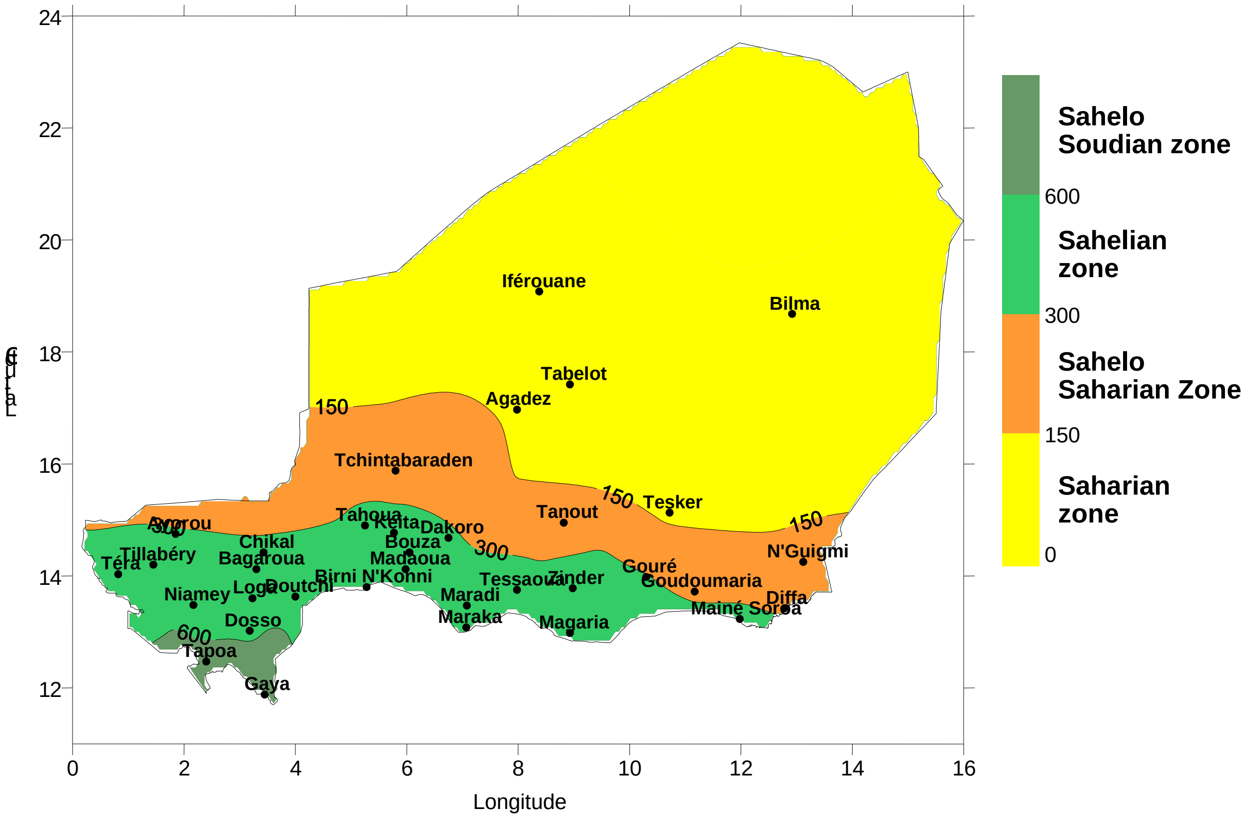


Figure 10. Agro-ecological zones in Niger

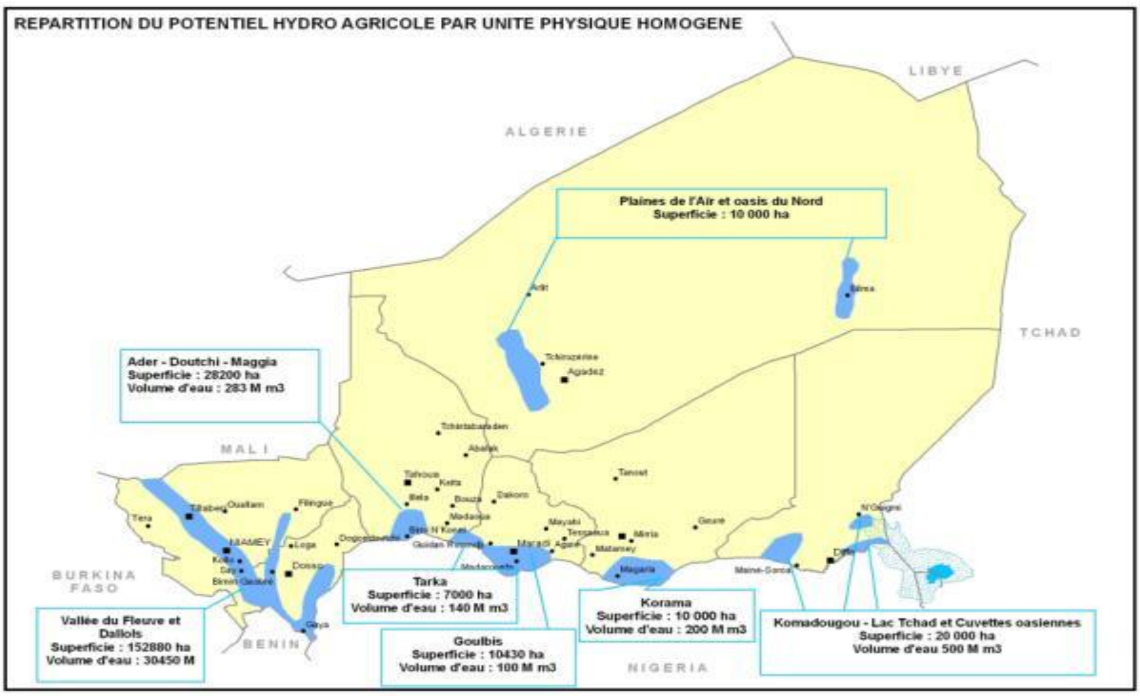


Figure 11. Distribution of homogenous hydrological potential

Surface water resources are dependent on the Niger River and its tributaries of the right bank. Although flows have reduced over time, significant areas of different regions (Ader-Doutchi Maggia, Maradi, and Komadougou Valley) are irrigated by this water (Table 6). Other territories have limited flows with large fluctuations from year to year.

Table 6. Characteristics of surface runoff of different rivers

Physiographic unit	Rivers	Control point	Catchment area (km^2)	Average annual runoff (10^6 m^3)
Niger river valley	River Niger	Niamey	700 000	30 000
	Gorouol	Alkonki	44 850	220
	Dargol	Kakassi	5 490	160
	Sirba	Garbey Kourou	38 750	680
	Goroubi	Dioungoré	15 350	160
	Diamangou	Tamou	4 030	100
	Tapoa	W parc	5 330	40
	Mékrou	Barou	10 500	800
Dallols, Bosso, Maouri		Bengou		Negligible, 4.3
Ader-Doutchi-Maggia	Maggia	Birn'Konni	2 500	118
	Vallée de Keita	Baga		101
	Badéguichiri	Badéguichiri	825	37
Goulbis	Goulbi N'maradi	Madarounfa	4 800	218
	N'Kaba			Negligible
Korama	Zermou	Zermou	474	9
Komadougou	Komadougou	Bagara	115 000	501
Aïr valley and oasis systems	Téloua	Azel	1430	21
	Kori d'Iférouane		4 130	12
	Tadrisa		1 760	11
	Tagoura		2 130	15
	Wederer		2 440	12
	Baouet		5 630	39
	Zilalet		3 600	36
	Makarer		2 740	33
	El Méki		2 800	28
	Berje Moustare		2 710	16
	Barghot			

The groundwater resources are 2.5-4.4 km^3/year. Major aquifers are given in Table 7.

- Alluvial aquifers of the goulbi Maradi, Aïr valleys, kori Teloua, koris of the Ader-Doutchi Maggia zone, Bosso, Maouri & Foga dallols, Komadougou Valley, koramas.
- Discontinuous aquifers of the basement, including Liptako and Damagaram-Mounio.
- Aquifers of the continental terminal and the continental hamadien.
- The water of the Pliocene of the basin of Lake Chad.
- The water table of the Manga in the basin of Lake Chad.
- The Agadez sandstone aquifer.
- There are two million m^3 of non-renewable groundwater reserves, to support mining.

Table 7. Major aquifers of Niger

Type of aquifers	Stratigraphic stage	Major Litho logy	Total area (km^2)	Superficie Zone à Surface Libre Km^2
Alluvial	Quaternary	Sand, gravel, silt	Dispersed	
	Koramas	Silty sand	13,430	13,430
Generalized	Plio quaternary Lac Tchad	Silty sand	125,190	125,190
	Continental Terminal	Sandy Silt, sand, laterit	103,000	103,000
		Sandstone of Bilma	Sandstone, silty sandstone	44,465
	Continental Intercalary and Hamadian	Sandstone, silty Sandstone, Sand	343,075	161,675
	Sandstone of Agadez	Sandstone, silty sandstone, sand	28,535	4,775
Single stratum or multistratum	Namurian Tarar, Guezouman)	Sandstone, silty sandstone		25,000
	Viséen (Farazekat, Amesgueur)	Cimented silty sandstone		25,900
	Devonian (Touaret, Idekel) Cambro-ordovicien quartzitiques	Sandstone, silty sandstone Coarse sandstone		3,150 7,700
Cracked	Voltaien	Quartz sandstone	3,360	
	Granitic bed, Metamorphic	Granite, quartzite, schist	148,425	

The success of SSI in Niger depends on the development and dissemination of low-cost irrigation technologies and addressing related technical and financial problems. The Californian and gravitation systems of irrigation are now widely used in Niger. The Californian is a small irrigation system, which distributes water to crops through PVC pipes buried in the ground. Water intakes are connected to these rigid pipes at regular intervals (18-36 m). Water is delivered to fields through terminals that are located at standard distances. Alternatively, a movable 14 m flexible hose can be attached to hydrants to irrigate plots. Water is extracted from river streams and groundwater using diesel or solar pumps.

This system allows serving the entire field regardless of topographical conditions. This system is suitable for irrigating small areas (0.1-2 ha). However, the pumping rate determines the size of the irrigable area. This system saves up to 40% water and reduces energy costs by 25%. The initial installation cost is US$ 600 to 1000 per ha with a return on investment in 2 to 3 years). The system can be extended depending on the financial capacity of the producer. Under West-African conditions, the life of the California system is 6-10 years, depending on the quality material and level of maintenance by farmers.

3.4 Senegal

Most of Senegal lies within the drought-prone Sahel region, with irregular rainfall and generally poor soils. With only about 5% of the land irrigated, the heavy reliance on rainfed cultivation results in large fluctuations in production. Agriculture accounts for 18% of GDP, with 70% population involved in farming. Most Senegalese farms are small (1.5–2.4 ha), and 11% of the total land area is cultivated. Pearl millet is grown on 40% of the cultivated land and peanuts on 36%. Senegal's climate is tropical with well-defined dry and humid seasons. The mean annual rainfall ranges from 270mm in the North to 1793mm in the South.

The largest water resource in the country is the Senegal River in the North, shared with Mauritania, Mali, and Guinea (Table 8). Its average flow is 37 Bm^3 per year. However, water in most parts of the country is scarce due to the lack of irrigation infrastructure. Senegal has about 3 Bm^3 per year of renewable groundwater resources, excluding those that overlap with surface water. The total surface water withdrawals are about 1.4 Bm^3, of which 92% is used for agriculture, 3% for industry, and 5% for domestic purposes. Groundwater stocks are 7 Bm^3. Groundwater over-exploitation is causing the lowering of groundwater levels in many areas. Currently, villagers need to drill as deep as 80m to pump groundwater. This has increased the cost of pumping, restricting groundwater accessibility for the poor farmers. This results in low crop productivity, reduced incomes, and increased household poverty.

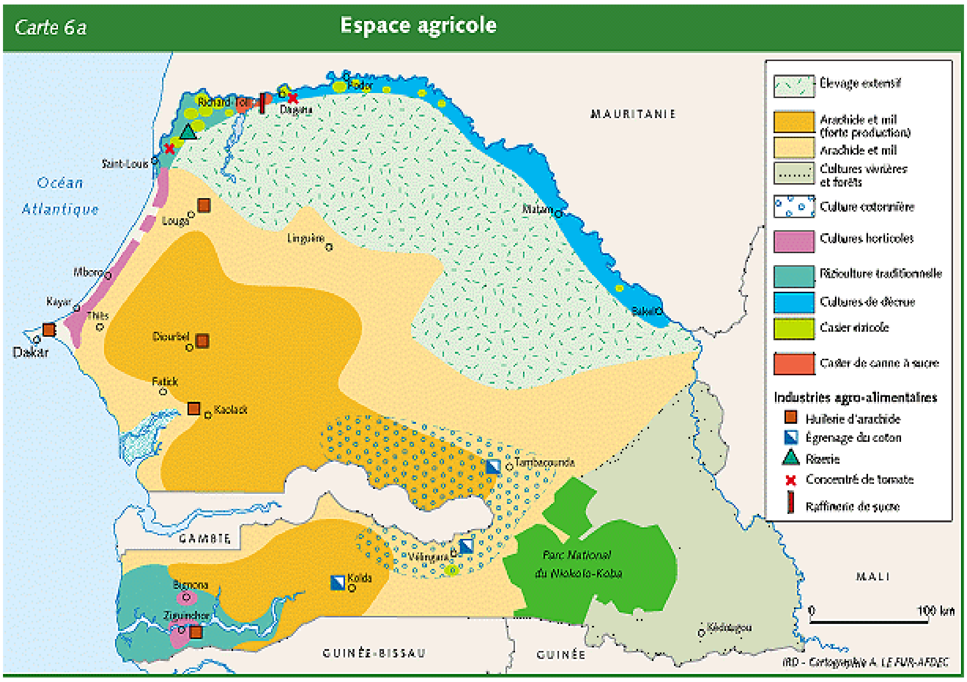


Figure 12. Agricultural production systems in Senegal

Agriculture is mainly subsistence farming, and the country is a net food importer of rice, which represents 75% of cereal imports. Peanuts, sugarcane, and cotton are important cash crops, along with fruits and vegetable. Fishing sector remains major foreign exchange earner while the poultry and livestock sectors are underdeveloped and needs modernization.

Senegal has an irrigable land potential of 400,000 ha, mainly in the Senegal River Valley (SRV). Schemes managed areas in total or partial control are estimated at 105,000 ha. They are distributed between the VFS (76,000 ha), the low and medium Casamance (15,000 ha), the Niayes (10,000 ha), the Anambe Valley (4,000 ha), and the Eastern Senegal (600 ha). Despite completing these schemes, the cultivation area remains low and would be 32% for the VFS and 17% for the Anambe. Even though the potential of irrigated areas is well-known, irrigated land occupies only 4% of the cultivated land is irrigated.

Table 8. Irrigation potential and level of planning and development

Zones	Irrigable potential (ha)	Schemes developed area (ha)	Cultivated area (ha)
Senegal River Valley	228000	76 000	41300
Low& mid-Casamance	70000	15000	9000
Anambé	16000	4000	500
Gambia	4100	600	250
Shallow water	5000	pm	pm
Niayes	12000	10000	10000
Groundnut basin	14 000	pm	pm
Total	349,100	104,780 (30%)	6,350(18%)

Tables 9-11 give an area of crops grown during different cropping seasons in the SRV.

Table 9. Area (ha) for major crops in different areas of the Senegal River Valley

	Planned crop area (ha)				
Crops	Dagana/Lake	Podor	Matam	Bakel	Valley
Tomato	1600	1560	150	0	3310
Onion	1600	3000	500	128	5300
Maize	750	360	1 500	43	3460
Sweet potato	1000	0	100	0	1200
Gombo	300	215	200	24	1400
Others	1000	215	250	329	3030
Total	6,250	4,042	2,700	552	17,700

Table 10. Area (ha) for major crops during dry hot season in the Senegal River Valley

Zones	Planned crop area (ha)	
	Total	Rice
Dagana/Lake	40,000	38,000
Podor	9300	8000
Matam	3745	3000
Bakel	1850	1000
Total	54,895	50,000

Others: Gombo, sweet potato, groundnut, etc. Rice representing 91%

Table 11. Area (ha) for major crops during rainy season in the Senegal River Valley

Zones	**Planned crop area (ha)**	
	Total	Rice
Dagana/Lake	32500	30000
Podor	11077	10000
Matam	10250	10000
Bakel	4000	1000
Total	57,827	50,000

4. Small-scale irrigation systems used in SSA

Smallholder farmers in Africa have been exposed to many SSI technologies during the last two decades. These include manually operated treadle pumps and small-scale drip systems (*e.g., Jain drip system from India*). The gravity-operated small-scale drip systems (i.e., JainDripKit) have proved successful in irrigating kitchen gardens. These systems are available for 50m^2 to 2000m^2 area and are simple and easy to install and operate. These systems are especially suitable for areas with a long gap between rainy and dry seasons and/or unavailable electricity. They are considered survival irrigation tools and are now being used by many small farmers in Asia and Africa, India, and Senegal. These systems have specific benefits for smallholder farmers but have their limitations and constraints.

