A WORLD BANK STUDY

Improved Agricultural Water Management for Africa's Drylands

Christopher Ward, with Raphael
Torquebiau and Hua Xie

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Foreword

Drylands—defined here to include arid, semi-arid, and dry sub-humid zones—are at the core of Africa's development challenge. Drylands make up 43 percent of the region's land surface, account for 75 percent of the area used for agriculture, and are home to 50 percent of the population, including a disproportionate share of the poor. Due to complex factors, the economic, social, political, and environmental vulnerability in Africa's drylands is high and rising, jeopardizing the long-term livelihood prospects for hundreds of millions of people. Climate change, which is expected to increase the frequency and severity of extreme weather events, will exacerbate this challenge.

Most of the people living in the drylands depend on natural resource-based livelihood activities, such as herding and farming. The ability of these activities to provide stable and adequate incomes, however, has been eroding. Rapid population growth has put pressure on a deteriorating resource base and created conditions under which extreme weather events, unexpected spikes in global food and fuel prices, or other exogenous shocks can easily precipitate full-blown humanitarian crises and fuel violent social conflicts. Forced to address urgent short-term needs, many households have resorted to an array of unsustainable natural resource management practices, resulting in severe land degradation, water scarcity, and biodiversity loss.

African governments and the larger development community stand ready to tackle the challenges confronting dryland regions. But while political will is not lacking, important questions remain unanswered about how the task should be addressed. Do dryland environments contain sufficient resources to generate the food, employment, and income needed to support sustainable livelihoods for a fast-growing population? If not, can injections of external resources make up the deficit? Or is the carrying capacity of dryland environments so limited that out-migration should be encouraged as part of a comprehensive strategy to enhance resilience? And given the range of policy options, where should investments be focused, considering that there are many competing priorities?

To answer these questions, the World Bank teamed up with a large coalition of partners to prepare a study designed to contribute to the ongoing dialogue about measures to reduce the vulnerability and enhance the resilience of populations living in the drylands. Based on analysis of current and projected future drivers of vulnerability and resilience, the study identifies promising interventions, quantifies their likely costs and benefits, and describes the policy tradeoffs that will need to be addressed when drylands development strategies are devised.

Sustainably developing the drylands and conferring resilience to the people living on them will require addressing a complex web of economic, social, political, and environmental vulnerabilities in Africa's drylands. Good adaptive responses have the potential to generate new and better opportunities for many people, cushion the losses for others, and smooth the transition for all. Implementation of these responses will require effective and visionary leadership at all levels from households to local organizations, national governments, and a coalition of development partners. This book, one of a series of books prepared in support of the main report, is intended to contribute to that effort.

Magda Lovei

Manager, Environment & Natural Resources Global Practice

World Bank Group

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This book is one of a series of thematic books prepared for the study, “Confronting Drought in Africa’s Drylands: Opportunities for Enhancing Resilience.” The study, part of the Regional Studies Program of the World Bank Group Africa Region Vice Presidency, was a collaborative effort involving contributors from many organizations, working under the guidance of a team made up of staff from the World Bank Group (WBG), the United Nations Food and Agriculture Organization (FAO), and the Consultative Group for International Agricultural Research Program on Policies, Institutions, and Markets (CGIAR-PIM). Raffaello Cervigni and Michael Morris (World Bank Group) coordinated the overall study, working under the direction of Magda Lovei (World Bank Group).

Christopher Ward (World Bank Group), with the assistance of Raphel Torquebiau (World Bank Group) and Hua Xie (International Food Policy Research Institute - IFPRI) prepared this book, entitled “Improved Agricultural Water Management for Africa’s Drylands.” It draws heavily on the findings of two other books prepared as part of the same study: “Improved Crop Productivity for Africa’s Drylands” by Tom Walker (World Bank Group), Tom Hash, Fred Rattunde, and Eva Weltzien (all of the International Center for Research on the Semi-Arid Tropics); and “Agricultural Water Management for the African Drylands South of the Sahara,” by Hua Xie, Weston Anderson, Nikos Perez, Claudia Ringler, Liang You and Nicola Cenacchi (all of the International Food Policy Research Institute).

Preparation of this book was coordinated by Michael Morris and Raffaello Cervigni (World Bank Group). The book was reviewed by Jacob Burke, Francois Onimus, Pierrick Fraval, Michael Morris, and Raffaello Cervigni (World Bank Group).

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Raphael Torquebiau is a water resources management specialist with nearly 10 years of experience in international development. His project experience has included a wide range of areas, including rural water supply and sanitation, agricultural water management, and watershed management. He holds a Master of Science in Water Management and an MBA.

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Executive Summary

Dryland areas of Sub-Saharan Africa (SSA) contain one-half of the region's population and three-quarters of its poor. Challenged by a meager natural resource base and suffering from a lack of assets and income, inhabitants of the drylands are highly vulnerable to shocks, especially those resulting from droughts and other extreme weather events. Despite numerous efforts to improve the circumstances of drylands inhabitants and lift them out of poverty, there have been few if any sustained large-scale successes. In this context, the World Bank and other partners launched the study on "Confronting Drought in Africa's Drylands: Opportunities for Enhancing Resilience," whose objective was to set out a practical framework for understanding vulnerability and resilience in drylands, as a way of informing the design of policies and programs that can help break the recurrent cycle of crises that for years have plagued the drylands.

This book describes the extent to which interventions designed to improve agricultural water management can enhance the resilience and improve the well-being of people living in dryland regions of SSA, and it proposes what can realistically be done to promote improved agricultural water management. More specifically, the purpose of the book is to demonstrate the potentially highly beneficial role of improved water management in drylands agriculture, especially when improved water management can be realized along with agronomic improvements, enhanced access to markets, and infrastructure development. In addition, the book assesses the technological and socioeconomic conditions that are conducive to improving agricultural water management, and it discusses the institutional policy frameworks that can remove barriers to adoption and allow large-scale take-up of improved agricultural water management in the drylands of SSA.

Agricultural Water Management, Vulnerability, and Resilience

Aridity is the main characteristic of drylands. Aridity comes about through a combination of low precipitation, high temperatures, and drying winds. Drylands are important in about 20 SSA countries, classified here into four regions: Central, Eastern, Southern, and Western Africa.[1] Agriculture is the most important sector in dryland economies. The cultivated area of 126 million hectares represents two-thirds of SSA's cropland, with the largest share (46 percent) found in Western Africa. Irrigated areas account for less than 5 percent of the farmed area (5.2 million hectare), but support a much larger population proportionally than pastoral and rainfed systems.

Considerable technical potential exists for increasing productivity in drylands agriculture, particularly in cereals, roots and tubers, pulses, and oil crops. Realizing increased productivity is made difficult by multiple constraints and barriers, however, some of which are specific to the drylands. Structural challenges are biophysical, infrastructural, and politico-economic in nature. Considerable institutional and socioeconomic challenges also exist. The inherent risks that are present in drylands are exacerbated by a variable and highly unpredictable climate, one that is characterized by frequent droughts. Naturally poor soil qualities, continual land degradation, and the socioeconomic profile of the farming population further constrain productivity. Overall, the combination of harsh production conditions, farmers' naturally risk averse reactions, and widespread poverty contribute to low levels of resilience in SSA drylands.

Because livelihoods in the drylands of SSA are predominantly agriculture-based, agricultural water management is a key instrument for enhancing resilience. Water is both an indispensable input and a key constraint. Improved water control, combined soil and water management, and increased water productivity are critical elements in helping farmers manage risks and in sustaining productivity and production. A number of promising pathways have been identified for improving rainfed productivity, but they all depend on water getting to the plant roots in the right quantity and quality at the right time.

Current State of Irrigation and Agricultural Water Management in Drylands

In dryland regions of SSA, rainwater is scarce and erratic, and availability of internal renewable water resources is generally lower than in other regions. Surface water resources are present within the region, as well as groundwater deposits, but often these are located far away from the human population. Mainly for this reason, water resources in the drylands are generally underdeveloped, and many existing dams are underused. Overall, the rate of water withdrawals from internal renewable water resources in dryland countries of SSA is less than one-third of the global average, suggesting that considerable scope exists for further harnessing and developing water resources. Fully irrigated agriculture is a relatively recent practice in most of SSA, and the region has the lowest level of irrigation development in the world. Almost all dryland zones are far from exploiting their (technical) agricultural water management potential.

Farmers in dryland regions often lack adequate supplies of soil moisture needed to achieve a decent yield, and many face total crop failure in times of drought. Many farming households are highly sensitive to soil moisture risk, and when irregular rainfall reduces crop yields, their livelihood is imperiled. Adoption of improved agricultural water management practices can reduce sensitivity and strengthen coping capacity of farming households in drylands by bringing moisture to the plant root zone and ensuring higher levels of productivity. A range of techniques is available for doing this, from simple, low-cost practices designed to capture and conserve rainfall, right up to complex, costly investment in large-scale irrigation systems.

Technical and Economic Scope for Irrigation Expansion in Drylands

As part of the research for this book, a team from the International Food Policy Research Institute (IFPRI) assessed the potential for irrigation development in the drylands of SSA, taking into account a diverse set of technical and economic factors. Depending on investment costs and on the minimum acceptable internal rate of return (IRR), the potential for small-scale irrigation in the drylands ranges from 5.2 to 11.6 million hectares, and the potential for large-scale irrigation ranges from 850,000 hectares to 2.5 million hectares (table ES.1).

Under a medium-cost scenario that assumes capital investment costs of US$12,000 per hectare for large-scale irrigation and US$4,500 per hectare for small scale irrigation, the IFPRI model suggests that approximately 9–10 million hectares could be economically developed for irrigation with acceptable rates of return. This would represent conversion of 7–8 percent of current cropland to irrigation, and even though the area is relatively modest as a share of total cultivated area, a change of this order of magnitude would have a transformational impact on drylands agriculture and livelihoods. The potential impact is especially pronounced in less arid zones, where as much as 10 percent of current cultivated area could be developed for irrigation, whereas in more arid zones, only 2–6 percent of current cultivated cropland could be developed for irrigation. Of the total area that could potentially be developed for irrigation in the drylands, one-half is located in Western Africa (up to 5.2 million hectares), and approximately one-quarter each is located in Eastern Africa (up to 2.7 million hectares) and in Southern Africa (up to 2.5 million hectares) (table ES.2).

Table ES.1 Potential for Irrigation Development in SSA Drylands, by Scale of Irrigation, 2050

Scenario	*Low cost (million ha)*	*Medium cost (million ha)*	*High cost (million ha)*
		Large scale irrigation	
IRR 5%	2.52	**1.60**	1.01
IRR 12%	1.44	1.15	0.85
		Small scale irrigation	
IRR 5%	11.60	**9.07**	6.22
IRR 12%	11.48	8.54	5.16

Source: Xie et al. (2014a).
Note: Baseline scenario of medium cost 5 percent IRR in bold; SSA = Sub-Saharan Africa.

Table ES.2 Potential for Irrigation Development in SSA Drylands, by Region, 2050

SSA region	*Cultivable area ('000 ha)*	*Potential irrigated area ('000 ha) (medium cost, 5% IRR)*			*As % of cultivable area*
		LSI	*SSI*	*Total*	
Central Africa	4,353	87	180	267	6.1
Eastern Africa	37,739	326	2,358	2,684	7.1
Southern Africa	26,472	389	2,159	2,548	9.6
Western Africa	57,481	801	4,378	5,179	9.0
Total	**126,045**	**1,603**	**9,075**	**10,674**	**8.5**

Source: Cultivable area from Ramankutty et al. (2008); other columns: Xie et al. (2014a).
Note: SSA =Sub-Saharan Africa.

Table ES.3 Cost of Developing Irrigation Potential in SSA Drylands

SSA region	*Large-scale irrigation at US$12,000/ha*		*Small-scale irrigation at US$4,500/ha*		*Total potential (Large- and small-scale)*	
	Potential ('000 ha)	*Cost (US$ billions)*	*Potential ('000 ha)*	*Cost (US$ billions)*	*Potential ('000 ha)*	*Cost (US$ billions)*
Central Africa	87	1.04	180	0.81	267	1.85
Eastern Africa	326	3.92	2,358	10.61	2,684	14.53
Southern Africa	389	4.68	2,159	9.72	2,548	14.4
Western Africa	801	9.62	4,378	19.70	5,179	29.32
Total	**1,603**	**19.24**	**9,075**	**40.84**	**10,674**	**60.08**

Source: Xie et al. (2014a).
Note: SSA = Sub-Saharan Africa.

Developing 10 million hectares of new irrigation would require an investment of around US$60 billion, including around US$19.2 billion for large-scale irrigation and US$40.8 billion for small-scale irrigation (table ES.3). Almost one-half of this investment would have to be made in Western Africa, where US$29.3 billion would be needed to develop the total potential of 5.2 million hectares. Eastern and Southern Africa would each require about the same investment envelope: US$14.5 billion to develop 2.7 million hectares in Eastern Africa, and US$14.4 billion to develop 2.5 million hectares in Southern Africa. The total potential of 267,000 hectares in Central Africa could be developed for about US$1.9 billion.