They can be operated only up to a maximum head of 4 m with a delivery discharge of 1.5 liters/h. Therefore, they are suitable only for kitchen gardens or where land holdings are minimal. These systems can operate in areas where a water source is available at the location. Mostly farmers make a water reservoir close to the field, and water is pumped into the 3-4 meters high water tank for use in the drip system. This requires land as well as money to build a water reservoir. Solar pumps have also been introduced to lift shallow groundwater for filling the water tank in a few places. The major bottleneck is that these systems cannot be used if the water source is far from the field. These irrigation systems cannot support fertigation unless liquid fertilizer is available to farmers, which is rare in SSA.

A brief description of different small-scale irrigation technologies used in SSA is given below.

4.1 Manual lifting system

The hand lifting technique is a traditional method to extract water from wells and rivers. This water is then used for irrigation using buckets. Women usually operate this system, and more than 80% of their household time is used in water lifting and irrigation. In the Africa region, more than 70% of vegetables are grown using this irrigation method.

Main characteristics of this system are as follows:

- Smallholder farmers use manual devices to lift water from river streams and wells.
- They are mainly used to irrigate small holdings up to 0.5 ha or less.
- These devices are pervasive to irrigate small vegetable and fruit gardens. Since flows are low, it takes a considerable amount of time to irrigate small parcels of land.
- In Burkina Faso – the average area irrigated by these devices is about 1000 m^2.
- About 80% of the labor time of the households is used in water lifting and distribution. Usually, men and women are both involved in irrigating lands with this method.
- In Senegal, for example, an estimated 7,000 hours are used to irrigate one hectare of land using this method. This discourages farmers from using this method of irrigation.

4.2 Treadle pumps

The treadle pumps were first developed in Bangladesh in the 1980s and then introduced in India where farmers used them to lift large quantities of water through shallow lifts of 1-2 meters. These pumps were later modified (*called as pressure pumps*) to meet the needs of African farmers, who lift water from deeper sources (>4m) and irrigate undulating land with sprinklers or hosepipes. The modified pumps were introduced in many African countries such as Senegal, Mali, Burkina Faso, Zimbabwe, Zambia, Kenya, and Niger. Initially, these pumps were welcomed as they helped farmers irrigate small fields, increasing their cultivation area and crop production. However, their utility becomes restricted over time because of their capacity to work at low heads and low discharges to irrigate large areas. Treadle pumps can work at greater depths (up to 5-8 meters), but the discharges are low (0.3 l/s), which are not feasible for the required physical human input.

The area irrigated with a treadle pump depends on the crop, the climate, and the irrigation application efficiency. In broader terms, assuming an irrigation time of 20 hours per week with a crop water requirement of 30 mm per week and a power input of 50 watts (only one person pumping water), the area that can be irrigated is approximately 0.20 ha. Under similar conditions, the bucket method would reduce the irrigated area to 0.05 ha (IPTRID, 2000). This shows that treadle pumps are slightly more beneficial than the bucket method.

Social and cultural issues vary from country to country. In Zambia, for example, irrigating crops, weeding, fertilizing, and harvesting are generally considered to be women’s activities. Women use treadle pumps and see this as an opportunity for empowerment. IPTRID (2000) has reported that women find the pumps harder to operate than men do. Of all the pumps sold in 1999 in Zambia, only four were purchased by women, though women are the primary users of treadle pumps. Although treadle pumps are not so widely used in Zimbabwe, the improvement of family nutrition because of the increase in garden produce has been noted in many areas. However, there is a little economic benefit as most communities produce just enough for their home consumption. The use of treadle pumps is still restricted to few framers because of its cost (US$ 100). More than half of the pumps in use were donated and are thus community property.

Another type of manually operated pump used in SSA is called “*Nafa pumps*.” These pumps are available in six different types, and farmers can select pumps depending on their cost and availability. However, their price remains a challenge for smallholder farmers.

The characteristics of different treadle pumps are given below:

1. *The Nafa suction pump with driving back arrangement:* Lifting depth is 8m with a driving back capacity of 150m on flat land. The flow rate is 6-8 m^3/h and can lift groundwater and surface water. The potential area that can be cropped is 0.5 ha
2. *The suction Nafa pumps:* Lifting depth is 8m but cannot deliver water under pressure. The flow rate is between 4.5 and 5.3 m^3/h with a potential irrigated area of 0.25 ha.
3. *The Nafa pumps for deep conditions (mono-cylinder and bicylinder):* Maximum lifting depth is 18m. The flow rate varies from 1.5-3.5 m^3/h. This pump is used for deep wells.
4. *The manual Nafa pumps:* Maximum lifting depth is 9 m. The flow rate is between 3.2 and 8.2 m^3/h. The potential area that can be irrigated with these pumps is 0.6 ha.
5. *The Big flow Nafa pumps:* Lifting depth varies from 2 to 3 m. These are suitable for surface water (wells, dams). The flow rate of these pumps is between 7.5-9.8 m^3/h.
6. *The Compact Nafa pumps:* The lifting depth is 7m. They are used for lifting water from wells and dams. The flow rate is between 2.2-5.2 m^3/h and can irrigate up to 0.4 ha.



4.3 Motorized pumps

Different types and capacity motor pumps are available in the region. Generally, 2-5 hp pumps are used for shallow groundwater and 12-15hp for deep groundwater areas. Small motor pumps can irrigate 1-2 ha of land, whereas large pumps can irrigate 2-5 ha. The fuel consumption of these pumps is around 1.0 to 1.5 liters per hour. The price of these pumps varies from US$ 230 to US$ 300. The cost of accessories depends on the quality and varies between US$ 40 to US$120. Most of the pumps are China-made and readily available in local markets. Maintenance is done locally or in the big towns. These pumps can lift water from 3 to 8m. The average life of these pumps is around five years.



4.4 Drip irrigation system

The drip irrigation system distributes water to individual plants through a network of tubes or pipes at a controlled low flow rate. This system reduces water losses, produces fewer weeds, and is suitable for coarse soils. However, high initial costs, clogging of drippers, and risk of damages during land cultivation and animal walk are few severe disadvantages. The drip irrigation system is mainly used for vegetables and fruits. In SSA countries, the adoption of this system is limited due to its cost, high maintenance, and low availability in local markets. The average cost of installation of these systems is US$ 2000-3000 per ha.

The drip irrigation system is mainly used for vegetables and fruits. Despite established efficiency, the adoption of drip irrigation systems in SSA countries is limited due to its initial investment cost, low availability in local markets, and lack of maintenance services. In Mali and Senegal, some private companies have started making local materials, which might help in reducing costs. In other countries, drip system systems are mainly imported, which makes it expensive for smallholder farmers.



4.5 Sprinkler irrigation system

The sprinkler irrigation system is used to imitate the rainfall. The water under pressure is supplied through pipes, and sprinklers do irrigation. Large commercial companies primarily use this system. These systems are adaptable to varied land topography, saves labor, reduce erosion and fertilizer loss. However, high installation costs, limited availability of equipment and maintenance services in the local markets are limitations in the large-scale adoption of these systems. The installation cost varied from US$600 to US$4000 per ha, depending on the location, type of soil, and crop.



4.6 Border and furrow irrigation systems

Farmers commonly use the border and furrow irrigation systems for irrigating lands. Water is applied to the field through an outlet, and water distribution within the area is done through gravity. The efficiency of these systems is generally low; however, farmers prefer them because they do not have high investment or maintenance costs.



4.7 Californian system

The Californian system is a network of PVC pipelines buried in the soil to route water from the source to farmer fields having an irregular topography. The PVC pipes are buried in the ground with several terminals for irrigation. Water is lifted from the surface or groundwater source and distributed through furrows with crops planted on ridges. This system is most suitable for irrigating areas up to 3-4 ha. This system has several advantages over traditional irrigation systems. These include:

- The system is well adapted for fields with varied topography as it minimizes water loss during water delivery and irrigation and ensures uniform water distribution.
- The irrigation frequency reduces to two times per week compared to three to four times a week with the bucket method. It also reduces irrigation time and gives the possibility to use several terminals at the same time.
- The labor needed for irrigation is lower with the Californian system. Two persons can irrigate a 0.5 ha plot with this system, compared to 4 to 5 men with the bucket method. It saves lots of lands because pipes take up less space compared to surface channels.
- Easy installation, use, and maintenance because all materials are primarily available locally. Easy extension and opportunity to expand the irrigated area.
- Unlike treadle pumps, there are no socio-cultural issues with this system. Women happily use these pumps because it does not involve a lot of physical labor.
- Due to sufficient water availability under this system, kitchen vegetables and legumes, grains, and fodder crops can be irrigated.
- During the dry periods when water level drops in channels and 2-cylinder pumps do not work, the Californian system works efficiently. Farmers can achieve higher yields due to timely plantation of seeds and timely irrigation of crops.
- The Californian system is efficient in saving irrigation water.

The installation cost of the Californian system varies between US$ 600-1000 per ha, depending on the topography and the soil type. For example, if the soil is sandy, the installation cost is higher because the number of terminals will increase to meet the water demand of this soil type. The life of the Californian system is 8-10 years compared to 2-3 years of drip system. Moreover, the maintenance cost of the Californian system is almost negligible compared to drip systems. The pump used for this system consumes 1.5 l/h of fuel and has a discharge capacity of 20 m^3/h discharge capacity. The pump needs to be operated 5-8 hours/day to irrigate one ha of land, depending on the crop's growth stage.

The average cost of this system is about US$ 600/ha. However, prices may vary from US$ 500 to US$ 800 for different locations depending on the land topography and the soil type. For example, in sandy soils, the cost is higher because the number of terminals will increase to meet the water demand of this soil type.

The economic analyses done for different crops grown in other countries have shown that farmers with the Californian system can earn up to US$ 1000-2000 per ha per season more compared to bucket and drip irrigation systems. The net benefit depends on the crop grown and its market price. This makes it possible for them to recover the cost of the system in 2-3 cropping seasons.

Since more than 70% of farmers in SSA are involved in subsistence farming (cultivating less than 2 ha), it would be prudent to promote the Californian system for irrigation because of its low cost. However, scaling up these technologies would require financial and technical assistance from the government, NGOs and/or other development partners. The kick-start provides pumps to farmers on easy installments in Burkina Faso and Ethiopia. NGOs in few other countries (i.e., Kenya) have also helped small farmers with credit facilities. Still, they do not have enough capital to expand and administer such loans on a commercial basis.

To increase accessibility, a reduction in the costs of these irrigation technologies would be inevitable. This objective can be achieved by involving the private sector in the local manufacturing of pumps and related accessories. Private manufacturers would require government support in building their capacity and knowledge for technology development and application into the agriculture sector (FAO, 2011). Improving local pump manufacturing capacity and facilitating imported pumps and spares at affordable costs can increase crop productivity while providing resilience against erratic rainfall patterns in SSA.



5. Introducing small-scale irrigation systems

Enormous conveyance and field application losses characterize irrigation in SSA countries. Due to varying topography and poor land leveling of farmer fields, irrigation efficiencies are low, resulting in poor crop yields and increased soil salinization. Water from the source to the areas is transported through earthen channels, which increases water loss through seepage, especially in sandy soils. The uneven fields are over-irrigated, resulting in uneven plant growth and poor water use efficiency. Under these conditions, the Californian system is more suitable as it can irrigate uneven fields. In addition, different SSI technologies were introduced to grow vegetables at various locations. The solar irrigation pumps were also introduced as a sustainable source of energy. The details of this activity are given below.

5.1 Burkina Faso

Four sites were selected for introducing SSI technologies. These include Nord region with the site of Kouni, the Centre-Nord region with Kora and Zorkoum, and the Auts-Bassins region with the location of Dandé. These sites have producer groups favoring the extension of SSI technologies. At three sites (Kora, Zorkoum, Dandé Dandé), diesel pumps lift water from wells. Due to the high cost, the solar pump system was installed only in the Kouni site of the Nord region. The location of these sites is given in Figure 13.

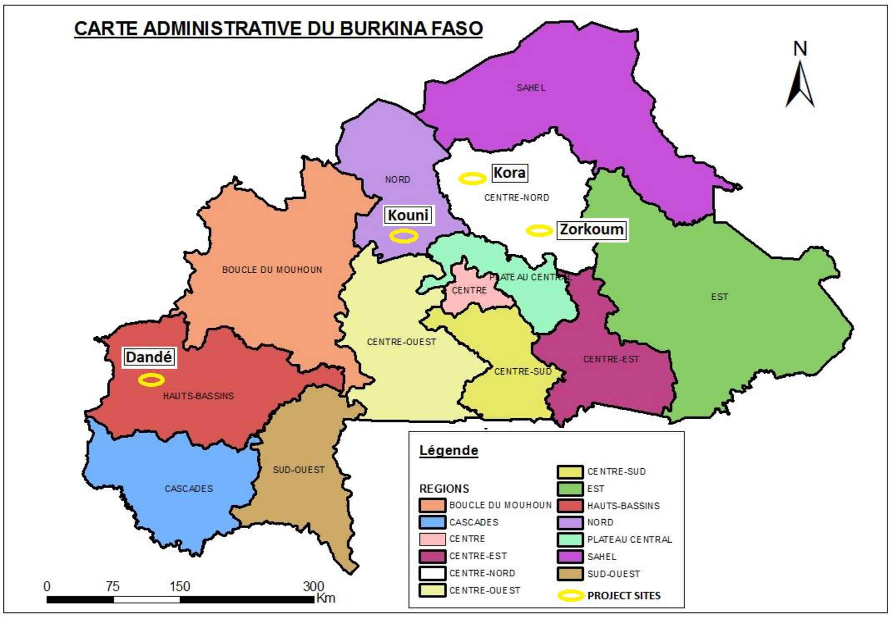


Figure 13. Sites for the introduction of small-scale irrigation technologies

Kouni field site

Californian irrigation system along with a 600W solar pump was installed on a 2500 m^2 site in the Kouni site of the Nord region. The pump has a flow rate of 2.3 m^3/hour and extracts water from a 9m deep well to irrigate different vegetable crops such as onion, eggplant, tomato, and sweet pepper. A group of 15 farmers shares the installed system. The project provided inputs to grow vegetables such as sprays and agricultural inputs (fertilizer, seeds, and pesticides) with the promise that farmers would manage these inputs during the next growing season. The irrigation to the onion field was done using the Californian system. The system got the attention of the local farmers because it has decreased the production cost due to reduced consumption of fuel. The yield of the onion crop achieved through this system was about 33 tons/ha. For large-scale demonstration to get farmers' attention, the project has also installed a Californian system (without a solar system) at three other locations (Dandé, Kongoussi, and Kaya regions), operated using motor pumps.



Dandé field site

The Dandé field site occupies an area of 4600 m². Onion crop was grown using Californian system. A pump (with a capacity of 60 m^3/h) was used to lift water from an open dug well. Several crops were successfully grown under the Californian system.



Zorkoum field site

The Zorkoum site occupies 6000 m², with 5700 m² for onion and 300 m² for tomato. A diesel pump powers the irrigation system. Farmers in the area used irrigation water from Lake Dem. Several crops were grown under the Californian irrigation system in two steps. During the first step, onion, tomato, cabbage, and sweet pepper were cultivated. Then cabbage was grown on an area of 1800 m². The obtained cabbage yield was 70 tons/ha. The onion, tomato, and sweet pepper yields were 25, 20, and 25 tons/ha.

Kora field site

The site of Kora occupies an area of 7500 m² with 5000 m² for green beans, 1500 m² for carrots, and 1000 m² for tomatoes. A diesel motor pump is used for water lifting from Lake Bam through the Californian irrigation system. Onion, green bean, and tomato crops were grown in this field. The crops performed very well. The onion, green bean, and tomato yields were 17, 5, and 23 tons/ha. Field activities at all sites were carried out in collaboration with the local partners. The members of farmer organizations helped in data collection and maintenance, and operation of the system.

5.2 Mali

Under this project, SSI technologies were introduced at three locations. These include Geralo, Koulikoro, and Mopti regions. At the Geralo field site, a solar panel irrigation system and the Californian irrigation system were installed, covering 2400 m^2. A submerged pump is installed to extract groundwater for irrigation. The pump was operated using photovoltaic solar panels (Solar pump). Four photovoltaic solar panels of 250 W each were installed to energize the submerged pump of 3 m^3/hr capacity. During this cropping season, farmers grow cabbage, onion, eggplant, lettuce, tomato, and sweet pepper.