Successful development of the region's irrigation potential could have a transformative impact on the lives of up to 60 million people, or about one-quarter of the total rural population living in the drylands. Because irrigation development has a pronounced multiplier effect, the total impact on local economies could be up to three times the direct income effect. Expanded irrigation would substantially improve the productivity of drylands farming systems and strengthen the resilience of farming households by facilitating diversification, boosting productivity, increasing monetary income, and reducing vulnerability to climatic risks.

What Does It Take to Exploit Potential, and How Can This Strengthen Resilience?

Agricultural Water Management in Rainfed Agriculture: Challenges and Opportunities

Generalizing across the dryland countries in SSA, irrigation will not be feasible for the majority of farmers. Only in Madagascar, Malawi, Guinea and Djibouti can more than 50 percent of the drylands cropped area potentially be developed for irrigation, and beyond those four countries, only in Angola, Ghana, Somalia, Tanzania and Swaziland can more than 20 percent of the dryland cropped area potentially be developed for irrigation. In all other dryland countries, the majority of farm families will continue to rely on rainfed agriculture to sustain their livelihoods. The very poor countries of the Sahel have especially limited irrigation potential. On average, 91 percent of drylands cropland in Western Africa has no irrigation potential.

While irrigation development remains technically unfeasible and/or economically unattractive in many parts of the drylands, alternative methods are often available to provide protection against the potentially devastating impacts of drought. Low-cost, accessible investments in integrated soil and water conservation technologies can improve agricultural water management in rainfed systems in the drylands and improve resilience for large numbers of people. Promoting adoption of these technologies requires flexible and adaptive approaches that empower beneficiaries, build local ownership, ensure inclusion, and pay attention to sustainability. The payoffs to such investments can be high, often reaching 20 percent or more.

Individual Smallholder Irrigation and Small-Scale Community-Based Irrigation: Challenges and Opportunities

Thanks to the availability of low-cost pumps capable of drawing water from both groundwater and surface sources, individual smallholder irrigation is expanding fast in the drylands, especially where there are ready markets for high-value products, such as in towns and cities. Provided water is available and farmers have access to markets, individual smallholder irrigation is often very profitable. In addition to generating increased revenues, individual smallholder irrigation can decrease dependency of individual farmers on others or on the government. At the same time, the spread of individual smallholder irrigation technologies often brings challenges, such as overexploitation of water resources. For this reason, the government may have a role to play in ensuring equitable access to water resources, for example by requiring that individual smallholder irrigation is regulated within a water resources management framework.

The irrigation technology with the greatest potential in the drylands is community-based small-scale irrigation; about 8 million hectares could potentially be developed using this technology. The main constraint to development of community-based small-scale irrigation in the drylands is the lack of technical know-how at the local level for building and operating such systems. An additional constraint is cost: the initial investment cost (up to US$6,000 per hectare) is beyond the reach of many rural households. Finally, ready access is needed to product markets to make the investment viable. Institutional challenges include the need for collaborative organization amongst farmers regarding agreed sets of rules for land and water management, and achieving the right balance between outside support and community and individual responsibility and ownership.

Large-Scale Irrigation Schemes for Smallholders: Challenges and Opportunities

The economic case for large-scale irrigation is based on the advantage of scale. Initial capital investment costs can be very high, however, often in the range of US$12,000 hectare or more. To compound matters, large-scale irrigation schemes in the drylands have in the past suffered from many problems, often with weak underlying economics, lack of a viable institutional model, and technical flaws that resulted in poor water service and diminished water use efficiency (WUE) and crop productivity. In view of these problems, improvement of existing irrigation schemes may be a better investment, unless new projects meet rigorous conditions.

Irrigation improvement on existing schemes could substantially raise yields and water productivity. Potential gains are considerable, especially as costs are low, typically only one-quarter of the cost of new scheme development and with the advantage of an existing institutional base, a working farming system, and relatively experienced irrigation farmers. The technical side of the irrigation improvement agenda includes measures to improve water service, raise WUE, and increase overall water productivity at both farm and scheme level. The institutional side typically involves decentralization and more direct farmer involvement.

Although there is considerable scope for developing new large-scale irrigation schemes in the drylands, the economic, institutional, and technical conditions remain demanding. It is important to design new schemes within the right enabling environment and incentive structure. Water allocations and investments must be optimized at the basin scale and within a water resources and environmental management framework. Furthermore, there is a need for more clearly defined roles and responsibilities of public and private actors. Economic feasibility will depend on finding efficient, least-cost designs, as well as on tapping into value chains that ensure efficient input and output markets and profitable production. The institutional model must provide for efficient management and full coverage of costs of management, operation, and maintenance (MOM). Additionally, land and water tenure must be assured, and, most importantly, farming needs to be efficient, productive, and profitable. Under the right conditions, large-scale irrigation can virtually eliminate vulnerability to drought through assured water service and high cash incomes, but typically these benefits come at a high cost and are available only for a limited number of beneficiaries.

Large-Scale Irrigation Schemes and Public-Private Partnerships: Challenges and Opportunities

Expansion of private, large-scale commercial irrigation schemes can be contemplated where such schemes represent the most economic and equitable way to use resources and generate incomes. In some dryland countries, innovative partnerships have been formed involving private firms, the state, and smallholder farmers. To the extent that these types of public-private partnerships can result in better water service, integrated inputs and advisory packages, and more assured marketing outlets, they can reduce the vulnerability of farming households to drought-related shocks and improve their resilience.

Prioritizing and Acting to Develop the Potential of Agricultural Water Management

Strategies for Agricultural Water Management in Drylands

Under what circumstances would countries in dryland regions of SSA be better off promoting the improvement of rainfed cropping activities, as opposed to promoting irrigation development? Across SSA as a whole, rainfed agriculture produces 90 percent of staple food needs and is much more important than irrigated agriculture with respect to food production. Unlike in most other regions, in SSA production of staples under irrigation is usually not economically viable, unless a profitable cash crop can be grown as part of a multi-crop rotation. This picture is not likely to change much for the foreseeable future. According to Food and Agriculture Organization (FAO) projections, irrigated agriculture is unlikely to contribute more than 10 percent of total food supply in SSA during the next two decades. Future food production increases in SSA are expected to come mainly through intensification of rainfed cropping systems, including rainfed cropping systems in dryland areas, even though yields in drylands are well below SSA averages. The most logical strategy for drylands agriculture therefore will be *to prioritize improving rainfed productivity for most staples while promoting irrigation for higher-value cereals, horticulture, and industrial crops*.

Investment in small-scale irrigation systems in the drylands will rarely lead to a complete transformation in the predominant livelihood strategy; in most cases, small-scale irrigation technologies will serve mainly to increase resilience of mixed rainfed or pastoral systems. In contrast, investment in large-scale irrigation schemes can lead to the emergence of specialized production systems, characterized by economies of scale and feeding into specialized value chains that strengthen household resilience through enhanced cash incomes. In this respect, small-scale and large-scale irrigation will have different impacts on resilience. In regions where mixed irrigated and rainfed systems dominate, small-scale irrigation could provide opportunities for large numbers of poor households to increase their income and reduce production variability. In regions where large-scale irrigated agriculture is feasible, commercial value chains could emerge, propelled by economies of scale, which will provide producers with higher and more stable cash incomes that will considerably reduce their vulnerability to shocks. To the extent that both types of irrigation permit intensification of dryland cropping systems, irrigation development could also create employment opportunities that enhance resilience for a broader segment of the rural population.

Action Plan for Agricultural Water Management in Purely Rainfed Environments

Developing the potential for improved agricultural water management in the drylands could make a significant contribution to strengthening resilience of rural populations, particularly in countries where a large proportion of the population depends on drylands agriculture but irrigation potential is limited (essentially the Sahelian countries), and in countries where drylands are less prevalent but still are home to significant parts of the population and where there is lower potential for developing irrigation (essentially the Eastern African countries).

Throughout much of SSA, many farmers living in dryland regions lack the knowledge, skills, and above all the financial resources to adopt improved production technologies, so governments have put in place policies and programs that promote rural development and technological change, often on a subsidized basis. Such policies and programs are particularly prevalent in the poorest countries, particularly the very poor Sahelian countries, and in areas where irrigation options are unavailable. Best practices for designing and implementing public interventions for agricultural water management development in purely rainfed environments suggest that it is important that the policy framework is conducive to pro-poor agricultural water management development and that there is a market-oriented economy, clear land tenure and water rights, and development policies that support pro-poor growth and rural infrastructure, especially roads. Experience suggests that development programs are best delivered by a single agency or program and that ensuring empowerment and promoting ownership by local people is essential.

Investment in drylands will inevitably be heavily constrained, and economic, socioeconomic, and equity criteria need to be applied to prioritize opportunities for improving agricultural water management. Simulations of potential can be downscaled and matched with locally relevant prioritization criteria, allowing for the selection of appropriate technologies. The last and most important step is to translate top-down strategy into a viable, demand-driven agricultural water management investment program for sustainable improvements in farmer incomes. Essentially, this requires a participatory planning process that reconciles what local people are willing and able to do.

An appropriate initial step would be to review existing strategies and investment plans against the findings and recommendations of this report and to prepare updates with the participation of all national stakeholders, especially farmer groups and representatives, and the collaboration of development partners interested in financing the resulting programs.

Action Plan for Developing the Potential for Expansion of Irrigation in Drylands

Investing in irrigation to reduce poverty and increase resilience in the drylands is a priority for many countries in SSA. Although only about 10 percent of the currently cropped area is technically and economically suitable for irrigation, this 10 percent has the potential to be three times as productive as non-irrigated land and to create three times as much employment. Investment in sustainable, profitable irrigation technologies is therefore a priority as a strategy for reducing poverty, strengthening resilience, and creating a growth dynamic.

The policy framework conducive to successful irrigation development is similar to that for rainfed agricultural water management, but with a greater need for open trade policy, a conducive business environment, and well-functioning infrastructure and logistics. Public agencies are essential for planning irrigation development, but recent experience has shown that public-private partnerships can efficiently implement and manage investments. Given the high cost of irrigation infrastructure, economic viability and sustainability are key when deciding on investments. In all cases, best practices in implementing irrigation investments include working with users' associations and granting them responsibility for operation and maintenance. To realize the potential for expansion, programs for cost sharing or credit will be required to remove barriers to access.

Countries interested in expanding irrigation capacity are generally well advised to consider first modernizing and upgrading existing large-scale irrigation schemes, which is generally more cost-effective than investing in new large-scale schemes. In countries with a relatively high proportion of the population living in the drylands (more than 50 percent) and with more than 10 percent of their drylands categorized as cropland with irrigation potential, developing irrigation potential would be a priority in reducing poverty and improving resilience.

Irrigation Investment Costs and Phasing

Fully realizing the potential for irrigation development in the drylands of SSA will not be cheap: according to IFPRI projections, the total cost would come to approximately US$60 billion. Almost one-half of the total cost (49 percent) would be incurred in Western African countries, including 23 percent in Nigeria alone. Approximately 32 percent of the total investment would be made in large-scale irrigation, which due to its higher cost would account for only about 15 percent of the total irrigated area.

Note

1. **Central Africa**: Burundi, Cameroon, Central African Republic, Congo, Democratic Republic of Congo, and Rwanda; **Eastern Africa:** Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan, Tanzania, and Uganda; **Southern Africa**: Angola, Botswana, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe; **Western Africa**: Benin, Burkina Faso, Chad, Cote d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Mauritania, Niger, Nigeria, Senegal, and Togo.

Abbreviations

AEZ	agro-ecological zone
AI	Aridity Index
ANPIP	*Agence Nigerienne pour la Promotion de l'Irrigation Privée*
AWM	agricultural water management
BCM	billion cubic meters
CDD	community-driven development
CFAF	CFA franc
CGIAR	Consultative Group on International Agricultural Research
CILSS	*Comité permanent inter-État de lutte contre la sécheresse au Sahel*
CWP	crop water productivity
DRC	Democratic Republic of Congo
ECA	Economic Commission for Africa
ERR	economic rate of return
ET	evapotranspiration
FAO	Food and Agriculture Organization (of the United Nations)
FDI	foreign direct investment
GDP	gross domestic product
ha	hectare
ICC	irrigation capital cost
IDA	International Development Association
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis for Agricultural Commodities and Trade
IRR	internal rate of return
IRWR	internal renewable water resources
IWMI	International Water Management Institute
IWUA	irrigation water users' association
LSI	large-scale irrigation

M&E	monitoring and evaluation
MCM	millions of cubic meters
MOM	management, operation and maintenance
MT	metric ton
O&M	operation and maintenance
ONAH	*Office National des Amenagements Hydro-agricoles* (Niger)
PPP	public-private partnership
SAED	*Societé d'amenagement et d'exploitation des terres du delta* (Senegal)
SLWM	sustainable land and water management
SSA	Sub-Saharan Africa
SSI	small-scale irrigation
t	ton
WRM	water resources management
WUA	water users' association
WUE	water use efficiency

CHAPTER 1

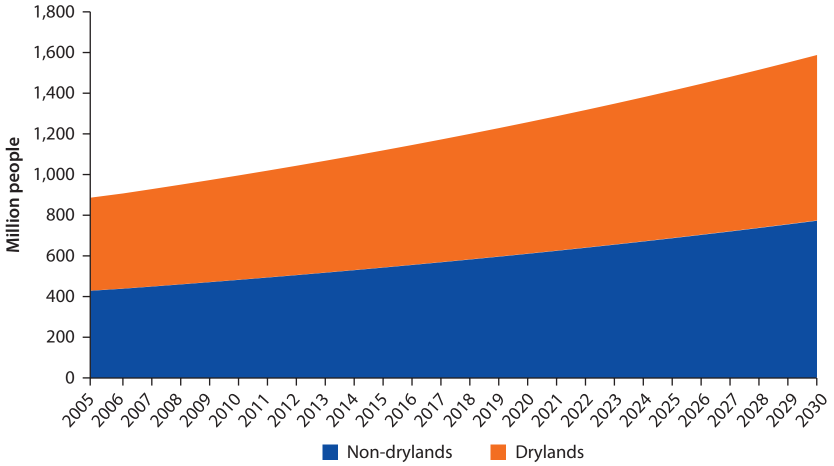
Introduction

The Development Challenge of Drylands in Sub-Saharan Africa

Drylands in Sub-Saharan Africa (SSA), defined here to include arid, semi-arid, and sub-humid areas, account for nearly one-half (43 percent) of the region's land area, one-half of its population, and three-quarters of its agricultural land. Three-quarters of Africa's poor (those living on less than US$1.25 per day) live in countries containing significant dryland areas.

Within the drylands, demographic pressure is intense and growing. It is expected that by 2030, assuming no outmigration, some 350 million extra people will be added to the existing population of about 390 million. This is a cause for concern, as the drylands have limited natural resources to support even the current population (figure 1.1).

Figure 1.1 Population Growth, Drylands vs. Non-drylands, SSA, 2005–2030



Source: Calculations based on data from LandScan (2005).
Note: SSA = Sub-Saharan Africa.

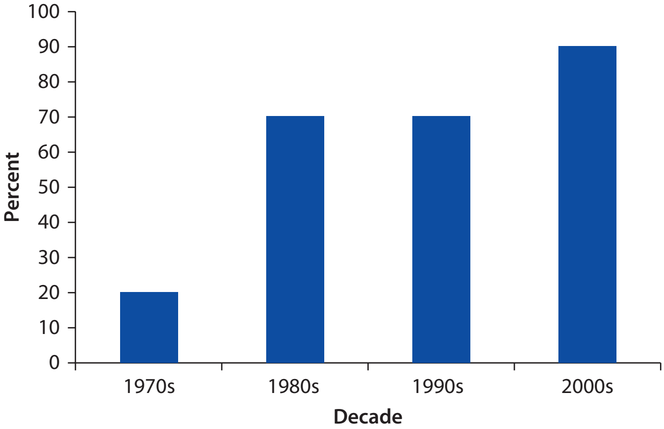
Because many of the people living in the drylands of SSA are poor in natural resources, assets, and income, they are highly vulnerable to shocks and have limited adaptation options. Adverse weather shocks are common and growing, with the frequency and duration of droughts increasing (figure 1.2).[1] Dryland areas and countries are also vulnerable to economic shocks, most recently in response to spikes in world prices of food and petroleum. In addition, social conflict is pervasive, and the impacts are severe: the Sahel region is home to more than 500,000 internally displaced people and 400,000 refugees, while the Horn of Africa is home to more than 4 million internally displaced people and 2.5 million refugees.

Compared to more humid areas, African drylands have lower population densities and their populations have generally poorer market access and limited options to adapt to the hot, dry climate and its vagaries.

The Africa Drylands Study

Despite numerous efforts to improve the circumstances of dryland inhabitants and lift them out of poverty,[2,3] there have been few if any sustained large-scale successes. Results have been positive but short-lived, and encouraging pilots have rarely been taken to scale. Multiple parallel conversations have led to a large range of views and an overall lack of consensus on how to build resilience for SSA dryland inhabitants into development planning. The scale of the challenge has led to calls for more systematic approaches to strengthening the resilience of people living in drylands. With this motivation, a broad coalition of development partners[4] joined hands to prepare a comprehensive study on

Figure 1.2 Frequency of Severe Droughts, SSA Dryland Countries, 1970s through 2000s (percent)



Source: EM-DAT (2015).
Note: SSA = Sub-Saharan Africa.

prospects for enhancing resilience in African drylands, for which this book serves as one of several background pieces.

The goal of the overall study is to improve understanding of the present and future vulnerability of people living in the drylands of SSA and to help identify effective interventions to strengthen their resilience. The study has five specific objectives: (i) characterize current and future challenges to reducing vulnerability and increasing resilience in drylands; (ii) develop an analytical framework for assessing the relative effectiveness of different interventions; (iii) estimate the likely cost of the investments needed at the national, subregional, and regional levels to reduce vulnerability; (iv) generate information and guidelines to inform policy making; and (v) promote sharing of regional and global knowledge.

The conceptual framework for the overall study calls for an assessment of policy priorities for resilience to shocks of people living in drylands. The study addresses issues of resilience at the individual and household level, at the local and subnational level, and at the national level. Resilience is assessed across three dimensions: (i) reducing exposure to shocks; (ii) reducing sensitivity to shocks; and (iii) increasing capacity to cope with shocks. The overall study is designed to reveal common challenges, generate new knowledge, and identify solutions that can be applied across several countries or can deal with common challenges.

Objectives of This Book on Agricultural Water Management

Two defining characteristics of the drylands are (i) the aridity of the environment, and (ii) the dependence of the majority of the population on agriculture as a main source of livelihood. In the face of these characteristics, dryland populations are highly vulnerable to climatic shocks, outbreaks of pests and diseases, and price volatility.

Productivity growth in drylands agriculture can be accelerated if controlled water can be added to the system. It is the purpose of this book to demonstrate the transformational role of water and water management in drylands agriculture and to assess the technological and socioeconomic conditions and policy and institutional frameworks that can remove barriers to adoption and allow take-up of improved agricultural water management on a wide scale in the SSA drylands.

The objectives of this book on agricultural water management include:

- Describing the extent to which agricultural water management interventions can enhance resilience and improve the well-being of people living in SSA drylands, under which conditions, and at what cost;
- Proposing what can realistically be done to promote improved agricultural water management in SSA drylands; and

- Assessing the most appropriate ways to approach agricultural water management and irrigation development, including identifying the prospective roles of various stakeholders.

The book is structured as follows. Chapter 2 assesses the potential role of agricultural water management in increasing resilience to shocks in the drylands of SSA. Chapter 3 reviews the current status of agricultural water management and irrigation, reviewing in turn improvements to rainfed agriculture, various forms of private irrigation, and larger-scale irrigation, both publicly developed schemes and schemes developed as partnerships between the public and private sectors. Drawing on the results of a separate study done by International Food Policy Research Institute (IFPRI) in 2014, chapter 4 assesses the potential for irrigation development in SSA drylands. Chapter 5 evaluates the key challenges and constraints in exploiting the agricultural water management development potential to strengthen resilience. Chapter 6 proposes a strategic framework for developing agricultural water in the drylands and lays out approaches for turning policies and strategies into action plans and investment programs together with their costs. Finally, chapter 7 summarizes key findings and recommendations.

Notes

1. Figures refer to droughts in Botswana, Burkina Faso, Central African Republic, Chad, Djibouti, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mali, Mauritania, Namibia, Niger, Nigeria, Senegal, Somalia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. *Source*: EM-DAT (2015).
2. For example: AGIR (Sahel), Technical Consortium (Horn of Africa), Sahel Initiative (World Bank), and Great Green Wall (World Bank).
3. For example, amongst regional organizations: CILSS (*Comité permanent inter-état de lutte contre la sécheresse au Sahel*), IGAD (Inter-Governmental Authority on Development), ECOWAS (Economic Community Of West African States). Amongst multilaterals: World Bank, Asian Development Bank, IFAD (International Fund for Agricultural Development), United Nations Development Programme, FAO (Food and Agriculture Organization), World Food Programme, World Health Organization. Amongst bilaterals: European Commission, United States Agency for International Development, *Agence Française de Développement*, GTZ (German Technical Cooperation Agency), UK's Department for International Development, Japan International Cooperation Agency. Among CGIAR (Consultative Group on International Agricultural Research) Centers: ICARDA (International Center for Agricultural Research in the Dry Area), ILRI (International Livestock Research Institute), ICRAF (World Agroforestry Centre), IFPRI (International Food Policy Research Institute), IWMI (International Water Management Institute), ICRISAT (International Crops Research Institute for the Semi-Arid-Tropics).
4. The development partners involved are: World Bank, FAO, IFPRI, ILRI, ICARDA, ICRAF, and CIRAD (Agricultural Research for Development)/CILSS (Permanent Interstate Committee for Drought Control in the Sahel).

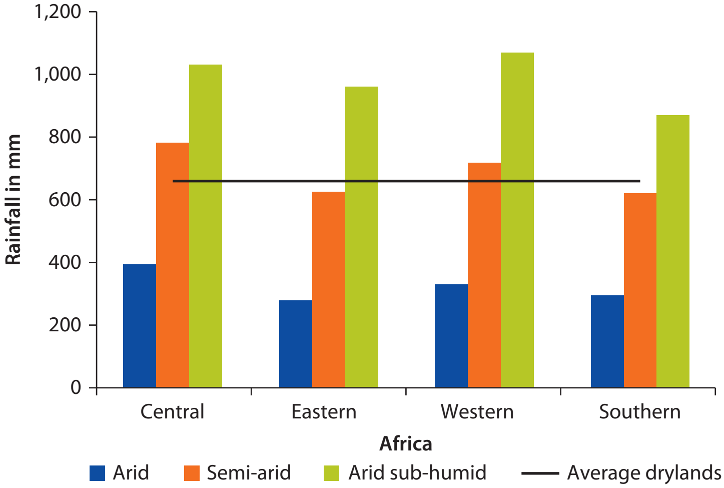
CHAPTER 2

Agricultural Water Management, Vulnerability, and Resilience

Drylands in Sub-Saharan Africa

Drylands can be defined on the basis of different criteria (for example, length of growing period, rainfall, aridity). The definition adopted here is based on the degree of aridity as measured by the Aridity Index (AI).[1] Aridity is not based on rainfall alone but on the mix of rainfall, temperature, and wind that determines the balance between rainfall and rates of evaporation. Although average annual precipitation across Sub-Saharan Africa (SSA) (795 millimeters) is only slightly less than the world average (815 millimeters), and even the SSA drylands still

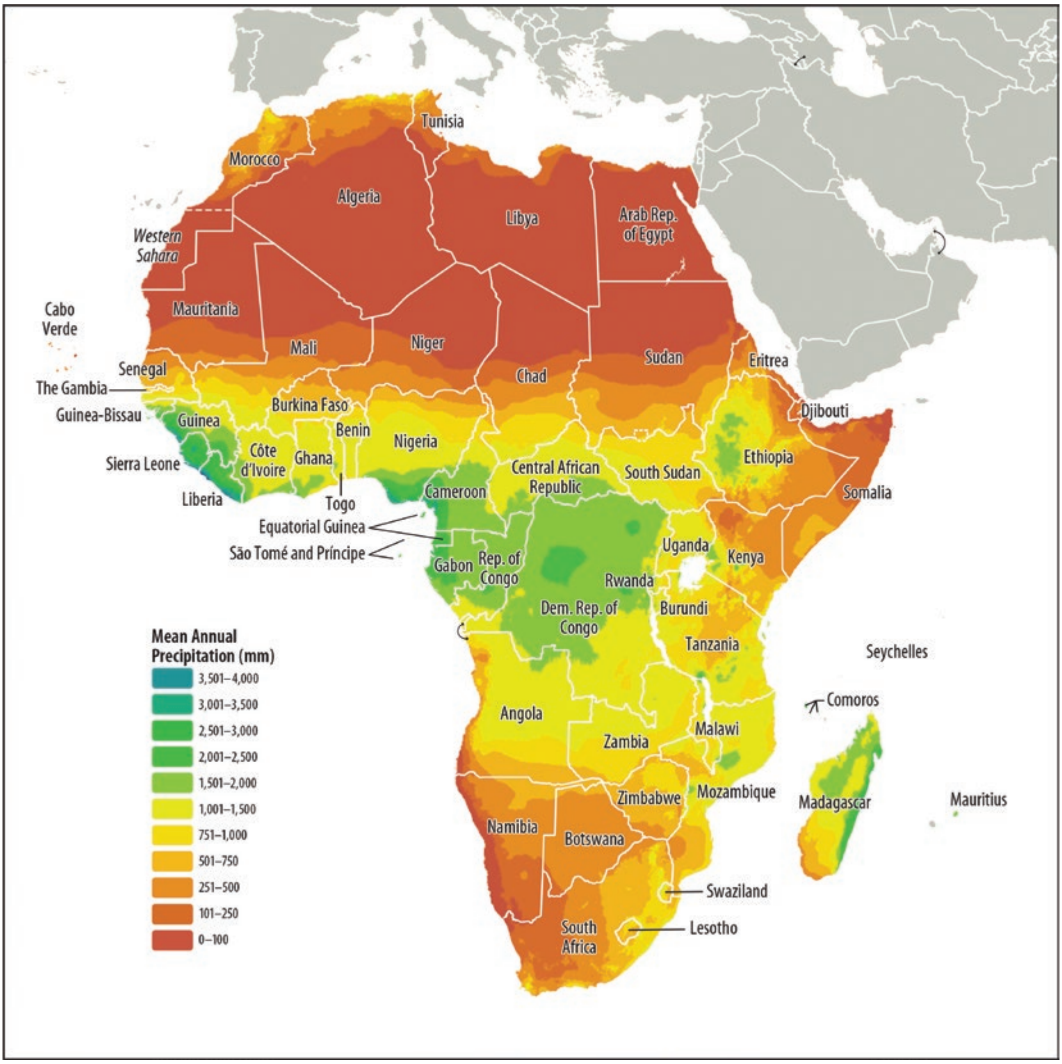
Figure 2.1 Annual Precipitation in Aridity Zones, by SSA Region



Source: IFAD (2008).
Note: IFAD = International Fund for Agricultural Development; SSA = Sub-Saharan Africa.

average 665 millimeters, SSA experiences very high aridity and consequently contains very large dryland areas due to the influence of high temperatures and drying winds. Additionally, the range of precipitation is very wide across SSA, from less than 100 millimeters per year in the Shelia strip and parts of Southern Africa up to more than 2,000 millimeters on the Gulf of Guinea and on the east coast of Madagascar. Figure 2.1 and map 2.1 show the average annual amount of precipitation occurring in the different aridity zones, broken down by SSA region and isohyet, respectively.