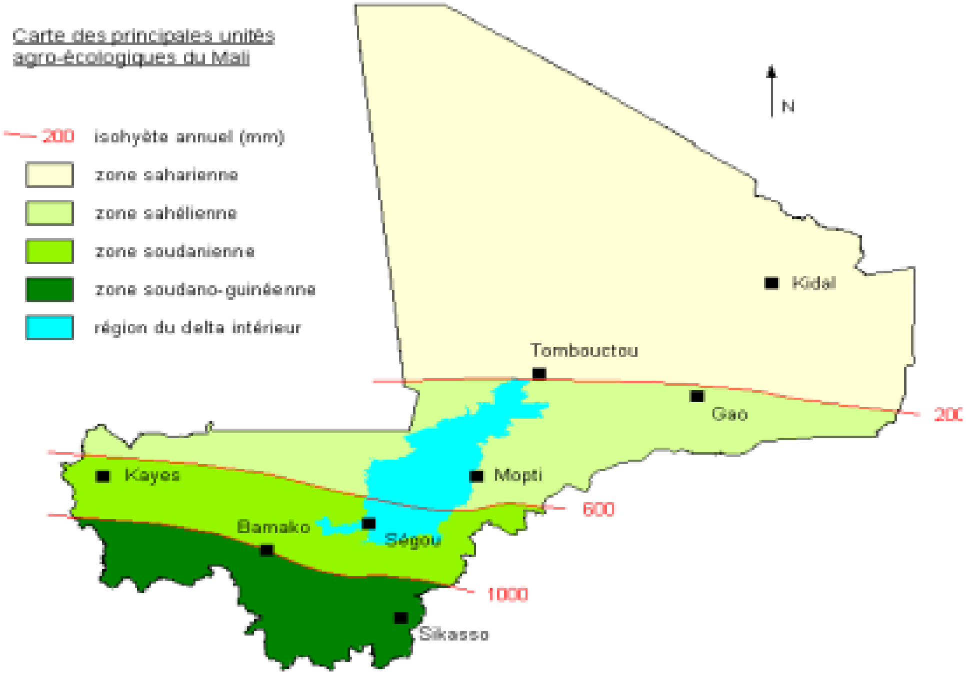


Figure 14. Sites for the introduction of small-scale irrigation technologies

The experimental site was jointly shared and managed by 100 smallholder farmers, including 77 women and 23 men. Each farmer was allotted a small field of 12 m x 2 m (24 m^2), and a schedule to use irrigation water through the Californian system was developed. The project also provided small market gardening equipment for the first growing season consisting of burrows, wheelbarrows, rakes, fittings, sprays, and agricultural inputs (fertilizer, seeds, and pesticides) to smallholder farmers.

The total area of this site was 2400 m^2. The place was managed by 77 women and 23 men at one California water outlet per beneficiary. The area per beneficiary is 24m^2 (12m x 2m). The site is managed by an administrative committee headed by a woman. The beneficiaries and the management were trained to monitor the project activities. At the Koulikoro and Mopti sites, only Californian systems were installed to grow tuber vegetables.

Solar pump at Garalo site

Californian system at Garalo site

The field data at all sites were collected on hydraulic, agronomic, and socio-economic parameters. For this purpose, fact sheets and data collection books have been made available to the agricultural service officer. The agricultural officers were trained in water management, crop management, and repair and maintenance of solar and Californian systems. Filed days were organized to raise awareness among neighboring farmers about gardening techniques, equipment, wheelbarrows, rakes, fittings, sprays, and inputs (fertilizer, seeds, and pesticides) needed to grow vegetables. For all three demonstration sites, farm inputs and equipment were provided by the project. The data on applied irrigation amounts, energy used, crop production, home consumption, and sold-out pieces were collected.

In Mali, the agriculture system is mainly based on small-scale farming, with more than 70% of farmers cultivate less than 4 ha of land and 14% are large farmers cultivating more than 10 ha. Therefore, it would be wise to promote a drip irrigation system for large farmers who can grow high-value crops and recover their investments in drip systems.

The Californian system may be preferred for smallholder farmers because of its low cost and acceptance within the farming community. Government should ensure financial support through policy reforms to encourage wide-scale adoption of this irrigation technology by smallholder farmers. The involvement of the private sector needs to be enhanced to promote local manufacturing of these systems to bring down costs and increase accessibility.

5.3 Niger

Four field sites were selected to demonstrate the Californian system. The first site is in Bonkoukou village in the Tillabery region. This site is 150 km far from Niamey. The town's population is 3,454 inhabitants, including 1,564 men and 1,890 women, divided into 573 households. The soil is rich and suitable to grow tubers, potatoes, and other vegetables. The Bonkoukou is the main potato production area in the Balleyara department. At this site, the Californian system was installed with the solar pump to lift water for the Californian irrigation system. This site is managed by 22 women farmers. At the other three field sites, Californian systems were operated using diesel pumps.

The second site (Salewa village) is in the Dogaraoua in the Tahoua region. It is 80 km far from the Tahoua region. The town has 2435 inhabitants, including 1,270 men and 1,165 women. The soil is rich and is suitable to grow tomatoes, onion, potatoes, and other vegetables. The Dogaraoua field is an excellent site for tomato production in the Tahoua region. Tomato production is the main activity of farmers between October and April. The introduction of varieties adapted in the rainy season is good news for tomato producers. The third site (Balleyara village) is in the Tillabery region (Figure 15). It has a population of 778 inhabitants, including 408 men and 370 women. The soil is suitable to grow crops such as cereals, sorghum, and other vegetables.

The fourth site (Nakoni village) is in the Tahoua region. The town has 1,946 inhabitants, including 1,045 men and 901 women. The soil is ‘’fakara’’ rich and suitable for growing tomatoes, onion, potatoes, and other crops.

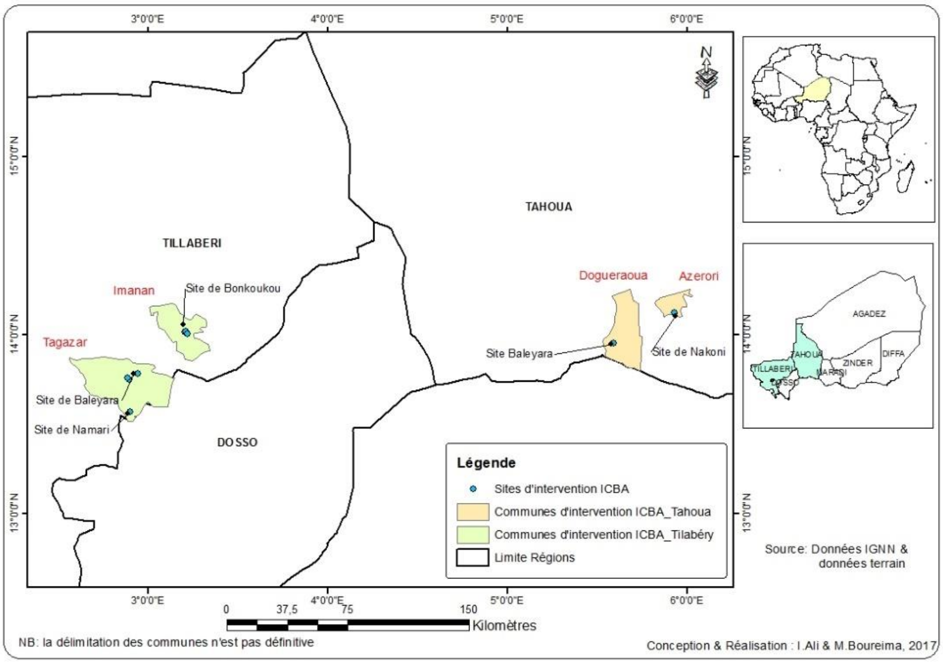


Figure 15. Sites for the introduction of small-scale irrigation technologies

The primary source of irrigation water is dug wells or river water. A Californian system was laid to transport water from the nearby river stream to the fields. Water distribution within the farmer's fields was done through furrows and flexible pipes. Farmers grow different vegetables such as lettuce, cabbage, tomato, onion, and okra. For our experiment, a tomato crop was raised, and the Californian irrigation system results were compared with the traditional bucket method.

Crop yields are generally low due to poor cultural and management practices and poor seed and fertilizer application rates. Farmers preferred the Californian system because of its suitability in controlling water infiltration losses in sandy soils. Water was stored in the tanks and later used for irrigation both for drip and furrow systems. Farmers also use the bucket method for irrigating small vegetable fields, especially those owned by women.



5.4 Senegal

Irrigation in Senegal is usually characterized by substantial water losses due to the high permeability of soils. Due to varying topography and poor land leveling of farmer fields, irrigation efficiencies are low, resulting in poor crop yields and increased soil salinization. Long channels are made in the ground to irrigate elevated portions with the traditional method, increasing water loss through infiltration during water transportation. The water loss is much higher in sandy soils. The capacity of commonly used two-cylinder pumps is meager and unsuitable for irrigation in low flow periods. For this purpose, the Californian irrigation system was selected for demonstration because of its suitability for delivering water in varying topography areas. The possibility of connecting flexible pipes to irrigation terminals makes it easier to irrigate elevated portions of the fields.

Four sites were selected after due consultation with the local partners. These include Sanente, Mbane, Nder, and Mbayene villages on the eastern and western bank of the Guiers Lake (Figure 16). One 0.5 ha farmer field was equipped with the Californian system at each site, and onion crop was grown in all areas. In the Sanent village, a solar system was also installed. The system was operated and shared by 30 women farmers. This helps women avoid the daily hassle of repairing and maintaining diesel pumps and bringing fuel from the nearby market. The main crops grown include maize in the rainy season, onion, tomatoes, sweet potatoes in the cold season, and rice and melon in the dry, hot season.

Figure 16. Sites for the introduction of small-scale irrigation technologies

Californian irrigation system was one of the most promising technologies in the region. Farmers from the nearby villages visited the project site and requested to extend this project to their villages. They agreed to contribute part of the installation cost if any government or private agency helped them get this system for their lands.

Farmers realized differences in the performance of the Californian system and the bucket method. They observed that the Californian system prevents soil compaction and allows soil aeration that helps the growth of shallot bulbs. They also preferred this system because of its low installation cost because most of the material is available in local markets. The life of this system is more than ten years, while the operation and maintenance costs are minimal.

The women farmer group developed their rotational system to irrigate water at regular intervals. The group also elected their president, who looks after the rights of all farmers to ensure that each farmer gets timely delivery of the allocated quantity of water for irrigation. This group developed contacts with the local traders to sell their produce at competitive prices. The project team helped them in the smooth functioning of the system. The data on water use, crop yields, fuel consumption, and income was collected to evaluate this system's technical and economic efficiency compared to traditional methods.



6. Land and water productivity of different irrigation systems

The data collected from the field trials were analyzed to determine vegetable crop water and economic productivities under different irrigation technologies. The performance of the Californian system was compared with the bucket method, drip, and sprinkler systems. The results of data analysis in each target country are presented below.

6.1 Burkina Faso

For this project, two significant crops (tomato and onion) were selected. Onion is grown on 48% of the cultivated area, whereas tomato occupies about 22%. Farmers practice mixed cropping (for example, tomato/maize and onion/maize under irrigation) and the monoculture of tomato or onion. Onion is grown with tomato in biannual rotation. Fertilizer application rates are low (150 kg/ha), which is the primary reason for low crop yields.

In Burkina Faso, 21% of the farmers have motor pumps for gravity irrigation, whereas the rest rely on the bucket irrigation system. The gravity pump irrigation is widely used for onion crops grown on large plots. Women mainly use the bucket system to irrigate small home gardens. In the Kouni site, a drip irrigation system for tomato and a Californian system for onion crops was installed. This site was also equipped with a solar system. The frequency of irrigation depends on the growth stage and soil type. Farmers always irrigate with the bucket method during the seedling stage and move to the Californian system one month later when crop demand increase. During the first month, irrigation frequency was three times a week with bucket method and twice a week with motor pump. The data regarding seasonal irrigation amount applied, crop yields, and water productivity for tomato and onion crops under different irrigation systems is presented in Table 12.

Table 12. Water productivity of vegetables under different irrigation systems in Burkina Faso

Experimental sites/Parameters	*Crop = Tomato*			*Crop = Onion*		
	Gravity method	Bucket method	Californian system	Gravity method	Bucket method	Californian system
Total water applied (m^3/ha)	9950	5270	4820	11750	11190	9863
Crop yield (kg/ha)	20500	16780	18650	16770	15375	15850
Water productivity (kg/m^3)	2.06	3.18	3.86	1.42	1.37	1.60
Economic Productivity ($/$m^3$)	1.03	1.59	1.93	0.71	0.69	0.80
Price of tomato = 0.5 $/kg and onion = 0.5 $/kg						

Table 12 shows that the Californian system conserves the highest amount of water compared to the gravity and bucket method. The total water used under bucket and gravity irrigation systems was 50% and 8.5% higher than the Californian system, respectively. The highest yields were obtained for the gravitational method, followed by Californian and bucket methods. However, yields obtained under the bucket and Californian systems were only 18% and 9% lower than the gravitational method. The water productivity for tomatoes was the lowest for the gravity method, whereas it was highest for the Californian systems. The water productivity of the bucket method was 54% higher than the gravity method, whereas it was 18% lower than the Californian system. Although the average onion yield obtained under the Californian system was only marginally higher than the gravity and bucket method, the amount of water applied for irrigation was 16% lower than these two irrigation systems. This indicates that the Californian irrigation system saves more water without compromising too much on crop yields.

These analyses suggest that farmers should prioritize the drip irrigation system to save irrigation water without compromising crop yields and reducing irrigation costs. However, the initial investment in drip systems (1000–4000 US$/ha) and operational and maintenance costs were a matter of concern for smallholder farmers. Farmers showed interest in the Californian System due to its low cost of installation (US$ 600/ha), ease of operation, and cost-effective operation and maintenance, in addition to significant water saving.

The products from small-scale irrigation are sold in the local market. The buyers come from the nearby big towns and neighboring countries (Ghana, Ivory Coast, Togo, and Benin). Prices are negotiated directly in the fields or the local market, and the products are immediately removed. This system does not benefit farmers because they are forced to sell their products at a low price due to limited access to big markets and a lack of storage facilities. The smallholder farmers from the villages have little access to loans from NGOs, and micro finance institutions to buy inputs (seeds, fertilizers, and pesticides).

Farmers use their income from vegetables, small ruminants (goats, sheep), and poultry to buy farm inputs. Farmers usually do not have extension services except for fields trials carried out by research institutes and NGOs. Therefore, to increase the income of smallholder farmers, greater market access and supply of farm inputs at affordable prices need to be ensured. The increased revenue will enable farmers to invest in SSI technologies to improve land and water productivity, enhance the livelihood, and reduce poverty.

6.2 Mali

In Mali, farmers use manual irrigation methods with calabashes to transport water from the source to the field and watering canes and buckets for water application to crops. Therefore, the performance of drip, sprinkler, and Californian systems was compared with the traditional bucket method. The Geralo site was equipped with a Californian system with a solar pump. The data on total water applied and crop yields for tomato and onion crops under different irrigation systems were analyzed, and the results are presented in Table 13.

Table 13. Water productivity of vegetables under different irrigation systems in Mali

Experimental sites/Parameters	*Geralo Crop = Onion*		*Koulikaro Crop = Potato*		*Mopti Crop = Tomato*	
	Californian	Bucket	Sprinkler	Bucket	Drip	Bucket
Total water applied (m^3/ha)	4100	6240	4260	8700	6300	7920
Crop yield (kg/ha)	22630	16250	16148	16060	48811	30304
Water productivity (kg/m^3)	5.51	2.60	3.79	1.84	7.74	3.82
Economic Productivity ($/$m^3$)	1.38	0.65	1.13	0.55	3.87	1.91
Price of onion = 0.25 $/kg, potato = 0.30 $/kg and for tomato = 0.5 $/kg						

Table 13 shows that the water productivity of drip, sprinkler, and Californian irrigation systems is almost double that of the traditional bucket method. The highest water saving, and yield gains were obtained for tomatoes under drip irrigation. The drip system produced a 38% higher yield and consumed 20% less water than the bucket method. The Californian system had a 28% higher yield and saved 34% water than the bucket method for onion crops. In the case of sprinkler systems, water-saving was the highest (51%) compared to the bucket method; however, potato yield was almost comparable. The economic productivity was highest (3.87 $\$/m^3$) for tomatoes under drip irrigation systems due to higher products and high prices in the market. Like water productivity, the economic productivity of the bucket method was less than half of the three (Californian, drip, sprinkler) irrigation systems.