Map 2.1 Average Annual Precipitation by Isohyets



Source: World Bank based on data from NEMA Uganda (http://www.nemaug.org/).

Table 2.1 Aridity Index (AI) Ranges Used to Define Dryland Zones

Dryland zone	*AI range*
Hyper-arid	0.00–0.05
Arid	0.05–0.20
Semi-arid	0.20–0.50
Dry sub-humid	0.50–0.65

For purposes of the present study, drylands are defined as regions having an AI of 0.65 or less. Drylands are furthermore subdivided into four aridity zones: hyper-arid, arid, semi-arid, and dry sub-humid based on their AI value (their ranges are shown in table 2.1).

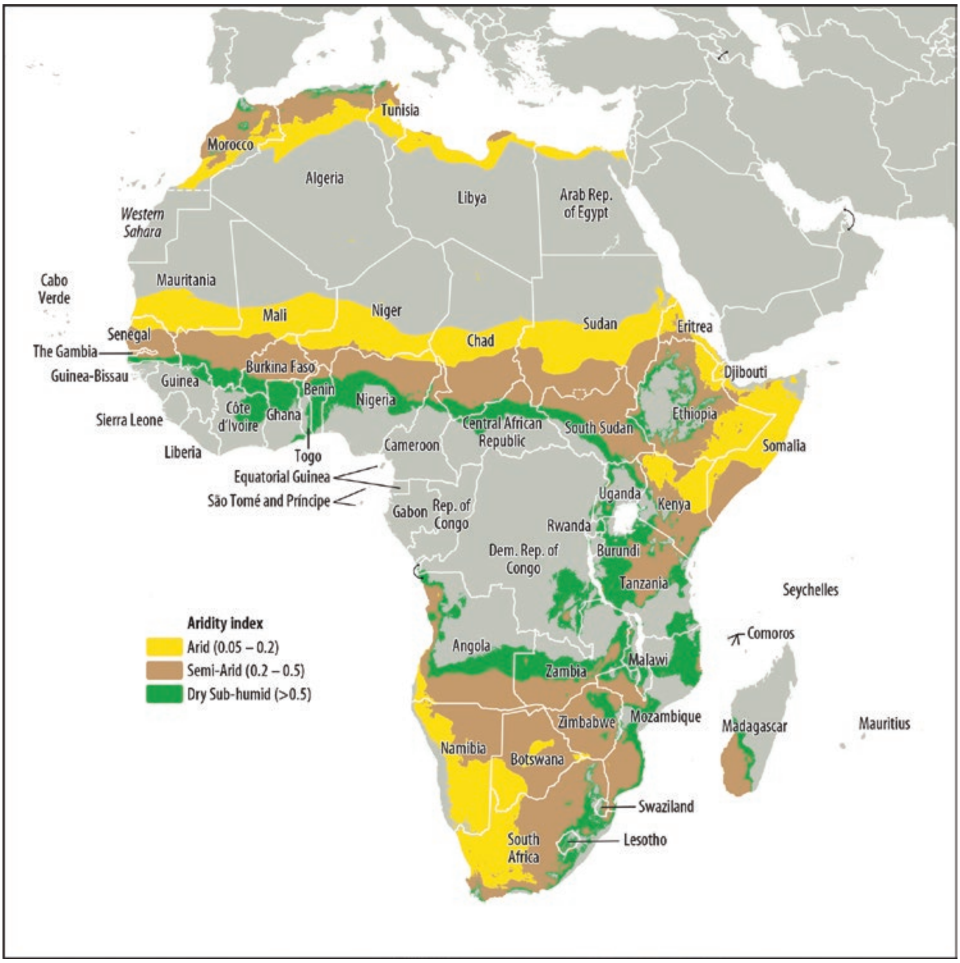
Because the hyper-arid zone (AI < 0.05) is incapable of supporting crop and livestock production activities, it is very sparsely populated and therefore is not considered here. For purposes of the overall study and this book, drylands are defined as areas characterized by an AI of 0.05 to 0.65, covering the arid, semi-arid, and dry sub-humid zones.

Defined on the basis of the AI, drylands make up nearly 55 percent of SSA, representing about 13 million square kilometers. Of this, the arid and semi-arid zones make up about 42 percent of the SSA land area, and the dry sub-humid zone another 13 percent. Map 2.2 shows how the drylands lie in a broad swath across the Sudan-Sahelian belt, extending south well into the Gulf of Guinea geographical zone. A second belt runs southwards down from the Horn of Africa and the Ethiopian foothills into Eastern Africa, and a third concentration runs right across Southern Africa.

Within the dryland areas of "dryland countries,"[2] the semi-arid zone typically predominates (figure 2.2). However, in the very poor countries of the Sahel (Chad, Mauritania, Mali, and Niger), the arid zone predominates, as it does as well in Somalia and northern Kenya and in significant areas of southern and eastern Ethiopia.

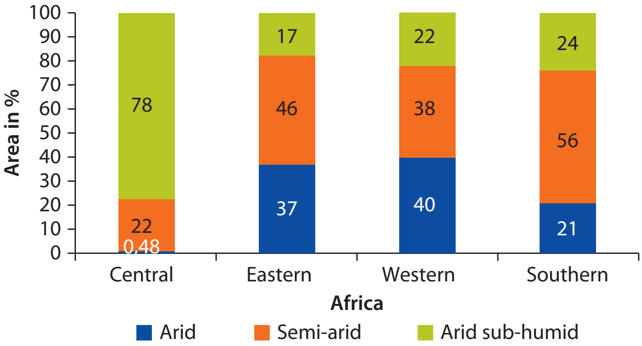
Defined in this way, dryland regions in SSA contain about 390 million people (figure 2.3), or roughly 48 percent of the region's total population. More than two-thirds of these (264 million people, or 68 percent of the total) live in rural areas (table 2.2). The highest concentration of population is in the drylands of Western Africa, where more than 90 million people live in semi-arid zones and more than 19 million live in arid zones (figure 2.4). The drylands of Eastern Africa also contain a large population: 56 million people live in the arid and semi-arid zones, and more than 51 million in the dry sub-humid zone. Poverty is high, with one-half or more of the population of drylands existing on less than US$1 a day (IFAD 2008).

Map 2.2 Dryland Zones Defined in Terms of AI



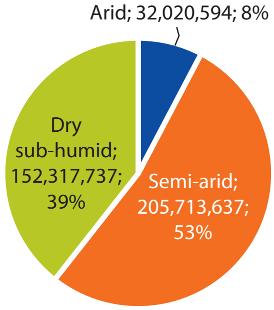
Source: World Bank based on data from HarvestChoice, IFPRI (2013).
Note: IFPRI = International Food Policy Research Institute; AI = aridity index.

Figure 2.2 Characteristics of Drylands, by SSA Region



Note: SSA = Sub-Saharan Africa.

Figure 2.3 Total Population in the Three SSA Dryland Zones, 2010



Source: HarvestChoice (2013).

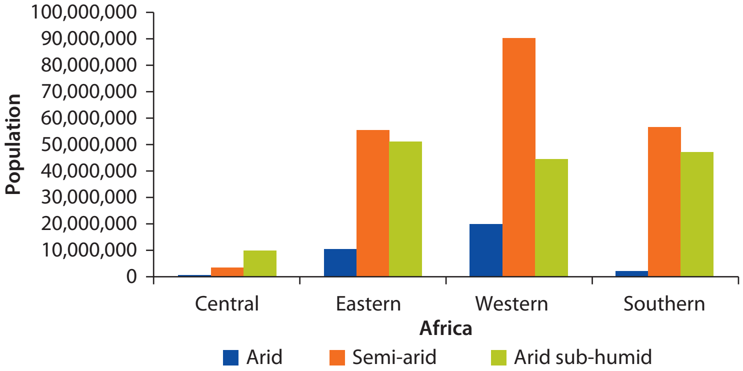
Note: SSA = Sub-Saharan Africa.

Table 2.2 Share of Population in Dryland Zones of SSA That Is Rural, 2010

	Dryland zones in SSA	*SSA*
Total population (millions)	390.1	857.2
Rural population (millions)	263.9	536.3
Percent	68	62

Source: HarvestChoice (2013).
Note: SSA = Sub-Saharan Africa.

Figure 2.4 Population Living in SSA Dryland Zones by Region



Source: HarvestChoice (2013).
Note: SSA = Sub-Saharan Africa.

Agriculture in the Drylands

Most inhabitants of SSA drylands depend on agriculture as their primary livelihood source. Regionally, agriculture employs 62 percent of the population in drylands and generates 27 percent of gross domestic product (GDP), consistent with the global pattern of labor productivity in agriculture being much lower than in other sectors. The share of agriculture in GDP varies across countries, however. Agriculture accounts for as little as 15 percent of GDP in Senegal and Mauritania and as much as 40 percent of GDP in Mali. Agriculture is also important in terms of trade: agricultural exports make up 14 percent of total exports from Southern Africa and 10 percent of total exports from Western Africa (FAO 2006; World Bank 2006; IFAD 2008).

Drylands occupy just over one-half (54 percent) of the total land area of SSA (1,300 million hectare out of a total 2,400 million hectares). The drylands cropped area (table 2.3) is 126 million hectares, of which almost one-half (45 percent) is found in Western Africa and 30 percent in Eastern Africa. The largest dryland cropped areas are found in Nigeria (19.8 million hectares), Sudan

Table 2.3 Cultivable Area, SSA Drylands ('000 Hectare)

SSA region and country	*Dryland cultivable area ('000 ha)*
Eastern Africa	
Djibouti	1
Eritrea	518
Ethiopia	7,467
Kenya	4,316
Somalia	1,093
Sudan	16,729
Tanzania	3,503
Uganda	4,111
Sub-total	***37,738 (30%)***
Western Africa	
Benin	2,540
Burkina Faso	4,348
Chad	3,527
Cote d'Ivoire	2,378
Gambia	261
Ghana	1,833
Guinea	31
Guinea-Bissau	17
Mali	4,531
Mauritania	820
Niger	13,809
Nigeria	19,801
Senegal	2,369
Togo	1,216
Sub-total	***57,481 (46%)***

table continues next page

Table 2.3 Cultivable Area, SSA Drylands ('000 Hectare) *(continued)*

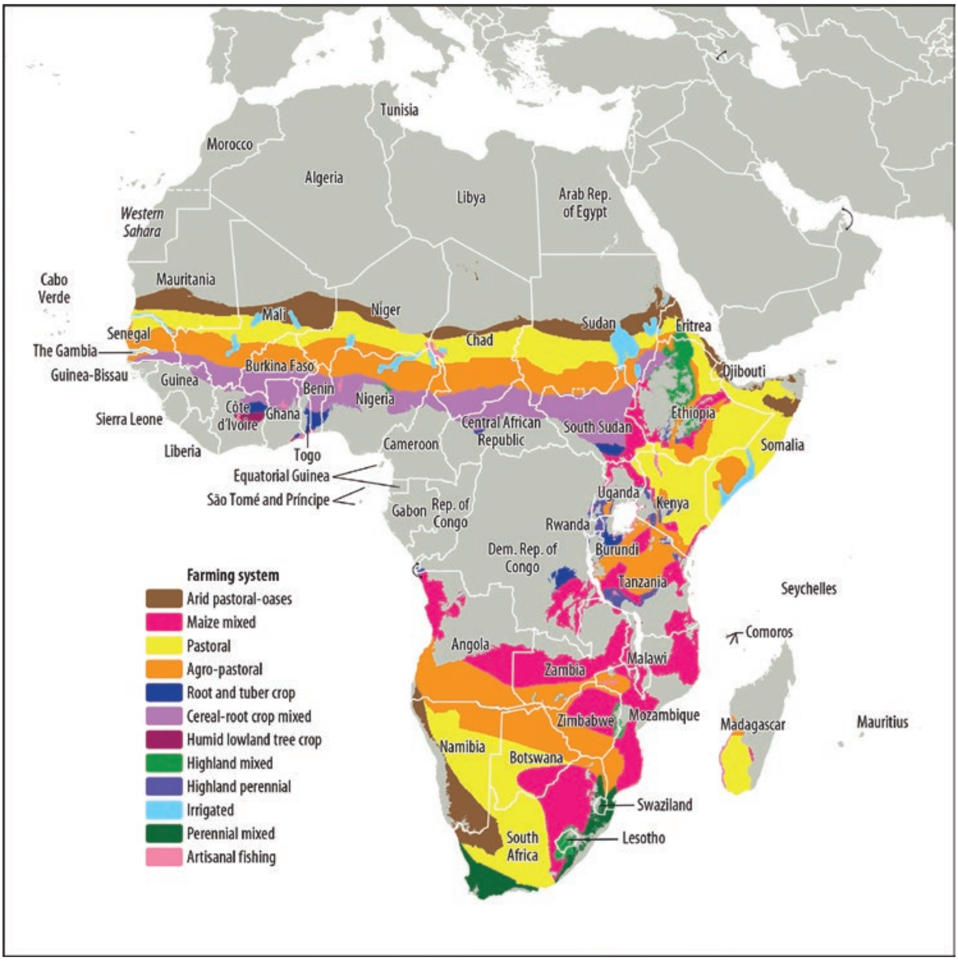
Southern Africa	
Angola	1,085
Botswana	828
Lesotho	226
Madagascar	682
Malawi	830
Mozambique	2,403
Namibia	812
South Africa	13,512
Swaziland	103
Zambia	2,677
Zimbabwe	3,313
Sub-total	**25,724 (20%)**
Central Africa	
Burundi	97
Cameroon	1,270
Central African Republic	867
Congo, Rep.	..
Congo, Dem. Rep.	1,792
Rwanda	326
Sub-total	**4,352 (3%)**
TOTAL	**126,045 (100%)**

Source: HarvestChoice (2013).
Note: SSA = Sub-Saharan Africa. .. = negligible.

(16.7 million hectares), Niger (13.8 million hectares), South Africa (13.5 million hectares), and Ethiopia (7.5 million hectares).

As shown in map 2.3, 12 of SSA's 13 farming systems are present in dryland regions.[3] Only *Forest-based* farming systems are not represented in drylands. The most important farming system found in drylands is the *Agro-pastoral* system (340 million hectares, with 120 million people) (table 2.4). Other important systems found in the drylands include the *Maize mixed* system (230 million hectares, 58 percent of the SSA total, with 81 million people living in that part of the dryland area); the *Cereal-root crop mixed* system (150 million hectares, 73 percent of the SSA total, 44 million people); and the *Perennial mixed* system (23 million hectares, 76 percent, 15 million people). Important in terms of area but with a much smaller share of the population is the *Pastoral* system, 360 million hectares. Only one-tenth of the dryland population (39 million out of 390 million) lives in these vast and largely arid areas. These five farming systems cover approximately 1.1 billion hectares (85 percent of the total dryland area) and provide livelihoods for two-thirds of the population living in those areas.

Map 2.3 Farming Systems Found in SSA Drylands



Source: World Bank based on data from HarvestChoice, IFPRI (2013).
Note: SSA = Sub-Saharan Africa.

Table 2.4 Areas and Populations of Farming Systems, SSA Drylands vs. SSA Total, 2010

		Area (ha)			*Population (number)*		
	Farming system	*SSA drylands*	*SSA total*	*%*	*SSA drylands*	*SSA total*	*%*
1	Arid pastoral—oases	114,674,213	459,948,473	25	4,279,538	5,649,497	76
2	Maize mixed	226,942,240	394,037,338	58	81,442,391	143,214,419	57
3	Pastoral	357,435,078	362,226,346	99	38,569,201	40,854,187	94
4	Agro-pastoral	336,977,976	361,915,616	93	120,469,580	128,755,565	94
5	Root and tuber crop	16,781,941	224,352,296	7	8,355,772	99,054,363	8
6	Cereal-root crop mixed	149,848,446	205,106,634	73	44,055,179	73,188,538	60
7	Forest-based	0	135,583,865	0	0	15,659,659	0
8	Humid lowland tree crop	3,444,880	63,080,787	5	4,363,912	73,517,683	6

table continues next page

Table 2.4 Areas and Populations of Farming Systems, SSA Drylands vs. SSA Total, 2010 *(continued)*

		Area (ha)			*Population (number)*		
	Farming system	*SSA drylands*	*SSA total*	*%*	*SSA drylands*	*SSA total*	*%*
9	Highland mixed	20,400,095	47,317,089	43	23,458,096	58,862,781	40
10	Highland perennial	14,244,740	41,841,870	34	19,487,103	79,477,002	25
11	Irrigated	29,192,804	35,800,402	82	19,994,389	19,994,389	100
12	Perennial mixed	22,823,343	30,101,801	76	15,300,438	25,204,233	61
13	Artisanal fishing	6,228,041	24,420,418	26	10,276,370	55,425,150	19
	Total	**1,298,993,797**	**2,385,732,935**	**54**	**390,051,968**	**818,857,466**	**48**

Source: HarvestChoice, IFPRI (2013).
Note: SSA = Sub-Saharan Africa.

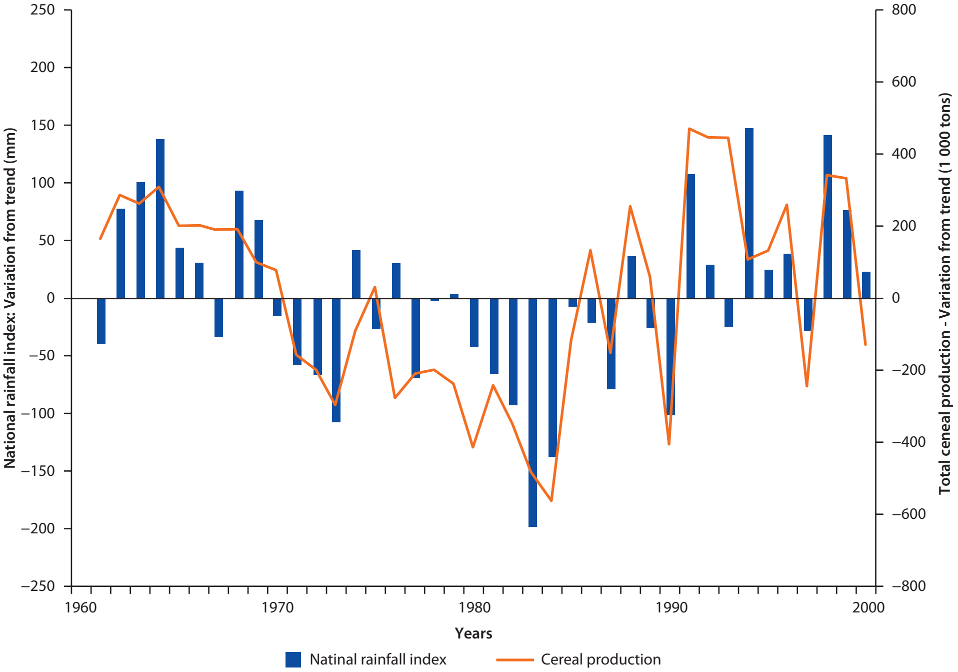
Vulnerability and Risks Associated with Drylands Agriculture

The first and most important fact about rainfed agriculture, the predominant system in the drylands, is that agricultural production is closely correlated with rainfall. In Burkina Faso, for example, over the 40 years between 1960 and 2000, cereals production almost exactly followed variations in rainfall (figure 2.5). Due to the importance of rainfed agriculture in the national economies of SSA dryland countries, GDP also tends to move in line with agricultural production. In Ethiopia, for example, over the 10 years between 1997 and 2006, agricultural output and GDP moved in very close harmony, with declines in agricultural production leading to equivalent declines in GDP (figure 2.6). As water is a key constraint in drylands agriculture, improving water control must therefore be an important component of packages to increase productivity, production, and ultimately economic growth.

Farmers in drylands face continual weather-related challenges, which introduce risk and uncertainty into their productive activities. For example, most dryland zones are subject to enormous variability in the length of the rainy season (which in many areas can last from as little as two months to as much as six months), in the distribution of rainfall within the season (which may not coincide with germination and crop water requirements), and in the nature of rainfall events (which may occur in destructive downpours leading to rapid runoff, with little infiltration into the soil profile). Extreme temperatures, uncontrolled bush fires, and erosive winds can pose additional risks.

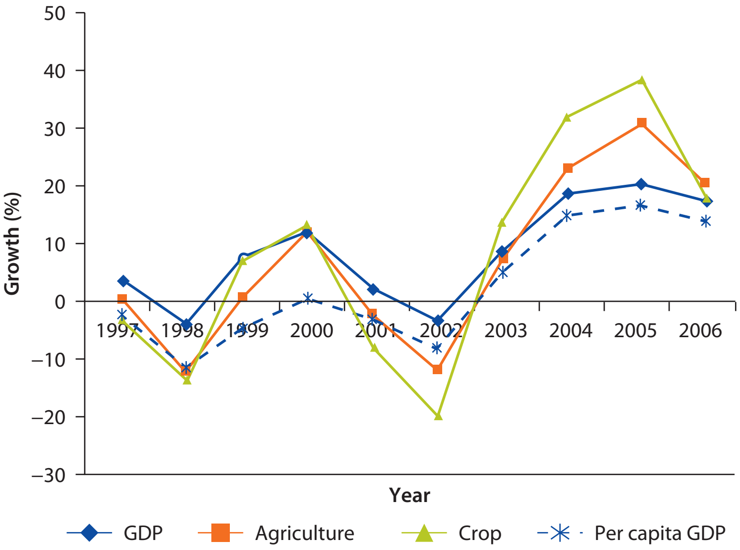
Over the longer term, the negative impacts of weather may be exacerbated by climate change. Although the risks from climate change are uncertain and vary according to location and farming system, there is a likelihood of negative impacts in most locations from increased temperatures, greater rainfall variability, and more extreme weather events. Studies predict probable large negative impacts on SSA agriculture, including a 12 percent loss of "cultivation potential" by 2080, mostly in the already vulnerable Sudan-Sahelian drylands.[4] An increase in farmer risk and risk-averse behavior is expected. Without mitigating

Figure 2.5 Rainfall and Cereals Production, Burkina Faso, 1960–2000



Source: Molden (2007).

Figure 2.6 GDP, Agriculture, Crop Production, and Per Capita GDP Growth, Ethiopia, 1997–2006



Source: Makombe et al. (2012).
Note: GDP = gross domestic product.

action, cereal production will drop below trend in many countries, and an overall reduction in food production and agricultural GDP is possible. Negative impacts are also expected on livestock, the main asset and coping strategy of the poorest. Improved water control, combined soil and water management, and water productivity will therefore be critical elements in helping farmers manage risks and in sustaining productivity and production (IFAD 2008; Molden 2007).

Productivity is also constrained by inherently poor soil qualities and by continual land degradation. Low soil fertility and nutrient depletion are chronic problems, with an estimated three-quarters of dryland soils now showing symptoms of one or more plant nutrient deficiencies. Most dryland soils are inherently low in organic matter, and the scarcity of natural vegetation and the prevalence of extractive rangeland management systems in the drylands contribute to poor soil nutrient status. Thirty-seven percent of the land that is currently cultivated is classified as "constrained" based on low soil nutrients. In SSA drylands, the nutrient balance of farming is highly negative, with on average four times more nutrients being removed in harvested products than being returned in the form of manure and mineral fertilizer. Lack of macronutrients is not the only challenge; deficiencies in key micronutrients such as zinc, boron, and sulfur threaten farming as well.[5] Poor soils also reduce the soil profile's water-retention capacity and result in increased runoff and percolation, reducing the moisture available to plant roots. Actions designed to improve soil consistency and nutrients therefore must accompany actions to improve water control. Uncontrolled burning and attack by insects such as locusts and army worms can further impair productivity and increase risk in drylands cropping systems (FAO 2011; Molden 2007).

Productivity is further constrained by the socioeconomic profile of farming populations. The drylands are characterized by a very poor and sparse population with low disposable income, a largely subsistence economy, high poverty levels, scant household assets or access to working or investment capital, and limited market access. The combination of harsh production conditions, farmers' naturally risk-averse reactions, and poverty contribute to SSA drylands dwellers' high vulnerability and low levels of resilience.

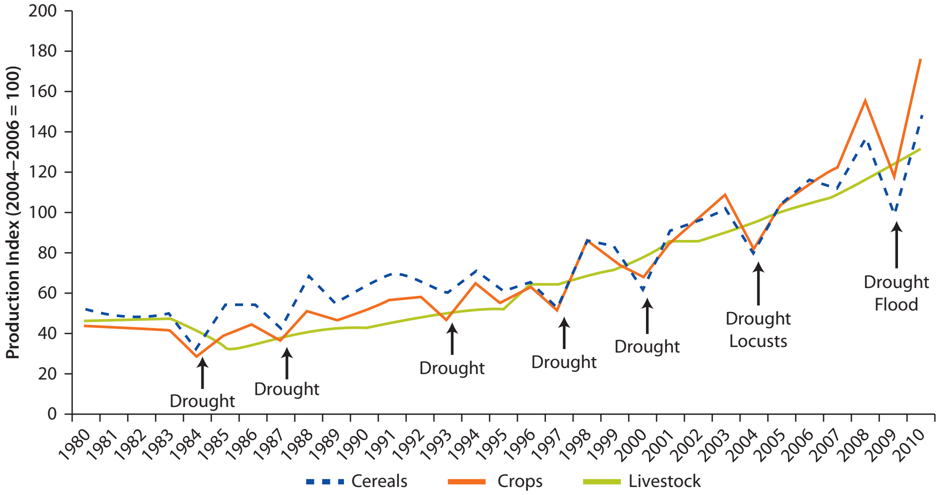
People living in the drylands have responded to the harsh conditions by developing low-tech, inherently risk-averse and low-yield farming systems that are adapted to local conditions. There are multiple barriers to intensification in terms of lack of natural resources, technology, and capital, and negligible means for managing the increased risk involved, including market risks. As a result, dryland smallholders, subsistence farmers, and pastoralists have extremely low resilience to shocks, as well as a low adaptive capacity due to low levels of livelihood assets (IFAD 2008).