Farmers much appreciated the drip irrigation system. They stressed the need for wide-scale dissemination of this technology because of its advantages such as uniform distribution of water to plants, water-saving, low labor requirements, better use of fertilizer, and increased crop yields. However, at the same time, they were concerned about the cost of this technology and suggested financial support from the government for its adoption by smallholder farming communities. Farmers felt that the Californian system prevents soil compaction and allows aeration of the soil that provides better crop stand.

In Mali, the agriculture system is mainly based on small-scale farming, with more than 70% of farmers cultivate less than 4 ha of land and 14% are large farmers cultivating more than 10 ha. Therefore, it would be wise to promote a drip irrigation system for large farmers who can grow high-value crops and recover their investments in drip systems. The Californian method is preferred by smallholder farmers because of its low cost and acceptance within the farming community. Government should provide financial support through policy reforms to boost wide-scale adoption of SSI technologies by smallholder farmers. The involvement of the private sector can help local manufacturing of these systems to bring down costs.

6.3 Niger

In Niger, the efficacy of irrigation technologies was tested at two locations in the Bonkoukou field site. This site is in the Sahelian agroecological zone. It is a small village of 573 households and 3500 inhabitants. The soil type was sandy loam suitable to grow multiple crops such as tubers, potatoes, and vegetables. Potato is the primary irrigated crop of this area, practiced on more than 65% of the area. The experiments for this study were conducted in the INRAN research station. Two plots of 500 m^2 each were selected. Each parcel was divided into two sub-plots (250 m^2 each). At the first location, the tomato was planted on drip and furrow system; At the second location, sweet potato was sown using Californian and furrow method.

The primary source of water is dug wells or river. The Californian system was preferred for field trials because of its suitability in controlling water infiltration losses in sandy soils. Water was stored in the tanks and later used for irrigation both for drip and furrow systems. Farmers use the bucket method for irrigating small vegetable fields, especially those owned by women. The data regarding the average seasonal irrigation amount applied, crop yields, and water productivity for Cowpea and tomato crops is presented in Table 14.

Table 14. Water productivity of vegetables under different irrigation systems in Niger

Experimental sites/Parameters	Bonkoukou (Location # 1) *Crop = Tomato*		Bonkoukou (Location # 2) *Crop = Sweet potato*	
	Californian system	Bucket system	Californian system	Bucket system
Total water applied (m^3/ha)	4250	8650	7980	8820
Crop yield (kg/ha)	32900	17735	26794	17200
Water productivity (kg/m^3)	7.70	2.05	3.35	1.95
Economic Productivity ($/m^3)	3.87	1.03	1.67	0.98
Price of tomato = 0.5 $/kg, sweet potato = 0.5 $/kg				

Table 14 illustrates that amount of water applied through the bucket method is 10% higher than the drip irrigation system. In contrast, the yield increases for tomato and sweet potato crops under the Californian system are 25% and 37% higher than the bucket method, respectively. The tomato yield under the Californian system was much higher than the bucket method, whereas the water application for irrigation was almost half of the bucket method. The water productivity of tomatoes for the Californian system was more than three times that of the bucket method. The water productivity of tomato and sweet potato under the Californian system was 46% and 76% higher than the bucket method, respectively.

The economic return per cubic meter of water use was significantly lower for the bucket method compared to the Californian system. The well-being of smallholder farmers is also directly linked with the higher crop yields because this can increase their income to recover investments in the installation of Californian and other irrigation systems. Increased crop production would also require better access to big markets to get the actual value of their produce. The shelf life of crops is minimal, forcing farmers to dispose of them quickly regardless of the price. Therefore, better access to good seeds with training to protect crops for a reasonable time after harvest needs to be given priority to reduce poverty.

In Bonkoukou, good quality potato seed was also supplied to FAO, ensuring higher yields. Similar arrangements should be made for providing seed for other crops such as maize and vegetables. Although 90% of farmers in Bonkoukou use fertilizer on their farms, the fertilizer use rate is much lower than required. According to an estimate, about 50% of farmers only apply inorganic fertilizer, 35% use organic fertilizers, 5% use microelement, whereas 10% do not use fertilizer. This is also one of the primary reasons for low crop yields. The results of this project suggest that, in Niger, provision of good quality seed, appropriate fertilizer amounts, and training on nutrient management is of paramount importance to ensure higher crop yields and livelihood of poor rural smallholder farmers.

6.4 Senegal

For this project, the performance of the Californian irrigation system was compared with the traditional bucket method. For this purpose, three field sites were selected in partnership with the producer organization. These sites were in Nder, Mbane and Mbayene villages. One 0.5 ha farmer field was equipped with the Californian irrigation system at each site, and an onion crop was grown in all areas. The data on applied irrigation volumes, crop yields, irrigation time, and irrigation frequency were collected for the Californian system and the bucket method. The results of the three sites are presented in Table 15.

Table 15. Water productivity of vegetables under different irrigation systems in Senegal

Experimental sites/Parameters	Nder *Crop = Onion*		Mbane *Crop = Onion*		Mbayene *Crop = Onion*	
	Californian system	Gravity method	Californian system	Bucket method	Californian system	Bucket method
Total water applied (m^3/ha)	4680	6720	6240	7200	5520	6480
Crop yield (kg/ha)	11610	7847	13200	9800	11600	6800
Water productivity (kg/m^3)	2.48	1.17	2.11	1.36	2.10	1.06
Economic Productivity ($/$m^3$)	2.98	1.40	2.54	1.63	2.52	1.26
Price of Onion = 1.2 $/kg						

Table 15 shows that the Californian system used 15% to 25% less water at all three sites than the bucket method. The Californian system produced a 48% higher yield and used 44% less water than the furrow method. Similarly, the Californian system and the bucket method noted 25% to 40% yield increases. The irrigation frequency for the Californian system was 5-7 days compared to 3-5 days for the manual systems. Differences in yields are related to soil characteristics and crop management practices of farmers at three sites. The water and economic productivities achieved under the Californian system are almost double the traditional techniques, which shows the superiority of this system over other systems.

The experimental results and the feedback from farmers suggest that the Californian irrigation system has advantages that justify its recommendation for other areas. The average cost of the Californian system is around US$ 1200 per ha, which is not affordable for most smallholder farmers. Therefore, wide-scale adoption of this system would require financial and technical support to farmers. For these experiments, the project provided good onion seed, which produces higher yields than neighboring farmer fields. This resulted in higher economic returns for farmers, and they spent this money to expand the Californian system in other areas. This implies that the economic viability of this system is linked with higher yields, which can be achieved by supplying good seeds to the farmers.

The results obtained from all partner countries reveal that Californian and drip irrigation systems performed significantly better in water use efficiency and crop yields than traditional furrow and bucket methods. On average, Californian and drip systems' economic and water productivity was two to three times higher than the conventional irrigation systems. Farmers showed great interest in these systems and were ready to adopt them to increase their agricultural productivity. The farmers were seriously concerned about the cost of the drip system and the operational and maintenance costs (US$ 2000-4000/ha). In contrast, the Californian system was cheaper to install and easy to maintain (US$ 600-1000/ha) because most of the material and skills are locally available.

Despite a solid wish to adopt this system, lack of capital was reported as the biggest problem. Therefore, there is a strong need to make concerted efforts to support farmers both financially and technically. Along with these irrigation systems, farmers should be provided with improved crop seeds and market access to maximize their economic returns. This will increase their incomes, enabling them to extend these technologies to more extensive areas using their financial resources.

7. Crop water requirements and irrigation schedules

7.1 Burkina Faso

The crop water requirements of vegetables were calculated using climatic data from local meteorological stations for all field sites. FAO's ClimWat 2.0 was used to generate climate data for two field sites. In contrast, FAO's CropWat 8.0 software developed data regarding effective rainfall, crop coefficient (Kc), soil hydraulic parameters, and crop calendar (Table 16).

Crop water requirements (ET_c) were calculated using the following equation.

$$ET_c = K_c * ET_0$$

K_c = crop coefficient; ET_o = reference evapotranspiration estimated by modified Penman-Monteith equation; P_{eff} (mm): the effective rainfall was calculated by "FAO / AGLW Method".

$$IRn = K_c * ET_C - P_{eff}$$

Table 16. Crop coefficients at different development stages of vegetables (FAO, 1986)

Crops		Development stages				Period (day)	Maximum Rooting depth (m)
		Initial	Development	Mid season	Late season		
Tomato	Kc	0.45	0.75	1.15	0.8	145	0.7 – 1.5
	period (day)	30	40	45	25		
Pepper	Kc	0.75	1.05	1.05	0.8		0.3 - 1
	period (day)	35	45	45	30	150	
Cabbage	Kc	0.45	0.75	1.05	0.9	120	0.4 – 0.5
	period (day)	20	25	60	15		
Onion bulb	Kc	0.5	0.7	1.0	0.8	155	0.3 – 0.5
	period (day)	35	45	45	30		
Green bean	Kc	0.5	1.05	1.05	0.9	90	0.7
	period (day)	20	30	30	10		

Table 17. Monthly ETo values in the Bobo-Dioulasso region

Month	Min Temp.	Max Temp	Humidity %	Win km/day	Sun hours	Rad. MJ/m²/day	ETo mm/d
January	18.4	32.4	18	277	8.1	19.1	7.26
February	21.2	34.5	20	277	7.9	20.1	7.81
March	23.6	36	*26*	277	7.6	20.8	8.11
April	24.3	35.5	47	311	6.3	19.2	7.25
May	23.5	34	60	328	7	20	6.44
June	21.8	31.4	71	311	6.8	19.4	5.25
July	21.1	29.7	78	277	5.9	18.1	4.38
August	20.8	29	83	242	4.5	16.2	3.69
September	20.7	29.5	80	207	57	17.9	3.98
October	21.4	33	67	216	7.3	19.5	5.03
November	20.3	33.9	44	199	7.9	18.9	5.69
December	18.5	32.5	25	233	7.8	18.2	6.36
Mean	21.3	32.6	52	363	6.9	18.9	5.94

The average monthly ET_o in the Bobo-Dioulasso region was 5.94 mm/d. The lowest ET_o was observed during August (3.69 mm/d) and the highest during March (8.11 mm/d) (Table 17).

The average ET_o in the Ouahigouya region was found to be 5.56 mm/d. The lowest ET_o was observed during August (4.55 mm/d) and the highest during May (7.08 mm/d) (Table 18).

Table 18. Monthly ETo values in the Ouahigouya region

Month	Min Temp	Max Temp	Humidity %	Win km/day	Sun hours	Rad. MJ/m²/day	ETo mm/d
January	15,9	32,7	25	156	8,1	18,5	5,16
February	18,4	35,9	22	156	8,7	20,8	5,89
March	22;1	38,4	22	156	8	21,2	6,47
April	25,6	40,3	30	156	7,7	21,4	6,80
May	26,7	39,8	44	190	8	21,6	7,08
June	24,9	36,9	60	190	8,1	21,5	6,21
July	23,1	33,5	71	164	7,6	20,8	5,16
August	22,5	32,3	80	138	7,2	20,4	4,55
September	22,6	33,4	79	130	7,5	20,6	4,60
October	22,6	37,1	60	104	8,5	20,8	5,06
November	18,7	36,2	39	112	8,8	19,6	4,97
December	16,3	33,3	30	130	8,2	18	4,73
Mean	21,6	35,8	47	148	8	20,4	5,56

Net water requirements of different vegetables at different field trial sites is given below:

- The net water requirement for tomatoes is 7055 m^3/ha; 7055 m^3/ha; 7120 m^3/ha, and 8692 m^3/ha for Zorkoum, Kouni, Kora, and Dandé sites, respectively.
- The net water requirement for cabbage is 7722 m^3/ha; 7722 m^3/ha; 8331 m^3/ha and 10757 m^3/ha for Zorkoum, Kouni, Kora, and Dandé sites, respectively.
- The net water requirement for peppers is 7781 m^3/ha; 7781 m^3/ha; 7851 m^3/ha and 9879 m^3/ha for Zorkoum, Kouni, Kora, and Dandé sites, respectively.
- The net water requirements for the pepper are 9588 m^3/ha; 9588 m^3/ha; 9815 m^3/ha, and 12662 m^3/ha for the Zorkoum, Kouni, Kora, and Dandé sites, respectively.

Net water applications to different vegetables at different project field sites is given below:

- The amount of water applied for tomatoes is 10,079 m^3/ha in Zorkoum and Kouni areas, whereas it was 12,417 m^3/ha in Dandé and 10,175 m^3/ha in Kora area.
- The amount of water applied for cabbage is 11,030 m^3/ha in Zorkoum and Kouni areas, whereas it was 14,533 m^3/ha in Dandé and 11,901 m^3/ha in Kora areas.
- The amount of water applied for peppers is 11,161 m^3/ha in Zorkoum and Kouni areas, whereas it was 14,113 m^3/ha in Dandé and 11,216 m^3/ha in Kora areas.
- The amount of water applied for the onion bulb was 9,588 m^3/ha in Zorkoum and Kouni areas, whereas it was 12,662 m^3/ha and 9,815 m^3/ha for Dandé and Kora areas.

Due to water shortage, farmers intentionally under-irrigate their fields to irrigate more area with the available water. The water application can be significantly reduced by using drip, sprinkler, and the Californian system. Therefore, it is suggested that farmers use advanced irrigation methods to optimize their crop yields with the minimum water use. As most of the irrigation water is pumped from surface streams or groundwater, lower water use for irrigation will decrease their production cost and increase farm income.

7.2 Mali

Field trials were established for the Californian irrigation system driven by a diesel pump in all field sites. However, all other activities were carried out in these locations as well. These include farmer training, organization of farmer field days, calculations of crop water requirements, and supply of inputs. During the farmer field days, local manufacturers were invited to contact with the farmers interested in installing this system on their lands. These manufacturers informed farmers about the cost and accessibility of these systems.

The actual crop water requirements of different vegetable crops grown in these locations were calculated using locally available climatic data to educate farmers about improving water use efficiency. This information was passed on to farmers for use in their experiments. Tables 19-22 show crop water requirements and irrigation schedules for the gardening crops grown in the Koulikoro and Mopti regions. Thus, in the Koulikoro region, the daily water requirements of fruit vegetables under drip irrigation from January to April vary from 5 to 7.5 mm/d. The daily irrigation rate is from 2 to 4 m^3/day. In the same region (Koulikoro), tuber vegetables are grown from January to March under the spray, crop water requirements range from 2.40 to 7 mm/d for daily irrigation rates of 3 to 8 mm/day.

In the Mopti region, daily irrigation rates to meet the water requirements of all garden crops during the periods from September to December and then from November to February vary from 4 to 8 mm/day.