Dryland countries have achieved significant improvements in productivity, but they remain vulnerable to climate, pests, and sociopolitical factors. Even where countries systematically invest in risk management and achieve significant agricultural growth as a result, as has happened for example in Niger, production remains highly vulnerable, particularly to drought but also to floods and pests. This vulnerability, combined with other factors such as instability and population increase, has resulted in erratic, often negative, per capita GDP growth and widespread household-level vulnerability (figures 2.7 and 2.8).

Increasing Resilience through Improved Technologies[6]

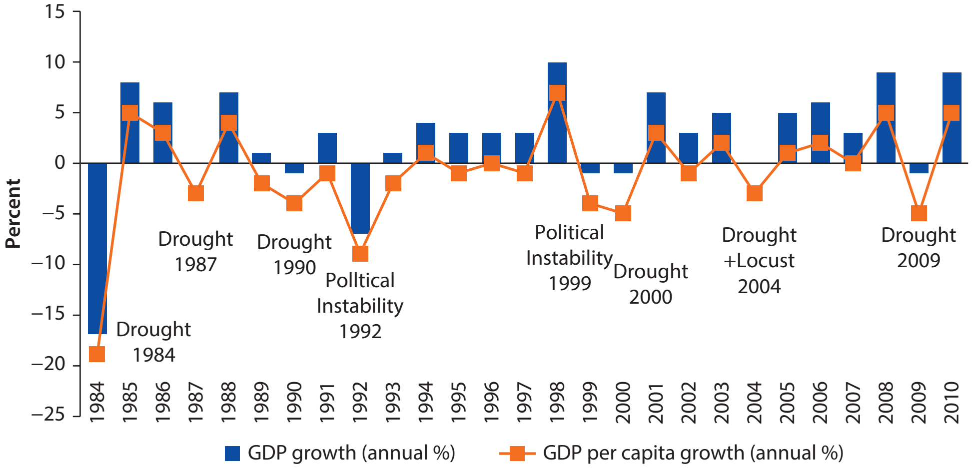
Because the majority of people living in dryland regions of SSA depend on agriculture and will continue to do so for the foreseeable future, increasing productivity and incomes from agriculture is key to reducing vulnerability,

Figure 2.7 Major Shocks to Crop and Livestock Production, Niger, 1980–2010



Source: World Bank (2013).

Figure 2.8 Risk Factors Affecting GDP Growth, Niger, 1984–2010



Source: World Bank (2013).

Note: GDP = gross domestic product.

increasing resilience, fostering growth, and reducing poverty. The challenge of increasing the productivity of drylands agriculture cannot be avoided.

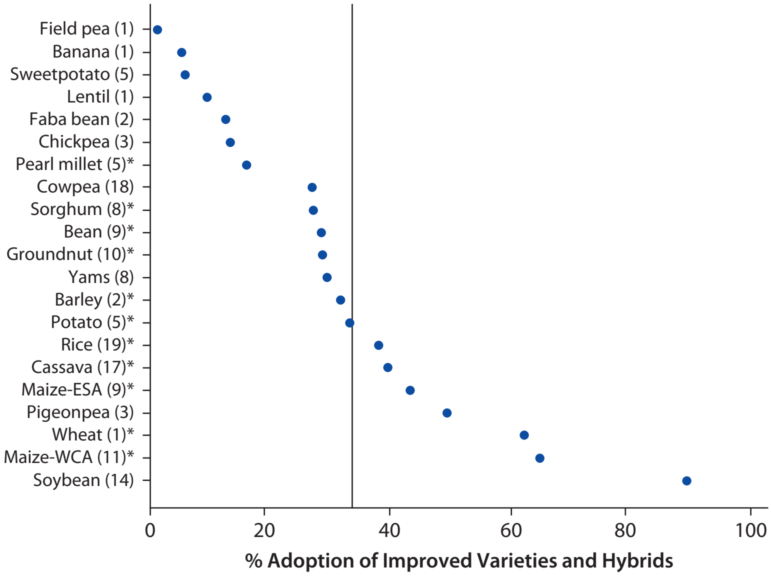
Despite the harshness of the environment, drylands have a number of agroclimatic features that are advantageous for agriculture, such as high levels of solar radiation and a relative absence of pests and diseases. These features confer possibilities for productivity gains. Where there are profitable markets and particularly where farmers have access to reliable water supplies, technological change can occur rapidly, bringing income gains, reduced poverty, and increased resilience.

Three opportunities for accelerating the pace of technological change in drylands offer particularly bright prospects: (i) accelerating the rate of varietal adoption; (ii) increasing the availability of hybrids; and (iii) promoting improved soil fertility management practices.

Accelerating the Pace of Varietal Adoption

Modern varieties of cereals such as rice, wheat, and maize played a major role in driving the Green Revolutions of Asia and Latin America, but have had much less impact in SSA, where their adoption has lagged. Across SSA as a whole, the average rate of adoption of modern varieties in 2010 among 20 field crops stood at around 35 percent (figure 2.9). While this adoption rate is considerably lower than the rate achieved in other developing regions, the uptake in Africa has accelerated in recent years, particularly for maize and cassava, the leading dryland cereal and root crop. If current adoption rates continue, two-thirds of dryland areas could be sown to modern varieties by 2030.

Figure 2.9 Adoption of Modern Varieties in SSA, Selected Crops, 2010 (percent of harvested area)



Source: Walker et al. (2016).

Note: SSA = Sub-Saharan Africa.

Increasing the Availability of Hybrids

Thanks to the phenomenon of heterosis (commonly known as "hybrid vigor"), well-adapted hybrids have two main advantages over well-adapted improved varieties: (i) higher yield potential; and (ii) greater yield stability. Because these advantages of hybrids are assured only when farmers purchase new seed for every cropping cycle, it is essential that farmers replace hybrid seed regularly, creating incentives for private companies to make sure that the market is well supplied. Yet despite the superior performance of hybrids and the stronger incentives for seed companies, adoption of hybrids remains low in many dryland regions, and hybrid seed remains scarce in local markets. Increasing the availability of hybrids could increase resilience, especially for maize, sorghum, and pearl millet in Western Africa, which accounts for about 40 percent of the dryland cropped area in SSA.

Promoting Fertility Management Technologies

Because low soil fertility constitutes a major constraint to farming in the drylands, diffusion of improved fertility management practices is essential for the sustainable intensification of dryland agriculture. Numerous improved practices have demonstrated their effectiveness under diverse dryland conditions, including mulching, green manuring, composting, intercropping with legumes, and judicious use of mineral fertilizer. The impact of improved soil fertility management technologies is amplified when modern varieties are introduced at the same time, due to synergistic effects between improved germplasm and improved management practices.

These and other improvements could contribute to productivity and strengthened resilience for the dryland population, but they all depend on water getting to the plant roots in the right quantity and quality and at the right time.

Increasing Resilience through a More Secure Agricultural Water Supply and Improved Agricultural Water Management

Productivity growth in drylands agriculture can be accelerated if controlled water can be added to the system. Irrigation and improved management of agricultural water therefore can have a transformational role and increase household resilience to shocks by: (i) improving the availability of water to the plant roots; and (ii) increasing the productivity of water use, resulting in more net income per unit of water consumed. If these changes can be effected, provided profitable markets are accessible, in association with the kinds of agronomic innovation discussed above, agricultural water management can have a transformational role on farming systems and on household incomes and resilience to shocks.

The multiple benefits of agricultural water management that can increase resilience at the household level include:

- Increased productivity and production;
- More stable production;

- Double cropping and agricultural employment in the off-season;
- Improved household food security and nutrition (dietary diversity); and
- More stable and increased disposable income at household level (Peacock and Ward 2007; IFAD 2008).

Under the right conditions, agricultural water management can also contribute significantly to reduced poverty and improved nutrition. The incidence of malnutrition is highest in drylands, and agricultural water management that helps to increase household incomes and food availability is likely to improve nutrition.[7] More generally, agricultural water management is a key instrument for poverty reduction in SSA drylands because rural livelihoods are predominantly agriculture-based and water is both an indispensable input and a key constraint. Water development can help not just agriculture but the local economy more broadly via potable water, livestock watering, second-round local and national economic impacts of increased agricultural production, and increased social capital from organization for water management (IFAD 2008).

Although increasing access to water and improving agricultural water management may be necessary to change the paradigm, a consistent theme throughout this book is that these efforts are insufficient. An integrated approach is required to enhance agricultural risk management and promote resilience of agricultural production value chains within the potential and constraints of the local natural resource and socioeconomic setting. Alongside development of agricultural water management, action and investment are needed in research and technology development and transfer, livestock development, and rangeland management. Improvements in market linkages, the value chain, and in the overall enabling environment and incentive framework are also important. All of these components can set the stage for transformative change to higher incomes and increased resilience for dryland dwellers.

Notes

1. UNESCO (United Nations Educational, Scientific and Cultural Organization) defines the aridity classification system based on average annual precipitation (P) divided by the average annual potential evapotranspiration (PET). The classes are: hyper-arid ($AI < 0.05$); arid ($0.05 < AI < 0.20$); semi-arid ($0.20 < AI < 0.50$); and dry sub-humid ($0.50 < AI < 0.65$).
2. Countries with significant areas of drylands have been grouped for analytic and discussion purposes into geographical groups as follows: **Central Africa**: Burundi, Cameroon, Central African Republic, Congo, Democratic Republic of Congo (DRC), and Rwanda; **Eastern Africa:** Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan, Tanzania, and Uganda; **Southern Africa**: Angola, Botswana, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe; **Western Africa**: Benin, Burkina Faso, Chad, Cote d'Ivoire, The Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Mauritania, Niger, Nigeria, Senegal, and Togo.

3. Farming systems in SSA can be classified according to the scheme developed by FAO (Dixon and Gulliver with Gibbon 2001) and more recently updated by FAO and CGIAR (Garrity, Dixon, and Boffa 2012). This classification scheme distinguishes 13 main farming systems, characterized by the predominant cropping and/or livestock production activities. Map 2.3 shows the distribution of the different farming systems within drylands.
4. See, for example, Schlenker and Lobell (2010), who developed a model of yield response to climate change based on historical crop production and weather data for maize, sorghum, millet, groundnut, and cassava. They found that "In all cases except cassava, there is a 95% probability that damages exceed 7%, and a 5% probability that they exceed 27%. Moreover, countries with the highest average yields have the largest projected yield losses, suggesting that well-fertilized modern seed varieties are more susceptible to heat related losses." This study with others predicts probable large negative impacts on SSA agriculture, including loss of 12 percent of "cultivation potential" by 2080, mostly in the already vulnerable Sudan-Sahelian drylands.
5. Research in India has shown that rainwater productivity increases 70–100 percent with micronutrient amendment, and net economic returns are 1.5–1.75 times higher (Molden 2007).
6. The material in this section draws on the companion background book "Prospects for Improving Crop Productivity in Africa's Drylands" (Walker et al. 2016).
7. For example, Map 8.1 at Molden (2007) shows that the incidence of malnutrition is highest in drylands.

CHAPTER 3

Current State of Irrigation and Agricultural Water Management

Current Adoption of Irrigation and Other Agricultural Water Management Practices

Water Resources

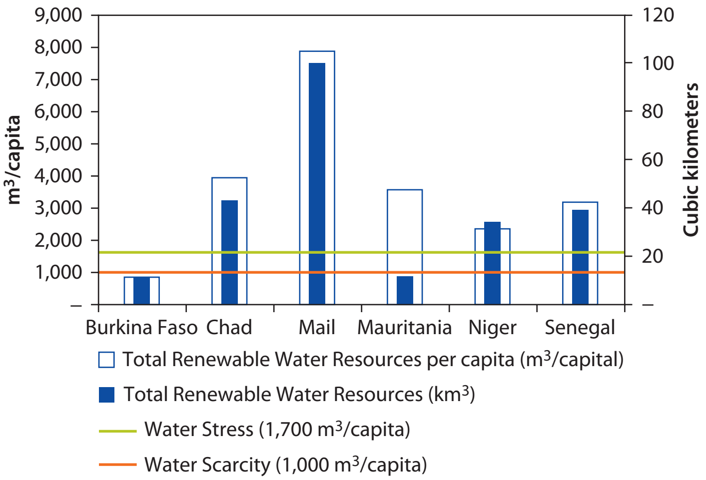
Drylands in Sub-Saharan Africa (SSA) are characterized by low and erratic annual precipitation, often coming during irregular and unpredictable short rainy seasons. Typically, the dry season lasts between 8 and 11 months each year. Internal renewable water resource (IRWR) availability in dryland zones is generally lower than in SSA as a whole, but in many countries with low rainfall, abundant water resources are still available from rivers, including transboundary rivers such as the Nile and the Niger, or from underground resources, including aquifers that extend across national boundaries.

Despite the low rainfall in the Sahelian countries, only Burkina Faso suffers from aggregate per capita water scarcity (figure 3.1). Renewable water resources, including surface water (rivers and lakes) and groundwater, are generally well above the notional water scarcity limit of 1,000 cubic meters (m^3) per year per capita. For Mauritania, Niger, and to a lesser extent Chad, most of the resources are available in the form of inflows from upstream countries, and the bulk of the irrigation potential therefore is localized along major rivers. In contrast, in Burkina Faso all resources are generated internally from rainfall, making them much more limited, although they are spread geographically throughout the country. Mali and Senegal have a mix of internal and external resources.

Water Uses

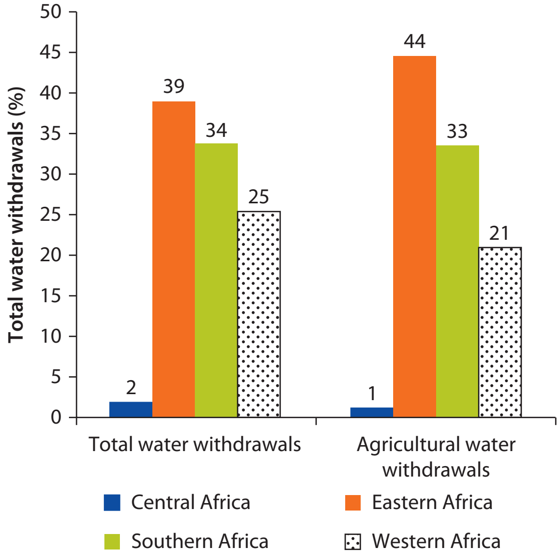
In 2004, total withdrawals across all of SSA from internal renewable water resources totaled 121 billion cubic meters (BCM). This amounted on average to about one-quarter of the IRWR and to about 170 cubic meters per capita, less than one-third of the worldwide average of 600 cubic meters. Figure 3.2 shows

Figure 3.1 Total and Per Capita Renewable Water Resources, Selected Sahelian Countries



Source: http://chartsbin.com/view/1470.

Figure 3.2 Distribution of Water Withdrawals, by SSA Region



Source: FAO/AQUASTAT.
Note: SSA = Sub-Saharan Africa.

the breakdown for the dryland countries, with the predominantly dry Eastern African countries withdrawing the highest share of IRWR (39 percent) and the predominantly humid Central African countries withdrawing the least (2 percent). This suggests that water resources in SSA are significantly underdeveloped, even within the dryland countries, and that there is considerable scope for further harnessing and developing water resources.

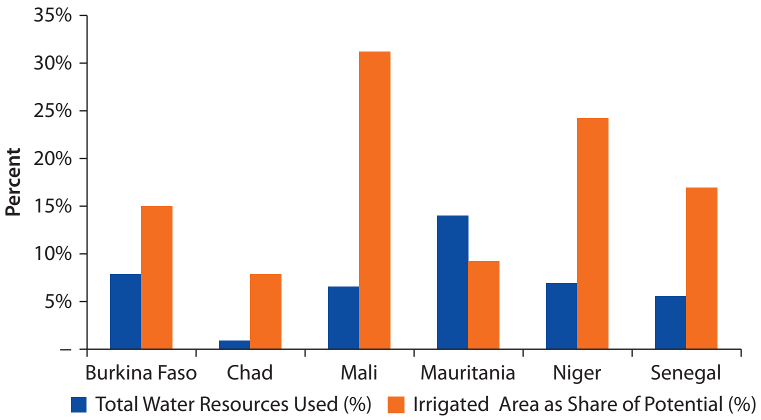
Agriculture accounts for 87 percent (105 BCM) of total water withdrawals across all of SSA, compared to a worldwide agricultural share of about 70 percent. Among the dryland countries, the Eastern African countries (notably Ethiopia, Kenya, and Sudan) withdraw the largest volume of water for agriculture (44 percent of the total withdrawals for agriculture for all the dryland countries, see figure 3.2). Domestic uses in SSA account for 10 percent of total withdrawals (global average is 3 percent), and industrial uses for 3 percent (global average is 20 percent). Average withdrawals for irrigated areas amount to 15,000 cubic meters per hectare. Total withdrawals for agriculture in SSA have doubled since 1960 (IFAD 2008).

In the six countries of the Sahel for which data are available, only 10 percent or less of potential water withdrawals are being used (see figure 3.3), and significant storage and irrigation development potential remains unexploited. Several existing dams remain underutilized due to slow progress of irrigation development downstream. Even in water-scarce Burkina Faso, a significant additional volume of water is available for irrigation and other uses, because many dams were constructed without development of the downstream command area.[1]

Level of Irrigation Development

Across all of SSA, about 7.1 million hectares have been developed for irrigation (table 3.1). Three-quarters of the total irrigation capacity is located in drylands, where irrigation is most needed. This irrigated area represents just 3 percent of the cultivable area, compared to about 20 percent of cultivable area worldwide that is irrigated (in South Asia the figure is 42 percent). Of the 7.1 million hectares that have been developed for irrigation in SSA, about 6.2 million hectares (90 percent) are classified as having "full water control,"

Figure 3.3 Water Resource Use and Irrigation Potential, Selected SSA Countries



Source: FAO/AQUASTAT.

Note: SSA = Sub-Saharan Africa; FAO = Food and Agriculture Organization..

Table 3.1 Area Under Various Forms of Irrigation, SSA

Type of water management	*Area (million ha)*	*Share of area (%)*	*Major countries*	*Other representative countries*
Full water control				
• Surface	4.9	54	Madagascar, South Africa, Sudan	Angola, Ethiopia, Mali, Mauritania, Mozambique, Nigeria, Senegal, Somalia, Tanzania, Zimbabwe
• Sprinkler	1.2	13	South Africa	Côte d'Ivoire, Kenya, Malawi, Swaziland, Zambia, Zimbabwe
• Localized/drip	0.2	2	South Africa	Malawi, Zambia, Zimbabwe,
Subtotal	*6.2*	*69*		
Partial water control				
• Lowlands	0.6	6	Mali, Niger, Nigeria, Zambia	Côte d'Ivoire, Senegal
• Spate	0.3	3	Somalia, Sudan	Cameroon, Eritrea
Subtotal	*0.9*	*9*		
Total equipped	**7.1**	**78**		
• Non-equipped*	2.0	22	Angola, Nigeria	Chad, Malawi, Mali, Mauritania, Sierra Leone, Uganda, Zambia
Total water-managed area	**9.1**	**100**		

Source: Table 2.1 and figure 2.2 in Peacock and Ward (2007) from AQUASTAT.
Note: *Non-equipped Includes Flood Recession and Wetlands Cropping.
Note: FAO = Food and Agriculture Organization.

defined as mainly publicly developed surface irrigation schemes, private sprinkler, or drip irrigation systems. The remaining 0.9 million hectares classified as equipped have only "partial water control." These are mainly community-managed schemes in valley bottoms, or schemes that involve diversion of "spate" flood waters onto cultivated lands. Another 2.0 million hectares are classified as "irrigated" but have not been equipped with permanent irrigation infrastructure—they depend on planting in areas when floods recede or on wetlands.

Not only is irrigation much less developed in SSA than elsewhere in the world, but a significant share of the area that has been developed for irrigation in SSA is underused. More than one-fifth of the area for irrigation in SSA is reported to be out of use, with only 5.3 million hectares of the 7.1 million hectares equipped for irrigation currently irrigated.

The prospects of SSA catching up to the rest of the world seem limited for the time being. The rate of expansion of new irrigation in SSA is slow, about 1 percent per year from 1995 to 2005 (FAO 2006; IFAD 2008).

Because definitions of what constitutes irrigation vary between countries, and because statistics on irrigation are often unreliable, some forms of agricultural water management and irrigation may not be captured in the official figures cited above, ranging from simple forms of soil moisture conservation and water harvesting to more sophisticated community-managed irrigation schemes. The official figures also may not fully reflect the fastest growing form of irrigation in SSA, which involves individual farmers pumping from water courses and groundwater. No reputable estimates exist of these forms of "below the radar" agricultural water management, but it is likely that the true extent of "water-managed area" is in excess of that indicated by the official figures.

According to the FAO AQUASTAT database, only 14 percent of the "irrigation potential"[2] in SSA has been developed, compared to the average for all developing countries of 50 percent. Based on this figure, International Fund for Agricultural Development (IFAD) and Food and Agriculture Organization (FAO) estimate that all farming systems in SSA are far from exploiting their technical potential for developing agricultural water management.[3] Especially in dryland zones, almost all of the farming systems experience water as a limiting factor, and according to FAO most have considerable technical potential for further water development.

Of the 7.1 million hectares developed for irrigation across SSA, approximately three-quarters (5.2 million hectares) are located in the drylands (tables 3.2 and 3.3). Of these, almost one-half are located in Eastern Africa,

Table 3.2 Irrigated Area in SSA Drylands, by Country and Region, 2015 ('000 Hectare)

Region and country	*Currently irrigated area ('000 ha)*
Eastern Africa	
Djibouti	1
Eritrea	21
Ethiopia	199
Kenya	58
Somalia	200
Sudan	1,700
Tanzania	152
Uganda	–
Sub-total	***2,330***
Western Africa	
Benin	9
Burkina Faso	25
Chad	28
Cote d'Ivoire	23
Gambia	2
Ghana	16
Guinea	–
Guinea-Bissau	–
Mali	237
Mauritania	43
Niger	70

table continues next page

Table 3.2 Irrigated Area in SSA Drylands, by Country and Region, 2015 ('000 Hectare) *(continued)*

Region and country	*Currently irrigated area ('000 ha)*
Nigeria	250
Senegal	120
Togo	–
Sub-total	***823***
Southern Africa	
Angola	78
Botswana	4
Lesotho	3
Madagascar	153
Malawi	15
Mozambique	97
Namibia	7
South Africa	1,344
Swaziland	45
Zambia	127
Zimbabwe	161
Sub-total	***2,034***
Central Africa	
Burundi	–
Cameroon	–
Central African Republic	–
Congo	–
DRC	–
Rwanda	–
Sub-total	**–**
Total	**5,187**

Source: FAO AQUASTAT.
Note: SSA = Sub-Saharan Africa; The dash indicates negligible.

Table 3.3 Irrigated Area in SSA Drylands, by Aridity Zone and Region, 2015 ('000 Hectare)

Region	*Arid ('000 ha)*	*Semi-arid ('000 ha)*	*Dry sub-humid ('000 ha)*	*Total ('000 ha)*
Central	0	12,876	15,781	28,657
Eastern	1,616,160	599,928	119,253	2,335,341
Western	257,904	438,481	139,839	836,224
Southern	190,074	1,362,709	445,589	1,998,372
Total	**2,064,138**	**2,413,994**	**720,462**	**5,198,594**

Source: FAO AQUASTAT.
Note: SSA = Sub-Saharan Africa.

with the bulk located in Sudan (1.7 million hectares). Over 1 million hectares are irrigated on Sudan's huge Gezira scheme alone, and many smaller schemes are found all along the Nile River. Ethiopia and Somalia have 200,000 hectares each. In Western Africa, Mali has over 200,000 hectares irrigated, and Senegal has 120,000 hectares irrigated. Irrigated areas in Burkina Faso (25,000 hectares), Chad (28,000 hectares), Mauritania (43,000 hectares), and Niger (70,000 hectares) are more limited, but they are of vital socioeconomic importance.

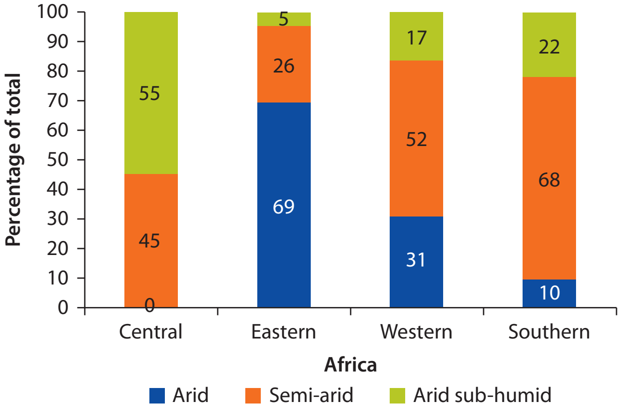
After Sudan, the country with the second largest irrigated area in drylands is in South Africa (1.3 million hectares). Madagascar, Mozambique, Zambia, and Zimbabwe also each have 100,000 irrigated hectares or more located in drylands.

Irrigation is more important in the dryland countries of SSA than it is in the rest of SSA. Approximately 4 percent of cultivable land in dryland countries is irrigated (5.2 million irrigated hectares out of total cultivable land of 126 million hectares), compared to the region-wide average of just over 2 percent. Due to the important transboundary rivers flowing through the Eastern African countries, two-thirds of the irrigated area in these countries (69 percent) is actually found in the zone classified as arid, whereas in the other dryland countries, most irrigation (one-half to two-thirds on average) is found in the semi-arid zone (figure 3.4). Rivers enable irrigation even in the driest conditions.