Table 19. Water requirements of vegetables in the Koulikoro region

Parameters	January			February			March			April		
Decade (days)	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
PET (mm/day)	4,7	4,7	4,7	6	6	6	6,6	6,6	6,6	6,6	6,6	6,6
KC	1,25	1,25	1,25	1,25	1,25	0,9	0,9	0,7	0,7	0,7	0,7	0,7
S (ha)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Need Crop water (mm/day)	5,88	5,88	5,88	7,50	7,50	5,40	5,94	4,62	4,62	4,62	4,62	4,62
Total water required (m^3/day)	3,08	3,08	3,08	3,94	3,94	2,84	3,12	2,43	2,43	2,43	2,43	2,43
Adjusted Irrigation Dose (mm/day)	6,17	6,17	6,17	7,88	7,88	5,67	6,24	4,85	4,85	4,85	4,85	4,85
Rainfall system or speed (mm/h)	3,33	3,33	3,33	3,33	3,33	3,33	3,33	3,33	3,33	3,33	3,33	3,33
System speed; Rainfall (m^3/h)	1,67	1,67	1,67	1,67	1,67	1,67	1,67	1,67	1,67	1,67	1,67	1,67
Duration of irrigation (h/day)	1,9	1,9	1,9	2,4	2,4	1,7	1,9	1,5	1,5	1,5	1,5	1,5
Irrigation time	1h 54 mn	1h 54 mn	1h 54 mn	2h 24 mn	2h 24 mn	1h 42 mn	1h 54 mn	1h 30 mn	1h 30 mn	1h 30 mn	1h 30 mn	1h 30 mn
Adjusted irrigation (m^3/day) or 1000 liters per day and by irrigation	3	3	3	4	4	3	3	2	**2**	**2**	**2**	**2**

Table 20. Irrigation schedules of vegetables in the Koulikoro region

Parameters	January			February			March		
Decade (day)	1	2	3	1	2	3	1	2	3
PET (mm/day)	4,7	4,7	4,7	6	6	6	6,6	6,6	6,6
KC	0,5	0,5	1	1	1,1	1	1	0,5	0,5
S (ha)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Need of plant in water (mm/mn)	2,35	2,35	4,70	6,00	6,60	6,00	6,60	3,30	3,30
Adjusted Irrigation Dose (mm/day)	2,82	2,82	5,64	7,20	7,92	7,20	7,92	3,96	3,96
System rainfall (mm/h)	8,62	8,62	8,62	8,62	8,62	8,62	8,62	8,62	8,62
Irrigation duration (h/day)	0,33	0,33	0,65	0,84	0,92	0,84	0,92	0,46	0,46
Irrigation duration (mm/day)	20	20	39	50	55	50	55	28	28

Table 21. Water requirements for different vegetables in the Mopti region

Decade	September			October			November			December		
	1	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***
ETP (mm/day)	4,9	4,9	4,9	4,7	4,7	4,7	4,7	4,7	4,7	4,1	4,1	4,1
Hydraulic Parameters												
Irrigation dose (m^3/day/ha)	37	37	58	57	78	78	78	78	78	61	61	49
Irrigation dose (mm/day/ha)	4	4	6	6	8	8	8	8	8	6	6	5
Irrigation duration (hour/day/ha) with motor-pump de 36 m^3/hour	2	2	3	3	4	4	4	4	4	3	3	3
Irrigation duration (hour/day/ha) motor pump de 35 m^3/hour	2	2	3	3	4	4	4	4	4	3	3	3
Irrigation dose (liters/2 days/ha) with pump motor 36 and 35 m^3/hrs.	73 000	73 000	116 800	113 806	156 484	156 484	156 484	156 484	156 484	121 935	121 935	97 548
Irrigation dose (liter/2 days) on an average elementary area of 0.42 m^2 (70 cm x 60 cm)	3	3	5	5	7	7	7	7	7	5	5	4
Irrigation dose (liter/2 days) on an average elementary area of 50 m^2 (25m x 2m)	365	365	584	569	782	782	782	782	782	610	610	488
Duration of irrigation (minute/day) for an irrigation frequency of 2 days with a motor pump of 36 m^3/hour on an area of 50 m^2	1	1	2	2	3	3	3	3	3	2	2	2
Duration of irrigation (minute/day) for an irrigation frequency of 2 days with a motor pump of 35 m^3 / hour on an area of 50 m^2	1	1	2	2	3	3	3	3	3	2	2	2

Table 22. Irrigation schedules for vegetables in the Mopti region

Decade	November			December			January			February		
	1	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***
ETP (mm/day)	4,7	4,7	4,7	4,1	4,1	4,1	4,6	4,6	4,6	5,6	5,6	5,6
Hydraulic Parameters												
Irrigation dose (m^3/day/ha)	35	35	56	49	67	67	76	76	76	84	84	67
Irrigation dose (mm/day/ha)	4	4	6	5	7	7	8	8	8	8	8	7
Irrigation duration (hour/day/ha) with motor-pump de 36 m^3/hour	2	2	3	3	4	4	4	4	4	5	5	4
Irrigation duration (hour/day/ha) motor pump de 35 m^3/hour	2	2	3	3	4	4	4	4	4	5	5	4
Irrigation dose (liters/2 days/ha) with pump motor 36 and 35 m^3/hrs.	70 500	70 500	112 800	97 548	134 129	134 129	151 161	151 161	151 161	167 143	167 143	133 714
Irrigation dose (liter / 2 days) on an average elementary area of 0.42 m^2 (70 cm x 60 cm)	3	3	5	4	6	6	6	6	6	7	7	6
Irrigation dose (liter / 2 days) on an average elementary area of 50 m^2 (25m x 2m)	353	353	564	488	671	671	756	756	756	836	836	669
Duration of irrigation (minute / day) for an irrigation frequency of 2 days with a motor pump of 36 m^3 / hour on an elementary area of 50 m^2	1	1	2	2	2	2	3	3	3	3	3	2
Duration of irrigation (minute / day) for an irrigation frequency of 2 days with a motor pump of 35 m^3 / hour on an elementary area of 50 m^2	1	1	2	2	2	2	3	3	3	3	3	2

7.3 Niger

Under this project, actual crop water requirements to grow different vegetable crops in different regions have been calculated using locally available climatic data. This information is provided to the local farmers, irrigation technicians, and extension workers to educate farmers. Training has also been organized to calculate crop water requirements to develop this information for other crops grown in the area. This information is vital for smallholder farmers because they are still using traditional irrigation methods based on the philosophy of "*more water more crop*" instead of "*more crop per drop*". The project team developed extension material in the local languages to educate them on crop water requirements for different vegetables.

7.4 Senegal

In the Sanente village, a small meteorological station was installed to collect climatic data to calculate actual crop water requirements and irrigation scheduling of different crops.

Installation of weather station in the Sanente village

In the Niayes zone, minimum and maximum potential evapotranspiration (Penman) values are estimated to be ~ 4.5 mm day^{-1} during the dry, calm, and 6 mm day^{-1} during the warm season. The minimum and maximum values of crop evapotranspiration (ET_{max} and ET_{min}) of the most grown crops in the Niayes zone are given in Table 23.

Table 23. Evapotranspiration values of different crops in Niayes zone of Mali

Crop	Kc-min (-)	Kc-max (-)	ETmin (mm day^{-1})	ETmax (mm day^{-1})
Tomatoes	0.7	1.15	3.2	6.9
Onion	0.7	1.05	3.2	6.3
Cabbage	0.7	1.05	3.2	6.3
Carrot	0.7	1.05	3.2	6.3
Eggplant	0.7	1.05	3.2	6.3
Sweet potato	0.7	1.15	3.2	6.9

In the Sanente village, climate data were used to develop irrigation schedules, which can be used in other farmer fields such as the Women Farmer Group and producers in a nearby village like Mbane, Nder, and Mbayene western bank of the Gueirs Lake. Data obtained from this station was used to determine irrigation amounts for pepper for three-day scheduling (Table 24).

Table 24. Irrigation requirements of Pepper with a three days schedule

Date	ETo (mm)	ETc (mm)	Adjusted Water Deficit (mm)	Net Irrigation Water demand (mm)	Gross Irrigation Water demand (mm)	Irrigation duration (min)
01/11	4.57	2.74	5.25	0	0	0
02/11	4.39	2.63	7.88	0	0	0
03/11	3.08	1.85	9.73	0	0	0
04/11	4.55	2.73	10.5	10.5	12.35	247
05/11	4.68	2.81	2.81	0	0	0
06/11	4.28	2.57	5.38	0	0	0
07/11	4.74	2.84	8.22	8.22	9,67	193.4

In Senegal, ISRA has also developed a simple model for calculating crop water requirements based on the global climatic data, which can be accessed free of cost. This model was shared with the researchers in the other three countries to calculate crop water requirements in their respective locations. The model is still not available to farmers as it has copy rights.

8. Economic analysis of different irrigation systems

8.1 Benefit-Cost ratio of different crops

A detailed study was conducted to calculate the benefit-cost ratio of different crops grown under different irrigation systems in Mali. The capital cost of irrigation systems was calculated at the prevailing market rate. The summarized results on running cost, duration to maturity, yield, and market information in the production of potatoes, tomatoes, and shallots in the various irrigation systems are presented in Table 25.

Table 25. Production costs and prices of vegetables (*1 US$ - 500 FCFA*)

Parameters	Crops	Tomato	Potato	Shallot
Running costs	Seeds	399,916	750,200	150,150
	Manure	125,400	125,000	120,000
	Fertilizers	150,050	212,540	206,420
	Pesticides	95,000	175,127	70,564
	Labor	250,000	415,625	350,061
	Transportation	125,000	125,000	115,372
	Other costs	2,530	5,050	3,040
Duration to maturity and yield	Vegetative cycle (month)	2 to 3	3 to 4	3 to 4
	Yield (t/ha)	10 to 40	25	70
Marketing	Producers (Fcfa/kg)	150	125 to 275	100
	Market (Fcfa/kg)	500	156 to 533	400
Return	Gross (Fcfa/ha)	37,500,000	34,450,000	112,000,000
	Net	36,377,500	32,644,375	110,992,000

The discount rate used must be the real interest rate. The present value of the benefits and costs are discounted at 13% back to time zero since the interest rate on long-term bonds is 18% and the inflation rate is 5%. The results of BCR of the three irrigation systems for different vegetables are given in Table 26.

Table 26. Comparison of BCR of the different irrigation systems for vegetables

Benefi-Cost Ratio (BCR)				
Irrigation systems	Potatoes	Shallots	Tomatoes	Mean
California system	1.899	2.124	2.147	2.086
Drip irrigation system	1.964	2.825	2.948	2.579
Sprinkler irrigation system	1.727	2.252	2.375	2.118

(Calculated F-Value (4,269) = 11.15, P-value = 0.001, Critical F-Ratio (2,267) = 3.03)

Table 26 shows that the BCR of all irrigation systems (California, Drip, and Sprinkler) is greater than unity (1), which implies that they lead to greater benefits than costs. The advantages compared to costs are highest in the drip system (BCR = 2.579), followed by sprinkler (BCR = 2.118) and the California system (2.086). The test of differences in average BCR of the various irrigation systems was performed using one-way ANOVA. The calculated F-value of 11.15 was more significant than the Critical F-ratio of 3.03. This implies that the average BCR for the selected irrigation systems differed significantly from the drip (2.579), yielding the highest BCR scores. This was followed by Sprinkler (2.118) and Californian (2.086), respectively.

The BCR analysis was also done for cabbage for the Garalo site, where the Californian system was installed with the solar pump. The irrigation systems used in this area include buckets and watering canes adopted by 31% of the market gardeners and the Californian system adopted by 69% of the market gardeners. The comparison was made for one hectare of land. Table 27 presents the results of benefit-cost analysis for cabbage.

The total operating expenses for the bucket system (585,883) were 21% higher than the Californian irrigation system (457,586). The crop yield with the Californian system was 143% higher than the manual system. The net margin with the Californian irrigation system was FCFA 4,959,334 compared to FCFA 1,362,061 for the manual irrigation system. The net margin per kg was FCFA 158 for Californian system compared to FCFA 106 for the manual irrigation system.

The results show that the benefits of growing vegetables under the Californian system are much higher than the common practice of manual irrigation systems. The production cost of cabbage manual irrigation system was FCFA 45 per kg compared to only FCFA 15 per kg for the Californian irrigation system. This clearly shows that farmers can earn up to three times more profit by growing vegetables by adopting the Californian system, mainly due to lower production costs. In addition, farmers are relieved of the hassle of bringing fuel for pumps from nearby towns and maintaining pumps over time. This way, farmers can save plenty of time, which can be utilized in other farm activities.

Adopting drip, sprinkling, and Californian technologies ensure that crops do not suffer from the water stress and help grow high yielding crop varieties due to consistent irrigation water supply. When irrigation farming is practiced, the outcome is credited with increased production and timely yields that can fetch better prices. These technologies are more likely to lead to more significant benefits than costs because irrigation and the simultaneous expansion of irrigated area results in numerous direct and indirect benefits.

Irrigation helps to increase agricultural production by two to three times higher. It helps to better utilize the land for agriculture. Farmers can also benefit from high-valued cash crops whose supply usually is not uniform throughout the year. The yields are stable and reliable from the irrigated fields, and assured production targets can be met. There are reduced fluctuations in the year-to-year products and the risk of crop failure due to drought. Irrigation allows for continuous cultivation.

Table 27. Comparison of BCR for cabbage for Californian and manual irrigation systems

Categories	All values in FCFA	
	Manual irrigation system	Californian irrigation system
Cost of seed	49,741	65,853
MIneral fertilizer	43,517	47,298
Organic fertilizer	43,586	41,533
Herbicides	8,977	10,768
Insecticides	12,000	15,939
Petrol cost	67,500	0
Engine oil cost	33,712	0
Operational cost	141,850	119,195
Irrigation water cost	140,000	112,000
Soil preparation costs (plowing, spreading, harrows, etc.)	25,000	25,000
Maintenance cost	20,000	20,000
Total operating expenses	**585,883**	**457,586**
Sales price per kg	188	188
Total yield (kg)	**12,888**	**31,340**
Value of production	2,422,944	5,891,920
Gross margin	**1,837,061**	**5,434,334**
Amortization	475,000	475,000
Net margin	**1,362,061**	**4,959,334**
Charges par Kg	45	15
Net margin par Kg	106	158

8.2 Economic efficiency of the motor pump and solar pump

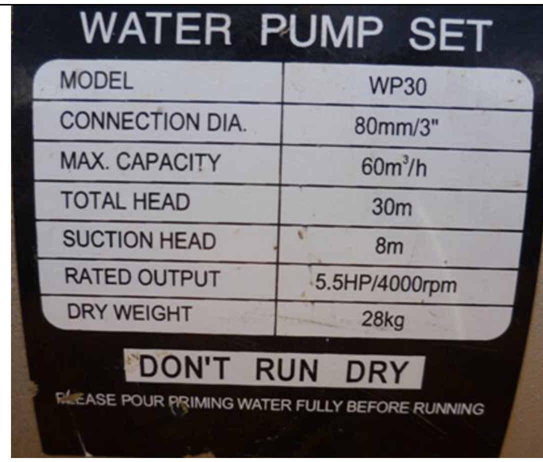
The technical and economic efficiency of a motor and solar pump was evaluated at Dandé site. The motor pump is used for gravity irrigation, whereas the Californian system with solar pump was the project intervention. The data for this study were collected from an onion field.

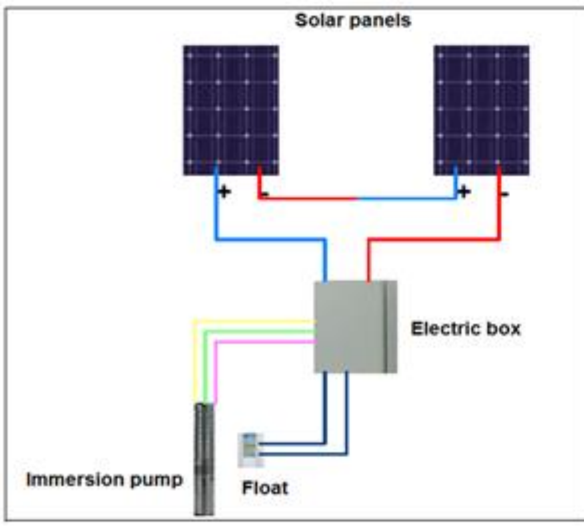
Irrigation with motor pump

- Water availability with motor pump is 60 m^3/h. The flow rate can reach up to10 m^3/h.
- The irrigable area is 428 m^2/h (0.0428 ha/h) or 3424 m^2/day with 8 hours of pumping.
- The maximum volume of water pumping is 480 m^3/day in 8 h of operation
- The net dose measured by the irrigator is 233 m^3/ha.
- The fuel consumption by pump is 1.5 liter/hour (FCFA 1050/hour or $1.76/hour).

Irrigation with solar pump

- The lifting system is a LORENS solar pump with an average flow rate of 1.25 m^3/h between 8-12 am and 2.1 m^3/h between 12 - 3.30 pm.
- The irrigable surface area in one hour is 68.5 m^2/h or 522 m^2/day (8 hours of pumping).
- The probable pumping volume per day is 12.8 m^3.
- The net dose measured by the irrigator is 233 m^3/ha.





Solar pump LARENS
- Model: 4LARS2.3/85-60/600
- Voltage: 60 V
- Power: 600 W
- Current: 10 A
- Outlet: 0.75
- Max Head: 85 M
- Max Flow: 2.3 M^3/H

Flow rate and pumping cost with motor pump and solar pump

The maximum water supplied by the solar system is 12.2 m^3/day or 366 m^3/month, with 8 hr/day pumping in the peak water-demand period.

A comparison of farmers' irrigation practice with motor and solar pumps is given in Table 28.

Table 28. Comparison of motor and solar pumps

	Farmer practice (with motor pump)	Irrigation practice (with the solar system)
Water flow	Constant flow rate of 10 m^3/h, but can go up to 60 m^3/h.	Flow rate varies with sunshine
Area irrigated (m^2/h)	428	65.2
Area irrigable (m^2/day)	3424 (8 h of pumping)	521.6 (8 h of pumping)
Irrigation time per day	8 h/day operation with possibility to irrigate at any time during day.	8 h/day with no possibility to irrigate during low sunshine and night.
Total water lifting per day	480 m^3	12.17 m^3

Table 29. Advantages and disadvantages of motor and solar pumps

	Solar pump	Motor pump
Advantages	No fuel charge	• High flow rate • Low cost of ownership ($168/pump motor pump)
Disadvantages	• High acquisition cost of the motor pump and solar plates ($2,837) • Low flow rate for sheet irrigation • Risk of equipment theft	High fuel charge

The solar pump for water lifting can reduce production costs and improve food security and farmers' income. However, because of extreme poverty, only projects can currently equip farmer fields with solar pumps. The average price of a motor pump is US$ 168 compared to US$ 2,837 for a 2.3 m^3/h solar pump. The solar pump remains a technology currently inaccessible to farmers without the support of state or project subsidies. Therefore, government support would be needed to support the adoption of solar pumps by smallholder farmers. The local production of solar pumps may help in reducing costs. For this purpose, the private sector can play an important role; therefore, their involvement should be encouraged.

9. Knowledge sharing and capacity building

9.1 Burkina Faso

During this project, several technical training and field demonstrations for farmers and extension workers were organized at the project locations. Farmers were briefed about different aspects of the Californian irrigation system and the working of the solar pump. Farmers (especially women) took a keen interest in these systems and asked to extend this facility in their areas. Farmers reported that the most significant advantage of these systems was that it makes crop production possible in the dry period of the year. The primary concern reported by farmers was the cost of solar pumps, which is beyond their reach. The farmers showed a willingness to pay back loans if they were provided loans on easy interest rates from the government or other funding agencies. The group discussion with farmers reveals that the government should facilitate the access of SSI technologies to farmers. These may include:

- The rehabilitation of irrigation and drainage systems in the country.
- Facilitate farmers' access to equipment (motor pump, piping, solar pumps, drip systems) through subsidy or soft loans.
- The market companies may set up processing units and storage facilities for vegetables as they are highly perishable.



Farmer Field Days at different locations in Burkina Faso

9.2 Mali

This project has been included in the National Proximity Irrigation Program (PNIP) of Mali, which focuses on strengthening the resilience of rural populations against climate change, youth migration, and food insecurity in the country. This is being done by equipping 80% of the farmers with SSI technologies. In this context, market gardening plays a vital role in diversifying the peoples' dietary habits and increasing the producers' income. This justifies an increase in areas planted with the SSI technologies for vegetable production. During the project, it was realized that the direct involvement of neighboring farmers was helpful to get them enthusiastic about this project and expressed their wish to extend this project's scope to other areas.

Several technical training and Farmer Field days (FFDs) were organized at different sites in Mali. Farmers, especially women, took a keen interest in the training and field demonstration, as they are mainly involved in small-scale irrigation to home gardens. Farmers were more attracted to the Californian system due to low cost and ease of maintenance. Since most of the material used in this system is locally available, farmers do not have to engage sale agents to access these systems. Training on micro-irrigation systems and good water management practices for farmers were also organized.

Farmer Field Days at the Garalo site in Mali.

9.3 Niger

The technical expertise about small-scale irrigation technologies in Niger is limited. Therefore, the project organized several training and field demonstrations for farmers. During these events, farmers can discuss their issues with the experts and learn from other farmers. Apart from the training, farmers are also involved in monitoring solar pumps to evaluate their technical and economic feasibility before they can be propagated on a large scale. One of the main problems is that the initial installation cost of these pumps is high and beyond the economic reach of smallholder farmers. If proved successful, the government must develop a policy to financially support farmers through subsidies or interest-free loans to buy these pumps. Meetings with policymakers were also arranged to discuss possible incentives for the farmers.

Farmer Field Days at different locations in Niger.

9.4 Senegal

The knowledge sharing and capacity building activities carried out in Senegal were as follows:

1. Technical training on on-farm irrigation and water management
2. Specialized training on soil and crop management
3. Training on the installation, operation, and maintenance of different irrigation systems
4. Special training for women on seed cleaning, storage, and preservation

These training events were attended by farmers, extension workers, and irrigation technicians. The training courses were articulated around different modules covering different aspects of irrigation management. The modules were based on theoretical lectures, class exercises, field visits, and brainstorming/discussion sessions.

Farmer Field Days (FFDs) were also organized to disseminate project outcomes to larger farming communities. Farmers of the neighboring villages attended these FFDs. They were keen to learn about new irrigation and soil and crop management techniques to improve agricultural productivity. Farmers were introduced to local manufacturers to get first-hand information about the availability of material for installing these systems, along with the costs.

Farmer Field Days at different locations in Senegal

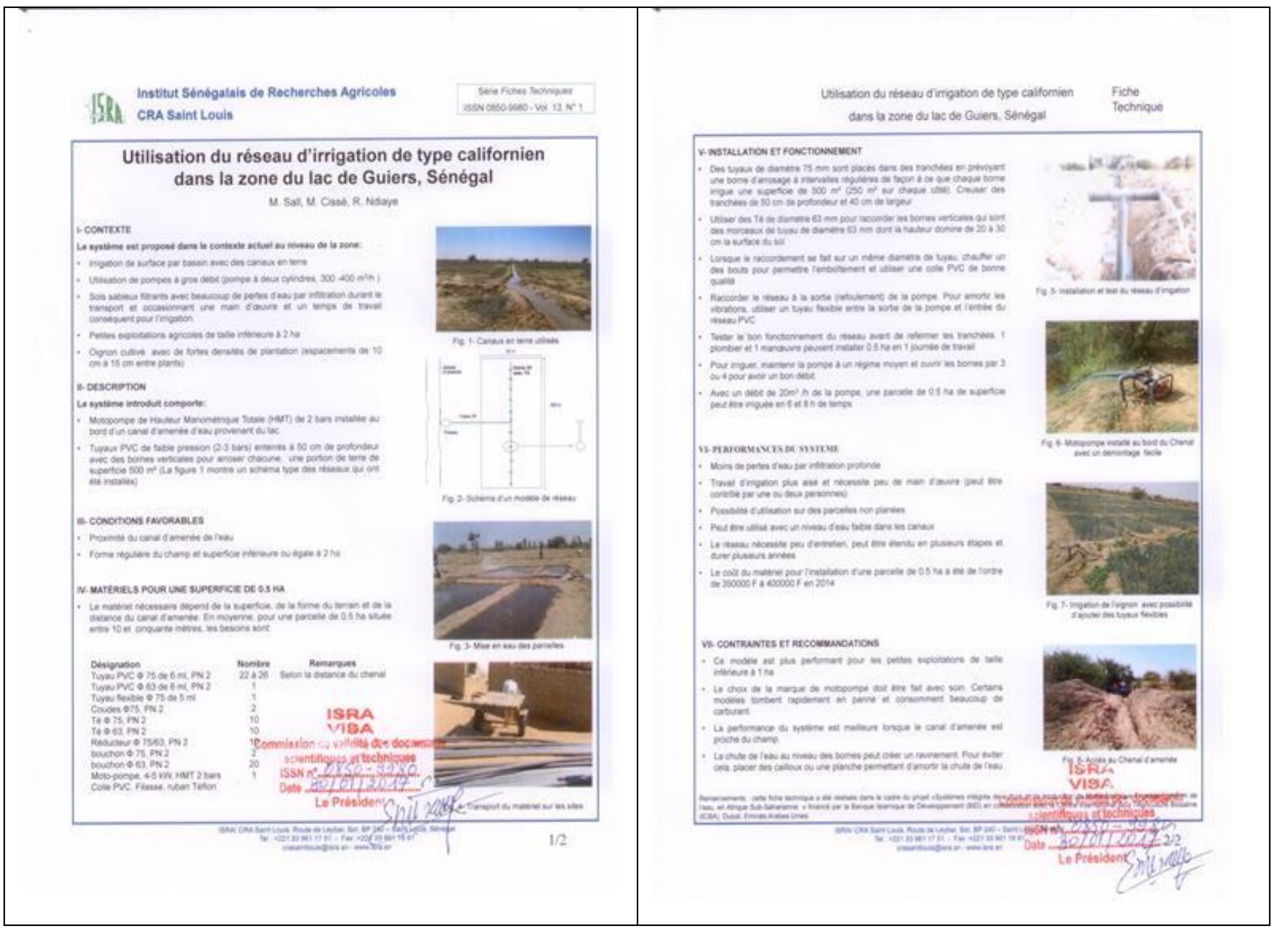
During the project's life, 920 extension workers and irrigation experts were trained in the target countries. For the training of farmers, 20 farmer field days were organized at regular intervals. Farmers were educated on SSI technologies and solar systems. During the field demonstration, 11,475 farmers visited trial sites to get information about these technologies.

The field survey shows that the Californian system was installed at more than 50,000 ha in all four target countries. This coverage may be higher as we surveyed the only limited area in each country. The adoption of the solar system was low due to its cost. A summary of the involvement of farmers in training, field demonstrations, and scaling up is given in Table 30.

Table 30. Summary of trainings and field demonstrations organized during this project

Project activities	Burkina Faso	Mali	Niger	Senegal	Total
No. of extension workers trained	220	272	204	224	920
Farmers attended field demonstrations	2875	3000	2750	2850	11,475
Adoption of Californian system (ha)	12,000	15,275	10,680	14,530	52,485
No. of FFSs established	4	5	6	5	20
No. of training materials developed	2	2	1	2	7
No. of brainstorming sessions organized	4	5	5	4	18
No. of PhD/MSc students supported	1	1	0	0	2
No. of articles published	1	1	1	1	4

A manual for the Californian system used for training of farmers in Senegal and other countries.


Institut Sénégalais de Recherches Agricoles
CRA Saint Louis
Série Fiches Techniques
ISSN 0850-9980 - Vol. 13, N° 1

Utilisation du réseau d'irrigation de type californien dans la zone du lac de Guiers, Sénégal

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Utilisation du réseau d'irrigation de type californien dans la zone du lac de Guiers, Sénégal

Fiche Technique

V- INSTALLATION ET FONCTIONNEMENT

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Fig. 6- Motopompe installé au bord du Chenal avec un démontage facile

2/2

10. Strategies for small-scale irrigation development in SSA

Water has been a constraint to agricultural development in West Africa, but not necessarily because of low availability but due to lack of irrigation infrastructure. This constraint is widely recognized by the New Program for Agricultural Development (NEPAD) in Africa and strongly reflected in Pillar 1 (agricultural water control and development) of its Comprehensive African Agricultural Development Program (CAADP). This constraint has been felt in all West African countries, especially those in the Sahel. Innovative water management practices and technologies are needed to realize the targets of CAADP and to maximize water availability to crops at appropriate times of year. Most irrigation technologies are now widely available in West Africa and elsewhere on the continent. What is required is an adaptation, scaling-up, and dissemination for use on a sustainable basis by poor rural communities.

Small-scale irrigation is understood in the context of either informal smallholder irrigation with limited irrigation infrastructure and technology, or small-scale community water control, which goes beyond conventional large-scale irrigation. Small-scale agriculture is the predominant form of agriculture on the continent, and that the majority is currently undertaken without organized or adequate water control. The strategic priority is to improve the reliability of these production systems – not only where rainfall is low but also where it is unreliable- to allow dry-season crop production. Where rainfall is low and unpredictable, enhancement may be possible by supplementary irrigation from water harvesting. With some 60% of production reliant on rain-fed production, the overriding requirement for resource-poor farmers is to overcome erratic rainfall and harvest sufficient foodstuff to ensure the households' nutrition.

The strategic priority for small-scale community water control embraces the three general types: water harvesting and soil and water conservation; inland valley/wetland cultivation; and small-scale community of smallholder irrigation in rural and peri-urban areas. Small-scale community water control embraces a range of options that extend from the most rudimentary of mulching and contour bunds to community vegetable gardens supplied from pumped groundwater, with various water distribution options.

The 2008 food crisis re-legitimized the intervention and showed the risks of a high level of dependence on food imports (including rice). Climate change and demographic dynamics have also led the West African states and their financial partners to reinvest in agriculture, especially irrigation. In 2013, the governments of Burkina Faso, Mali, Niger, and Senegal appealed for investment in the irrigation sector to increase the irrigated area to one million ha by 2020, at a total cost of $7 billion. The World Bank supported this Initiative Sahel (IS) program. The Program suffered a delay and started only in 2017.

As in many other parts of the continent, erratic rainfall creates uncertainty for rainfed agricultural producers in the four target countries. This uncertainty complicates the planning and execution of national agricultural development programs and the implementation of effective policies to optimize the allocation of scarce resources. In many instances, severe food shortages are attributed to extreme climatic events, including floods, and more often, droughts. The role of irrigation in reducing the risks associated with rainfed agriculture has long been recognized in the Sahel. Therefore, water storage and distribution techniques for food production and the conservation of the environment have become highly relevant.

The population growth rate in the West African countries is above 2.5% with increasing food requirements. Rainfed farming is responsible for 58% of food production in Africa (FAO, 2015) and 99% production of the main cereals, such as maize, millet, and sorghum in SSA (Wani et al., 2009). The water and irrigation development remain an indispensable constituent of the overall strategy for increasing food production.

The four target countries of this project are among the poorest countries in the world and have underdeveloped economies. These countries fall under the low-income category (GNP per capita of Burkina: $822.3; Mali: $793.5; Niger: $558.4; Senegal: $1584.5) (World Bank, 2015). Despite high irrigation potential, the proportion of the irrigated area formally developed is the world's lowest (between 1 and 6.8% of the potential). The distribution of potential and actual irrigation land in the project countries as distributed in the basins is presented in Figure 17.

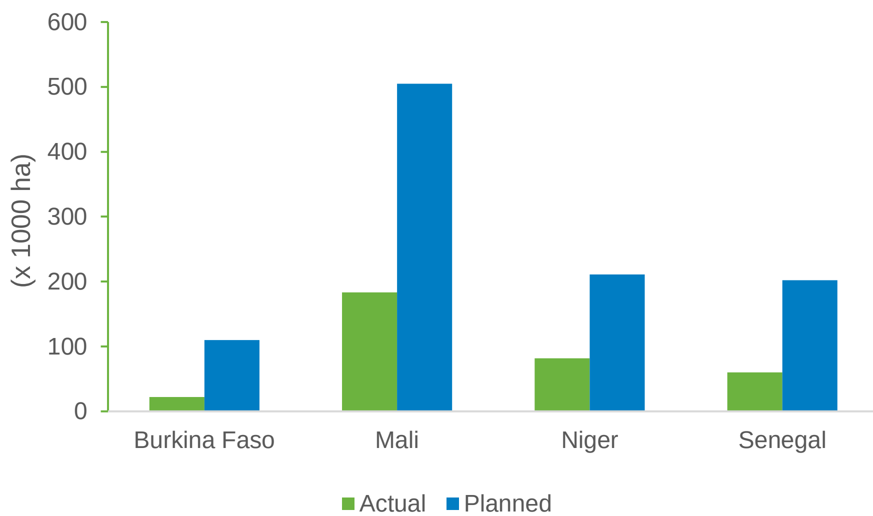


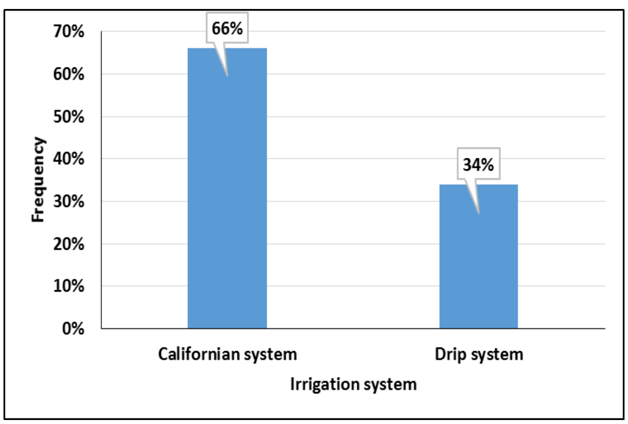
Figure 17. Potential and actual irrigated area in the target countries

Farmers in these countries derive their income from rainfed agriculture that is highly linked to the vagaries of climate change. Therefore, development of irrigated agriculture is central to make crop production resilient to the high vagaries of climate. The irrigation development will increase crop water availability, secure production, and control soil erosion and salinization problems. In all countries, the development of viable and sustainable large and small-scale irrigation systems is considered a strategic response to contribute to food security and income generation. However, there are several constraints in the development of irrigation systems in these countries.

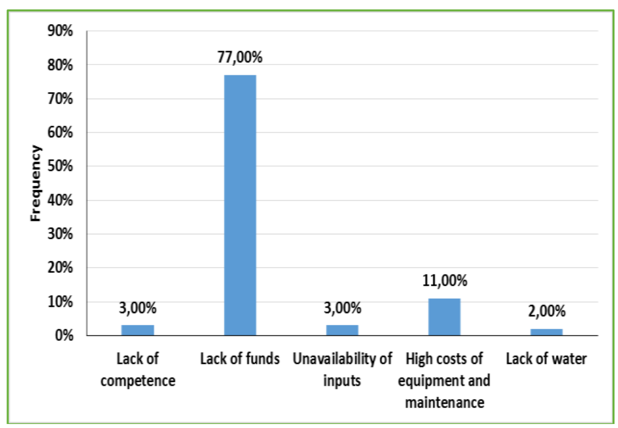
10.1 Farmers' perceptions about small-scale irrigation technologies

During the last year of the project, an impact evaluation survey was conducted in all partner countries. For this survey, a comprehensive questionnaire was developed and pre-tested in the field. The survey data was analyzed to document farmers' perceptions about the performance of different irrigation technologies introduced by this project. The results indicate that the exposure to improved cultural practices for irrigated crops was considered as the most important benefit derived from the project because this helps farmers increase their productivity which in turn improved their income and standard of living. Formation of women farmer groups was also highly appreciated because this helps them to share scarce water resources and establish links with sources of genuine farm inputs and markets. During the survey, farmers also highlighted their concerns regarding constraints in improving agricultural productivity and farm incomes.

This survey results showed a great satisfaction by the farming community about the SSI technologies. The farmers also realized true benefits of these technologies and demanded that more work should be done to improve farmer access to these technologies. These include provision of technical and financial assistance and availability of improved seeds. Farmers were convinced that these interventions will enhance their agricultural productivity and farm incomes. However, high costs of engines, pumps and lack of funds were described as the major bottlenecks in the adoption of these technologies by farmers. They stressed the need for credit facilities on soft conditions from government or other financial organizations to acquire these technologies.



Farmer preferences of irrigation technologies



Challenges in the adoption of irrigation technology

More than 70% farmers think that better access to funds would accelerate the adoption of these technologies. For this to happen, reduction in the installation costs of these technologies and making maintenance costs affordable would be inevitable. This objective can be achieved through the involvement of private sector in the local manufacturing of pumps and equipment used in these irrigation systems. Manufacturers of low-cost equipment face a host of problems. Their knowledge for technology development limited and government policies are more focused on crop and livestock research and little attention is given to support agricultural engineering.

Improving pump manufacturing capacity and availability of imported equipment and spares at affordable costs can help increase crop productivity while providing resilience against erratic rainfall patterns of SSA. The national governments need to formulate policies to facilitate private equipment manufacturers, importers of spares and providers of maintenance services. The Asian countries (India, Pakistan, Bangladesh) have revolutionized their irrigated agriculture through increased access to irrigation and energy. In these countries, electricity and diesel supply for agriculture was supplied at discount rates and import of irrigation pumps were heavily subsidized. These policies increased agricultural production making them self-sufficient in food despite growing concerns that indiscriminate use of energy for irrigation is causing environmental problems. The SSA countries may also follow these models to revitalize agriculture.

In SSA countries, farm products are generally sold in the local markets where buyers come from the nearby big towns and neighboring countries. Prices are negotiated directly in the fields or in the local market and the products are immediately removed. This system does not benefit farmers because they are forced to sell their product at low price due to limited access to big markets and lack of storage facilities. Lack of market information restrict farmers to transport their produce to distant areas due to the fear of market saturation. Improving road infrastructure can enhance market access, which may lead to increased farm gate prices by lowering transactions costs. Smallholder farmers also need help to fortify processing activities to reduce post-harvest losses and earn better price in the market. In countries such as Mali and Senegal, few farmers have contracts with exporters, which allows them to earn competitive profits.

Farmers may be encouraged to form cooperatives or farmer to afford installation of expensive equipment for shared benefits. Farmer groups may acquire bank loans and establish links with sources of genuine farm inputs and markets. This will reduce poverty at the community and household levels and contribute positively to overall national economy. However, this process needs strong motivation because experience in Kenya has shown that farmers often pool their resources to pay for conveyance systems but are extremely reluctant to share irrigation pumps.

The crop yields in smallholder farms of SSA are far lower than regional and international standards. In addition to lower water availability, poor soil fertility, low fertilizer application rates and use of poor-quality seed are the major contributing factors. Smallholder farmers of SSA are in desperate need of good quality seed to enhance their agricultural productivity. Low soil fertility problem can partially be solved by micro-dosing of fertilizers with sufficient farmyard manure and organic matter. Farmer need to be educated in integrated nutrient management, which involves timely application of nitrogen as per crop demand and irrigation schedules.

The accessibility to better quality seed is the key to narrow down potential and existing yield gaps and reduce post-harvest losses with minimal spoilage during storage; unlike the local varieties which mature late, produce low yields, and do not withstand stress during handling and long-distance transportation. Better quality produce therefore earns good market price. This advocates that economic viability of improved irrigation systems is directly linked with the provision of good quality seed to the farmers.

10.2 Constraints and limitations for SSI development in SSA

The main constraints related to the development of irrigation are: (i) high cost of construction and rehabilitation of large and medium-sized perimeters, (ii) technical and economic problems in mobilizing groundwater resources, (iii) siltation of reservoirs and streams due to water erosion and poor cultural practices, (iv) poor condition of water infrastructures and the degradation of the vicinity of reservoirs and reservoirs, (v) the mismatch between inland valley hydrological development and regime, (vi) lack of regulations for water withdrawals from water bodies; (vii) use of many temporary water sources or low flows of many water structures, (vii) difficult access to water for animals often results in conflicts between farmers and herders, and (viii) malfunctioning of water bodies and lack of maintenance of facilities.

The main constraints related to the development of small-scale irrigation schemes and agricultural water management are: (i) rainfall hazards jeopardizing the filling of small water-harvesting structures and depletion of soils under irrigation due to the low use of organic fertilizers, (ii) poor control of irrigation techniques by farmers, (iii) non-compliance with the crop calendar by different farmers, (iv) high cost of equipment, (v) accessibility of equipment In local markets, (vi) insufficient agricultural equipment and limited access to good quality credits and seeds, (vii) secondary salinization of soils, (viii) overexploitation of watersheds resulting in the degradation of soil fertility through intensive double-cropping systems, (ix) pollution of surface and ground water resources, (x) persistent land issues (many producers do not own their plots) which limits investments in the maintenance of soil fertility, and (xi) limited availability of water.

Land issues are critical to the development and success of smallholder irrigation schemes. Land problems faced by potential private irrigators are very different from country to country with other proposed solutions. In Mali, obtaining land titles (topographical plan, red tape, and taxes) is subsidized; this component has been hijacked to the extent that some subsidies have not invested in irrigation. In Burkina Faso, DIPAC (Pilot Project for the Development of Private Irrigation and Related Activities) supports potential homeowners without subsidies. In Niger, the law recognizes customary ownership of land with a title to the property. In Senegal, though the land tenure system exists, the land belongs to the state, the only entity that can deliver a title.

Other constraints that inhibit the growth of small-scale irrigation in SSA include (i) the low involvement of credit institutions, (ii) the slow processing of contracts by donors (iii) the lack of partners for the financing of development and rehabilitation, (iv) lack of human resources for the proper technical supervision of producers, (v) the low level of professionalization of the actors of irrigated agriculture (producers, upstream and downstream actors), (vi) incompatibility with the process of the transfer of the management of irrigated perimeters.

The major technical and institutional constraints and limitations in SSI development in SSA are given below.

1. High cost of equipment and lack of technical skills.
2. Lack of funding to develop irrigation. National financial institutions provide virtually no long-term financing to enable the development of private irrigation.
3. The preliminary design of irrigated systems and poor maintenance and management of the irrigation infrastructure often leads to their abandonment.
4. Limited access to rural markets, credit, and maintenance services.
5. Inadequate monitoring and coordination capacity due to understaffing and low levels of training, logistical problems, and low pay levels.
6. Non-functional consultation frameworks at the local, regional, and national levels.
7. The current strategies for agricultural production, conservation, and processing of farm products results in high transaction costs, fewer market opportunities, and inadequate consultation between public and private actors.
8. There is no coordination at the national and regional levels despite the problems associated with the jurisdictional conflict.
9. Existing land-tenure laws discourage farmers from investing in irrigation schemes.
10. Agricultural production developed on irrigated perimeters is grouped into two main categories: (i) irrigated cereal production where rice is mainly dominant, with some experiments on maize and sorghum in inland valleys; and (ii) horticultural production dominated by onion and tomato. Investment efforts have focused on maximizing irrigated cereal production without considering the economic cost of this approach.

10.3 Institutional and policy constraints and interventions

(a) Consolidating the legal basis for building economically viable farms

Although the national law does not recognize the land as an economic good, it is increasingly becoming a scarce resource. Suppose one chooses to irrigate a plot of a viable size (one hectare on average). In that case, it will be necessary for him to respond to two problems: the recovery of plots of developed perimeters that are not currently cultivated and the revision of allocations within the boundaries to ensure coherent operations. Current regulations determine the appropriate bodies and procedures for various stakeholders to access irrigable land. The rules should be revisited to protect access to irrigable land for the potential stakeholders.

It is necessary to develop a framework for interventions to the various public and private actors involved in irrigated agriculture. This should include provisions relating to the (i) definition and control of development based on the capacity to supply water to the parcel; (ii) the decommissioning and reallocation of undeveloped stocked plots; and (iii) a mechanism to pay back investments to the people wishing to leave their lands.

(b) Review of water management procedures

The review should focus on two points: (i) the easing of administrative procedures by limiting the authorization; (ii) the reconciliation of users' water management (the public water law which involves the central and decentralized administration. In the local context, it is difficult to get the farmer to admit that water has a price, and therefore charging for water may be difficult. It would be desirable creating local funds fueled by a percentage of the levy to be determined. These funds would be allocated to social investments such as water, health, and education).

(c) Institutional orientations

There is a need to take corrective measures to address the institutional constraints identified, with the threefold concern: (i) clarification in the division of roles of the decentralized institutions, (ii) better adequacy of the means and powers of the decentralized communities, and (iii) a more adapted structuring of the peasant world. There is a need to develop framework defining the area of intervention of each of the partners involved in developing SSI. The technical guidance about these systems is either non-existing or unavailable at the time of need.

(d) Investment policy

The investment policy would include the categorization of irrigation investments, the technical design of the facilities, and the financing methods differentiated by the type of beneficiaries.

- ✓ Categorize investment by type of development and development zone.
- ✓ Establish technical standards and an effective monitoring system for their application.
- ✓ Promote and monitor the performance of specific investment management provisions.
- ✓ Ensure recapitalization of the agricultural sector.

(e) Agricultural investment valuation policy

The agricultural investment policy should include the interests of producers, processors, and traders to develop cooperation and a fair distribution of risks, profits, rights, and duties.

- ✓ Focus on high-value market speculation and increase the intensities of rice systems.
- ✓ Focus on diversification of production.
- ✓ Ensure competitive prices to farmers.
- ✓ Provide specialized advisory support to the irrigator.

(f) Environmental policy

Proposals in this area aim to introduce a natural environment (which is currently lacking) into the development process of small-scale irrigation to planning bodies and investors:

- Establish and enforce specific environmental standards by homogeneous zone, and systematize, for any development study, the identification of ecological constraints induced by investments and the mandatory implementation of the corrective actions.
- Public investments need to be distributed judicially for the structural development of areas weakened by climate change and/or soil degradation and SSI development.
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(g) Policy of integrating women into the development of small-scale irrigation

The following strategic proposals should be part of the overall agricultural development policy and consider the need for the involvement of all stakeholders in the sector, particularly women, depending on its essential place in this sector:

- Systematically apply the gender approach to small irrigation development programs.
- Strengthen women's participation in preparing, implementing, and monitoring small irrigation development programs/projects.
- Strengthen women's participation in preparing, implementing, and monitoring small irrigation development programs/projects.
- Focus on informing and training women in irrigation schedules.
- Strengthen the structures of women irrigators.

10.4 Strategic approaches for SSI development in SSA

The future of irrigation in SSA will be governed by decisive external factors, such as rapid urban growth, climate change, and land acquisitions. Farmers' ability to adapt to this context will depend on the agricultural, energy, and land policies that the respective governments will implement. Vast areas are experiencing new dynamics, especially in Senegal, Mali, Burkina Faso, and Niger through private agro-industries and individual small systems, with or without the support of governments (Sonou and Abric 2010; Bélières et al., 2013).

With the climate and physical resources available, and given the economic opportunities for specific agricultural sectors, the small-scale irrigation could contribute: (i) to reduce the current deficit in certain products (including horticultural); and (ii) to develop exciting initiatives to promote export to regional and international markets. Agricultural production developed on irrigated perimeters is grouped into two main categories: (i) irrigated cereal production where rice is mainly dominant, with some experiments on maize and sorghum in inland valleys; and (ii) horticultural production largely dominated by onion and tomato.

Irrigated cereal production (including rice) accounts for most of the developed areas in the study countries. The main zones of paddy rice production are located along temporary and permanent rivers and created inland valleys. In any study country, the total rice production barely satisfied the national demand, making respective countries highly dependent on imports. In Senegal, for example, the average national paddy production covers a small share (20%) of the national consumption (500,000 tons/year), and the difference is imported, mainly from Asia. Cereal production has significantly increased in the four countries with the development of irrigation schemes, the introduction of new high-yielding varieties, and the institutional and financial reforms of the irrigation sector.

The data shows a continuous increase in the output over 2005-15, especially in the cultivation of tubers and horticulture products for export in Senegal and Burkina Faso. It can therefore be pointed out that irrigated production has contributed significantly to food security in various forms as it: (i) is used as an alternative to food to household food stock; (ii) generates revenue used to purchase cereals during the welding period; (iii) improves the nutritional status of populations by providing certain vegetables and other foods rich in vitamins.

Many conflicts remain between the technical services of the State and technological services and civil society (NGOs, projects). For example, many rice irrigated or market gardening perimeters are carried out on external financing under the guidance of NGOs or state projects whose support in terms of advice for development (extension) is not well done by the Directorate of Agriculture. The reasons given are the lack of human and material resources, the non-involvement in the upstream process. The only valid explanation would be the lack of consultation for a better set of roles and responsibilities of each. It remains clear that state support for communities remains sustainable while interventions by technical and financial partners are limited in time and space.

The economic profitability of irrigated rice is limited, among other things, by the characteristics of the socio-economic environment related to the size of the plots, the difficulty of improving marketing, a lack of capacity and initiative to channel rural savings towards productive agricultural investments, and finally, a limited supply of financial products in line with the needs of producers.

The investments have focused on maximizing irrigated cereal production without considering the economic cost of this approach. The lack of economic competitiveness of irrigated rice farming, the substitution of imports for domestic production, the imbalance between urban and rural demand for rice, the lack of capital accumulation, and self-financing are clear indicators of an inefficient economic allocation of resources. Added to these are the constraints associated with poor financial services and a lack of structuring of the supplying sectors to give a rather negative framework for irrigated agriculture.

The strategic approach for developing smallholder irrigation can be strengthened by:

- ❖ the inclusion and accountability of all public and private actors involved in the development of irrigated agriculture. These include producers, suppliers, processors, transporters, distributors, research, extension institutions, and funding institutions.
- ❖ valuing the comparative advantages of regions where smallholder irrigation has a high potential through the implementation of agricultural investment plans.
- ❖ promoting the various sectors for the collection of farm products in well-defined regions for processing and marketing while providing facilities to attract private investments, the creation of cross-sectoral interactions, the supervision, and financing of the actors involved as well as for research and action.
- ❖ systematic consideration of gender and good governance in all interventions.

The experience of the few small private irrigation development projects, i.e., individual, or small voluntary groups, has provided some lessons: Smallholder irrigation, especially private schemes, is irreplaceable for the development of high-value crops added to the market, whether local or export; As such, it deserves to be supported by development projects. The management of a private irrigation support project by a private association, even if it is poorly organized, is no worse than management by a service State; On the contrary, state control can be exercised without influencing the direction of the day-to-day project. It is easy to promote simple technologies (manual drilling, treadle pumps, solar pumps) without resorting to credit provided that the methodology of NGOs launched the spread of treadle pumps in Africa (IPTRID, 2000).

In addition, only technically proven products with a critical mass should be sold in the market. The cost of the equipment should be affordable and should not be directly subsidized to ensure that the sale continues after the project. The equipment must be sold primarily to individual farmers or small groups. We need to use local builders and work with the private sector responsible for providing maintenance and after-sales service.

The projects must include a well-defined monitoring and mitigation component of irrigation's environmental impact on depletion of groundwater tables and pollution of minor aquifers. A methodology for the follow-up involving the irrigators is still to be worked out. In Niger, there is a component to protect against water erosion and wind turbines. Indeed, many small irrigation sites are attacked by dunes or Wadis. Most projects also include integrated pest management and awareness-raising of risks associated with fertilizers and pesticides. The development of smallholder irrigation must include a social dimension by providing the needs of the poor and women. Support for women could be done by promoting the post-harvest activities.

10.5 Prospects of SSI and solar pumps development in SSA

Smallholder agricultural growth is critical for to ensure food security ad poverty alleviation in Sub-Saharan African countries (Deininger and Byerlee, 2012). Agricultural growth was found to be five times more effective in reducing poverty than non-farm growth in low-income countries but 11 times more so in SSA (Christiansen et al., 2011; FAO 2012). Increasing population at a rate of 3% per year in SSA would increase the future food-demand. Furthermore, anticipated climate changes are predicted to increase the variability of precipitation in SSA, increasing the risks associated with rainfed farming and posing new challenges of drought mitigation and adaptation. At the turn of the millennium, agricultural economy of SSA must grow at a rate of 6% per year to provide enough food for the growing population, reduce rural poverty, and accelerate economic growth in a sustainable manner (FARA, 2003). Given little irrigation development in Sub-Saharan Africa so far, there is enormous scope for expanding smallholder irrigation areas at modest investments over a short period.

The global experiences of last three decades dictate that farmers and governments are interested to lay greater emphasis for accelerating agricultural growth on small-scale irrigation as a viable alternative to large-scale irrigation projects whose benefits were increasingly being questioned (Woodhouse et al. 2017). By expanding small-scale irrigation, SSA can be moved from an unpredictable rainfed farming system to a more sustainable irrigation farming regime. According to the World Bank estimates, about 85% of Sub-Saharan Africa’s population lives more than 10 kilometers from a major river or lake, and they are unlikely to benefit from gravity irrigation (World Bank 2018). This means that small-scale irrigation development will depend on scavenging water from small reservoirs or shallow groundwater. Chances are that irrigation schemes that require complex collective action will gradually give way to smaller, simpler irrigation structures driven by individual or small group entrepreneurship.

Sub-Saharan Africa has 660,000 km^2 of nonrenewable deep groundwater resources, which are expensive to develop due to high cost of drilling and energy. Therefore, they are beneficial to meet municipal demand and for large-scale commercial farming than smallholder irrigation development (MacDonald et al., 2012). Even in the driest regions of SSA, which compose 40% of its land mass and houses 64% of its population, has ample groundwater available at the depths of 25m or less (World Bank, 2028). Groundwater irrigates only 0.4 meters per hectare in SSA, and the region has enough shallow groundwater to irrigate between 44.5 million ha and 105.3 million ha (Altchenko and Villholth, 2015). Based on a comprehensive study of 13 SSA countries, Pavelic et al. (2013) has suggested that the known groundwater resource can easily support 120 times their current groundwater-irrigated area.

In Sub-Saharan Africa, more than 600 million rural people are without access to electricity (Okoye and Oranekwu-Okoye, 2018). Therefore, solar irrigation pumps (SIPs) can help in advancing the agenda of small-scale irrigation development in this region. Studies have shown large swaths of SIPs in SSA due to abundant solar radiation and availability of shallow groundwater (Smitter et al., 2018). The initial capital investment in solar irrigation pumps may be a deterrent; however, when volumes are large, SIP costs are dropping sharply. In India, for example, SIPs (panels, pumps, invertor, and meters) costs were more than US$1,500 to US$1,700/kWp in 2015. However, they dropped to US$850 per kilowatt-peak (excluding pumps) in 2018. Sub-Saharan Africa should also experiment with alternative techno-institutional models of SIP irrigation—including mini-SIPs popular with NGOs; mobile, cart-mounted SIPS; solar irrigation service–providing entrepreneurs; and others and choose what is best suited to its specific conditions.

Governments are once again at the forefront in promoting SIPs among smallholders in large groundwater extraction countries such as India, Pakistan, China, Bangladesh, etc. In India, the number has crossed 180,000 in 2018 from 1,000 in 2012. Throughout Bangladesh, eastern India, and Nepal terai, there is a strong demand of solar pumps due to increasing prices of diesel and lack of electricity network. Like many nongovernmental organizations (NGOs) and donors in Sub-Saharan Africa, governments are promoting miniature solar pumps of 0.1 to 2 kilowatt-peaks for garden irrigation. The objective is to demonstrate solar technology and spread limited subsidy funds over many smallholders. However, it is being recognized that right-sized SIPs (that is, 3.5 to 5 kilowatt-peaks) can play a far bigger role in promoting irrigation. The governments of Asian countries are assisting entrepreneurs in operating SIPs for providing irrigation service to smallholder farmers. The governments of SSA can also use these models to accelerate the adoption of small-scale irrigation technologies and solar irrigation pumps.

11 Conclusions and recommendations

Developing irrigated area, improving water use efficiency and increasing productivity of irrigated agriculture remain the most important domains of the strategy needed to achieve sustainable water management, food security and economic growth in SSA. Food production in the area is still almost entirely rain-fed with irrigation playing a minor role. Despite abundant renewable water resources, only 2% of the area is irrigated. Only 4% of the region's total cultivated area is irrigated compared to 37% in Asia and 14% in Latin America. Thus, Africa is far from realizing its irrigation potential, estimated at 42.5 million ha. Helping farmers to access irrigation water by developing small-scale irrigation can enable them to boost agricultural production, achieve food security, and nutritional health. This is now increasingly realized that access to irrigation water can give a considerable boost to production of food staples and high value export crops and insure farmers against droughts and famines.

The main constraints related to agricultural water development and management are: (i) lack of a coherent and efficient mechanism for synergizing irrigated agricultural and water development between agriculture and other sectors, (ii) planning developments according to administrative redistricting does not consider watershed boundaries. In addition, the low involvement of credit institutions in the financing, the high dependence on grants and other support from the State, the low participation of private developers in the financing of developments, and the weakness of the human resources of the decentralized services for the technical supervision of producers are considered major constraints for the development of SSI in Sub-Saharan African countries.

Over the past three decades, several initiatives have been initiated in SSA to introduce irrigation systems, but the success has been limited. The slow irrigation development in Africa is linked to high development costs, weaker participation of farmers, and issues related to land tenure. On the contrary, there is a long history of reforms in Asia regarding the land tenure, water, and energy sector to address the changing needs of farmers. The success of irrigation schemes in Asia was achieved by recovering the capital cost from the farmers. In contrast, the involvement of farmers in the development, rehabilitation, and management of irrigation schemes in Africa has been peripheral. Cost recovery of irrigation schemes is critical to avoid the built-neglect-rebuild and neglect syndrome, especially in Africa where national governments have financial constraints.

The development organizations such as World Bank, IsDB, IFAD, OFID, AfDB, and many others have invested heavily in the development of irrigation schemes in SSA. However, due to the magnitude of the problem, donor-driven solutions are not enough. Therefore, local governments need to designate more capital and resources to achieve the targets. With targeted investments and policies to expand small-scale Irrigation, the problems of hunger, poverty, and malnutrition can be addressed. The research organizations such as ICBA can help in identifying potential solutions based on their experiences in SSA and other regions. This involves an understanding of SSA's water resources and geohydrology to know where and how much irrigation capacity can sustainably be developed. They can also train farmers in different on-farm water conservation strategies, including economical cropping patterns, to maximize returns on their investment.

A new irrigation development paradigm has now emerged, and its major focus is on market-driven prosperity and private investment. Under this approach, commercial profitability is the superseding concern, and the private sector (farmers and private suppliers of irrigation technologies and services) should assume the leading role in investment and management. The government only facilitates the private development and invests in economically viable and financially sustainable schemes. With this approach, smallholders can also become commercial farmers and governments have a major role to play in facilitating this transition.

The entry point for policy makers should be to identify effective irrigation development and management practices. To effectively identify these practices, policy makers should be informed about research findings. The SSA governments should take appropriate measures should make special arrangements to scaling out and up of “successful” irrigation development initiatives. Since scaling-up and scaling-out is a complex task, concerted actions and commitment are required both from governments and development partners. It also requires a paradigm shift from holding onto rigid and centrally managed irrigation to implementation of more flexible and holistic governance and development of irrigation schemes. This in turn, highlights the need of SSA water governance regimes to overcome the existing institutional and political drawbacks.

The key policy lessons drawn from this review of irrigation development in SSA are:

- Governments in SSA need to recognize the importance of irrigation development for enhancing food security and economic growth, as well as the need for water to be developed within a broader framework that promotes agricultural growth through profitable investment and market-oriented production.
- Irrigation development can only contribute to food security and economic growth when investments are profitable at the farm level, economically viable and sustainable
- Efforts should be made to identify the kind of investments in irrigation development that give the best return
- Governments need to provide incentives for farmers to adopt new technologies and move towards intensification of agricultural production, while encouraging the involvement of the private sector to create competitive markets for agricultural inputs and outputs. The relative roles of public and private investment must be clarified to foster private investment
- Governments in SSA can promote private investment into irrigation by developing the legal and institutional framework governing agriculture and by investing in infrastructure and research and development
- Transparent, accountable, efficient, and financially self-sustaining institutions are key to successful improvement of large-scale irrigation

- Many of the donor-financed projects that have been evaluated as successful on completion in recent years have been characterized by both decentralized and participatory approaches
- More reliable access to irrigation water is part of the story, but other components (e.g., markets, inputs, extension, environmental management, etc) are part and parcel of a comprehensive package that enables farmers to maximize productivity and profitability in agricultural production
- Water markets and pricing mechanisms which were adopted by many governments as water management tools have proven to be ineffective, at least in the context of SSA.
- Farmers in the irrigated areas are mostly unaware of the concepts of '*usual*' or '*optimum*' irrigation depths. Therefore, applied irrigation amounts are usually much higher than the actual crop water requirements. Crop yields are well below their productive potential due to deficient use of fertilizers, and poor access to irrigation water. Water use efficiencies are only 22-25%, which is half of the world average of 45%. This suggests that farmers need to be educated on improved water management practices, including water-saving techniques as a demand management strategy.

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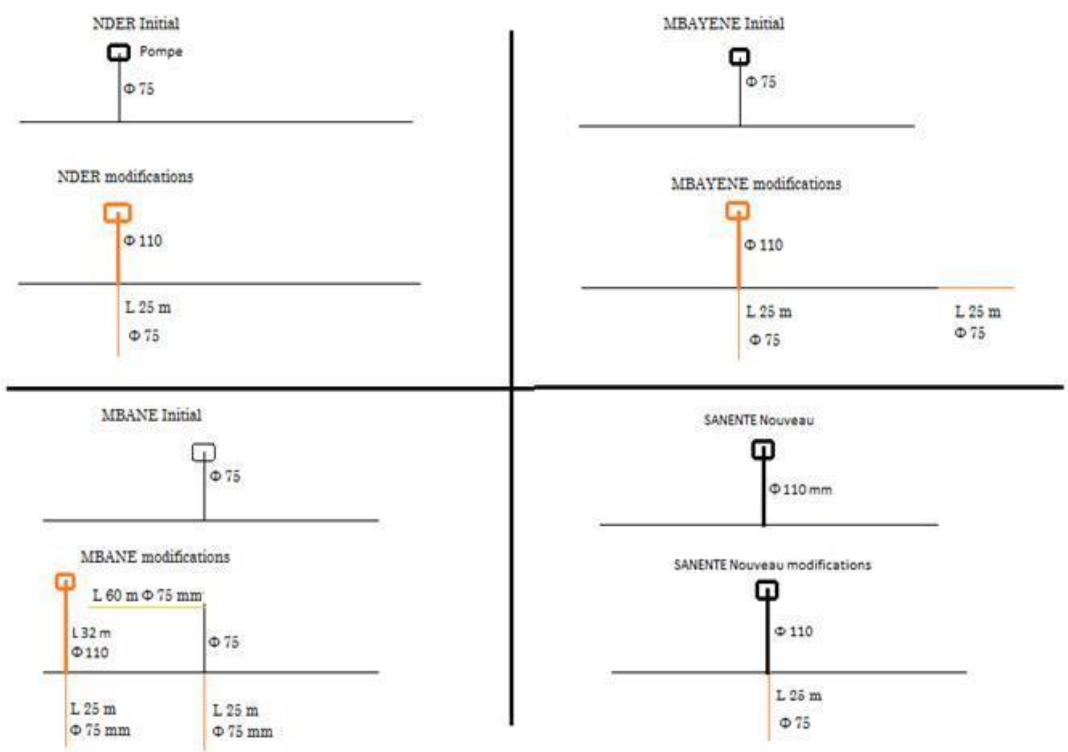
ANNEX- I: A modified design of the Californian system in Senegal

Based on their experience, farmers modified their design and recommend the following actions:

- Use diesel pumps instead of gasoline.
- Use pumps with a higher flow rate and a larger diameter. The central pipe diameter of 75 mm should be changed to 110 mm as shown in below diagram.
- Avoid soil erosion due to water fall at the water outlets. For this purpose, a plastic sheet or cemented hose can be used at the outlet of the pipe.
- To reduce the time spent for irrigation, more PVC pipes were added in the farmer fields. These modifications were made for Nder, Mbayene, Mbane and Sanente villages.



Due to the lack of robustness and poor performance of GMP pumps, diesel pumps were introduced. This pump reduces drastically the number of pump failures during the operation. During the quasi-running session, no pump failure in the new gasoline pump was observed. This improves the performance of the Californian system as continuous water supply was available for irrigation.

ANNEX– 2: Cost for a Californian system in Senegal and Burkina Faso

Item	Number	Length (m)	Unit price (FCF)	Total price (FCF)	Total price (US$)/hectare
Tuyaux PVC	26	156	4600	119,600	240
Tuyaux PVC	1	6	3500	3500	7
Tuyau Flexible	1	5	30,000	30,000	60
T – 75	1is com0	-	1000	10,000	20
T - 63	10	-	1000	10,000	20
Reducer - 63	10	-	1000	10,000	20
Embout – 75	1	-	3000	3000	6
Coude - 75	2	-	900	1800	3
Bouchon - 75	2	-	1000	2000	4
Bouchon – 63	20	-	1000	20,000	40
Motor pump	1	-	125,000	125,000	250
Total				**334,900**	**670***

(I US$ = 500 FCFA)

* The installation cost of the Californian system may vary from country to country depending on the type of soil, crops to be grown, availability and price of materials in local markets.

About the International Center for Biosaline Agriculture (ICBA)

ICBA is a not-for-profit, international center of excellence for research and development in marginal environments. It was established in 1999 through the visionary leadership of the Islamic Development Bank (IDB), the Organization of Petroleum Exporting Countries (OPEC) Fund, the Arab Fund for Economic and Social Development (AFESD) and the Government of United Arab Emirates. The host country, through the Ministry of Climate Change and Environment and the Environment Agency – Abu Dhabi extended the agreement with IDB in 2010 and increased their financial support to the Center.

ICBA originally focused on the problems of salinity and using saline water for irrigated agriculture. Over the last 15 years, ICBA has evolved into a world-class modern research facility with a team of international scientists conducting applied research to improve the well-being of poor farmers in marginal environments. In 2013, the Center developed a new strategic direction addressing the closely linked challenges of income, water, nutrition, and food security. The new Strategy takes innovation as a core principle and identifies five innovations that form the core research agenda: assessment of natural resources; climate change adaptation; crop productivity and diversification; aquaculture and bioenergy, and policy analysis. ICBA is working on several technology developments including the use of conventional and non-conventional water (s saline, treated wastewater, industrial water, and seawater); water and land management technologies; remote sensing and modeling for climate change adaptation.

ICBA is a unique institute with a clear mandate and capacity to work on the rehabilitation of salt-affected lands. ICBA is custodian of the world's largest collections of genetic resources of crops and forages suitable for salt-affected lands with a proven capacity of seed development and seed multiplication for variety of environments. In addition, ICBA's long history of working in Africa with local partners makes it fully qualified and eligible to lead this project.

The International Center for Biosaline Agriculture (ICBA) implemented a four-year project titled **“Scaling up small-scale irrigation technologies for improving agricultural productivity in Sub-Saharan Africa”.** The project was funded by the **OPEC Fund for Agricultural Development (OFID)** and executed with the technical and logistic support of the Ministries of Agriculture of the four West0African countries (**Burkina Faso**, **Mali**, **Niger**, **Senegal**).

The project is of great importance for the smallholder farmers, especially women and children, who face high food insecurity and malnutrition. The project has introduced small-scale irrigation technologies and solar irrigation pumps to promote irrigated agriculture for improved agricultural production. The adoption of small-scale irrigation technologies will enable farmers to irrigate their small plots to boost crop harvests, family incomes, and nutritional health in the target countries.

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