Why Is Irrigation So Underdeveloped in SSA?

Across SSA as a whole, irrigation is far less developed than in the rest of the world, even in dryland zones where it is urgently needed. In many dryland zones in the Middle East and North Africa that are comparable to the dryland zones of SSA, up to 90 percent of the technical potential for irrigation has been developed, compared to just 14 percent in SSA. The reasons for the discrep-

Figure 3.4 Distribution of Irrigated Area Across Aridity Zones, by SSA Region



Source: Xie et al. 2014a.
Note: SSA = Sub-Saharan Africa.

ancy are fourfold. First, the economic case for investing in irrigation has been less strong in SSA, due to the more dispersed population, small local markets, low levels of transport infrastructure, and limited export possibilities. By contrast, in many parts of the Middle East and North Africa population densities are high, local markets are large, and labor is cheap enough to permit labor-intensive production. Second, there is historically little or no tradition of irrigated agriculture in most countries of SSA, with the exception of Madagascar. Third, costs of irrigation development are relatively high due to the remote location of many sites and generally higher construction costs, and many of the countries are extremely poor and lack the fiscal resources to underwrite costly irrigation expansion. Fourth, the wave of irrigation development that took place in SSA during the 1970s and 1980s brought disappointing results. For example, between 1975 and 1979, nine major externally financed irrigation projects generated average rates of return of just 2 percent, and many nationally financed schemes (for example in Nigeria) were complete failures (Peacock and Ward 2007). As a result, governments and donors were for a long time hesitant to finance further expansion; only in recent years has interest been renewed as new lower-cost, more economic and sustainable technical models (largely for small-scale irrigation) and institutional set-ups (participatory, bottom-up models) have been introduced.

Who Develops and Manages Irrigation in SSA?

At least one-half of the irrigated land in SSA is privately developed and/or privately operated. According to the AQUASTAT database, 4.2 million hectares of irrigated land is under private commercial irrigation systems (sprinkler and drip on 1.3 million hectares) or under community-managed schemes (2.9 million hectares).[4] In South Africa, where commercial irrigated farming is widespread, the private sector has been a major investor.

In some countries in SSA, the public sector has led investments in large-scale irrigation for the benefit of smallholders. The largest irrigation scheme in SSA is in Sudan, which contains the huge, publicly developed Gezira scheme, the largest scheme under single management in the world. In addition to supporting development of large-scale schemes designed to benefit smallholders, in many countries of SSA governments have financed the development of small-scale irrigation schemes that following the construction phase have been turned over to community groups and associations of private operators.

Why Is Agricultural Water Management So Important in the Drylands?

Typology of Irrigation Systems

A typology of agricultural water management systems was adopted for this book, based on the scale of the technology and the management arrangements (table 3.4). This typology is consistent with the "Irrigation Business Lines" adopted by the World Bank in organizing its work on irrigation in SSA.

Table 3.4 Typology of Agricultural Water Management Systems

Agricultural water management type	*Agricultural water management system*	*Main technologies*
Improved water management in a rainfed environment	1. Pure rainfed cropped area	Managing soil moisture
	2. Improved rainfed	Small-scale water harvesting
SSI (individual, community-based)	3. Individual low-cost irrigation	Pump irrigation, both manual and motorized
	4. Community-based irrigation	Low-cost diversion, flood recession, communal pump schemes
Large-scale public irrigation	5. Large-scale irrigation	Dams or weirs; surface canals; furrow irrigation
Large farmer irrigation and PPP	6. Private commercial irrigation	Dams or weirs; surface canals; furrow irrigation
	7. Market-oriented irrigation on a PPP basis	Piped irrigation; drip, sprinkler; protected (greenhouse) agriculture

Note: SSI = small-scale irrigation; PPP = public-private partnership.

Role of Agricultural Water Management in Increasing Resilience in Drylands Agriculture

In dryland regions characterized by conditions of chronic water scarcity and climatic unpredictability, farmers are often faced with inadequate soil moisture to achieve a decent yield, and during periods of drought they may face total crop failure. In view of the vulnerability of many dryland farmers, households are highly sensitive to soil moisture conditions and understand the perennial risk of low yields or outright crop failure.

The fundamental objective of agricultural water management in dryland environments is to reduce the possibility of crop losses or crop failures by bringing moisture to the plant root zone in the right quantity and quality and at the right time needed to achieve higher levels of productivity. This can be accomplished essentially by one or more of three routes, listed below in ascending order of complexity and productivity:

1. Bridging periods of low soil moisture content to reduce plant stress and so save the crop. In dryland environments prone to drought, ensuring crop survival by "just-in-time" watering is the first order objective.
2. Ensuring vigorous plant growth by delivering quality water at optimal intervals to the plant root zone. This typically has an off-field component (assuring water service to the field) and an in-field component (conveying water efficiently to the plant root zone at the right time and in the right quantity and minimizing nonproductive evaporation).
3. Combining water management with soil and crop management to increase crop water productivity (CWP) (kilograms per cubic meter or dollars per cubic meter).

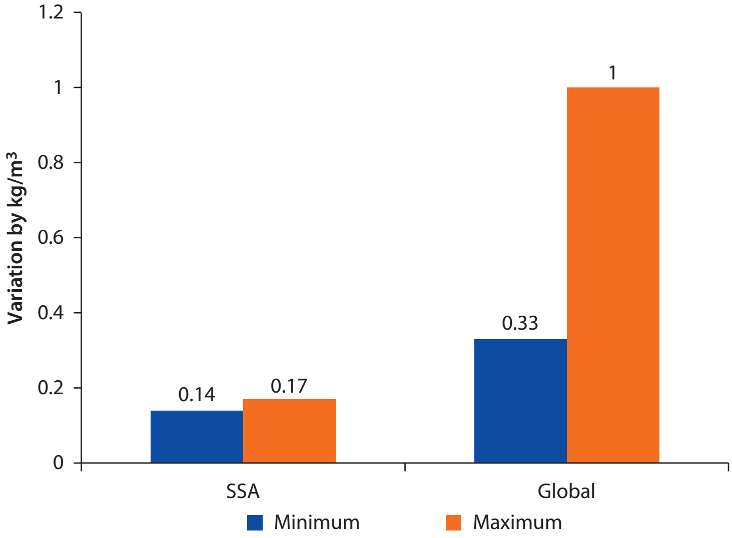
Techniques of combined water, soil, and crop management include:

- Selecting crops and varieties to provide increased yield per unit of water consumed or to consume less water;
- Managing soil and water to promote soil fertility and reduce salinity;
- Preparing land appropriately so as to conserve soil moisture, for example through zero or minimum tillage;
- Using deficit, supplemental, or precision irrigation;
- Timing irrigation water delivery to reduce stress at critical moments in crop growth;
- Managing nutrients efficiently;
- Lessening nonproductive evaporation by mulching, enhancing soil infiltration and storage properties, enhancing canopy cover, installing subsurface drip irrigation, and matching planting dates with periods of less evaporative demand;
- Managing weeds and pests effectively; and
- Managing harvesting and post-harvest activities effectively to avoid crop losses.

The Scope for Increasing Crop Water Productivity in Drylands

Crop water productivity is typically low in dryland zones of SSA. Studies dating back to the 1990s have consistently found crop water productivity in SSA of between 0.14 and 0.17 kilograms per cubic meter for food grains, whereas global averages have consistently been in the range of 0.33–1.00 kilograms per cubic meter (figure 3.5). Crop water productivity in the SSA drylands is low

Figure 3.5 Crop Water Productivity for Food Grains, SSA vs. World (kilogram grain/cubic meter water)



Source: Rockstrom et al. (1999).
Note: SSA = Sub-Saharan Africa.

due to a combination of poor water management, poor soil management, and poor crop management. If crop water productivity is low, the corollary is that the scope for improvement is enormous, with increases of two to four times possible if technical, resource, and market hurdles can be overcome (Rockstrom et al. 1999).

The rest of this section discusses how those conditions have been brought together in practical examples in the drylands. Sections "Improved Water Control in a Rainfed Environment," "Small-Scale Irrigation" and "Publicly Developed Large-Scale Irrigation" examine each of the agricultural water management types listed in table 3.4 by describing the techniques available, experiences and results to date, and lessons and recommendations for the future. The approach is based on case studies. Section "Improved Water Control in a Rainfed Environment" discusses agricultural water management in rainfed areas; private irrigation is the subject of section "Small-Scale Irrigation"; and section "Publicly Developed Large-Scale Irrigation" reviews experience with publicly developed large-scale irrigation and public-private partnerships (PPPs).

Improved Water Control in a Rainfed Environment

This section looks at ways in which agricultural water management has been and can be improved upon in rainfed areas in dryland zones of SSA. The analysis is divided into two parts. Section "Managing Soil and Water in Drylands Rainfed Agriculture" looks at techniques and experiences in managing soil and water in drylands rainfed agriculture where no water resource is available other than the rain that falls onto the field. Section "Improved Rainfed Agriculture: Water Harvesting and Watershed Management" assesses systems in rainfed areas that harness extra water for dryland farming from outside the field, essentially through supplementary irrigation.

Managing Soil and Water in Drylands Rainfed Agriculture

Where no water resource is available other than the rain that falls onto the field, sensitivity to drought can be reduced and productivity improved by reducing unproductive evaporation and run-off while at the same time concentrating moisture around plant roots. These measures, combined with improvements in soil texture and fertility and introduction of more effective crop management practices, can maximize water available to plants during dry spells, lessening the impacts of drought stress and boosting crop water productivity.

A series of techniques exists for concentrating moisture around plant roots, including planting pits, the use of which is common throughout the drylands of SSA. On slopes, vegetative and structural techniques can be used to retain moisture and prevent erosion. Vegetative measures usually require lower investment and are more easily established than structural measures and may also have some economic value in themselves (Napier or vetiver grass, for example). Table 3.5 summarizes the strategies and techniques generally employed.

Table 3.5 Agricultural Water Management Strategies and Techniques for Improving Productivity of Rainfed Agriculture

Objective	*Agricultural water management strategy*	*Purpose*	*Techniques and structural measures*
Improve WUE by increasing water available to plant roots	Soil and water conservation	Concentrate rainfall around crop roots	Planting pits
		Maximize rainwater infiltration	Terracing, contour cultivation, conservation agriculture, dead furrows, staggered trenches
	Evaporation management	Reduce non-productive evaporation	Dry planting, mulching, conservation agriculture, intercropping, windbreaks, agroforestry, early plant vigor, vegetative bunds
Improve water productivity by increasing productivity per unit of water consumed	Integrated soil, crop, and water management	Increase proportion of evapotranspiration (ET) flowing as productive transpiration and so obtain "more crop per drop"	Increase plant water uptake capacity through conservation agriculture, dry planting (early), improved crop varieties, optimum crop spacing, soil fertility management, optimum crop rotation, intercropping, pest control, organic matter management

Source: Adapted from Molden (2007).
Note: WUE = water use efficiency.

Integrated soil, crop, and water management approaches can improve soil fertility and water productivity. Effective technologies include organic matter management, improved crop varieties, minimum- and low-till methods, rotational grazing, and intercropping. These techniques have been promoted and spread throughout the Sahel Region and the Horn of Africa through the work of TerrAfrica.[5]

In many parts of SSA, drylands agriculture increasingly involves the use of integrated agro-silvo-pastoral systems in which crop production, maintenance of trees, and livestock keeping support one another. Crops produce food and fiber products for the benefit of humans, but they also generate residues that can be used to feed animals and mulch trees. Trees can furnish fruits, wood, thatch, and other economically valuable products, while at the same time providing fodder for livestock and fertilizer for crops. Animals produce meat and milk products, but they also generate fertilizer that improves soil organic matter and moisture retention capacity (FAO 2011; Molden 2007).

Successes with integrated approaches have been achieved in many parts of the drylands. In the central plateau of Burkina Faso, a sustained program of soil and water conservation helped farmers through drought spells and triggered a sustained process of agricultural and pastoral intensification that has had lasting benefits. Success of the program was helped both by its sustained nature and focus on institutions and by a conducive policy context. The introduction of improved planting pits that concentrated and retained moisture around plant roots proved profitable and sustainable in the drylands of Niger. A long-term program in Niger's Keita Valley has reclaimed large areas for productive use and raised incomes sustainably. Tanzania learned from two decades of poor experience and has since launched participatory and "holistic" approaches to land and water management in semi-arid areas.

Technology is now available in many dryland areas to improve agricultural water management and increase profitability of rainfed farming systems (see table 3.5). Studies have shown that in many dryland zones, techniques for improving water infiltration into the soil profile can raise water use efficiency from the usual 10–30 percent to as much as 60 percent. Consistently good returns are achieved when improvements in agricultural water management are combined with improvements in soil management and agronomic practices, and where agricultural activities are integrated into a larger, integrated farming system (for example, an agro-silvo-pastoral system).

Despite their potential, some improved technologies have been rejected by farmers because they are seen as risky or costly. For example, in the soil and water conservation program in Niger discussed above, in a dry year millet yields averaged 144 kilograms per hectare when the crop was grown using traditional methods, rose to 393 kilograms per hectare following the adoption of *zai* pits and the use of manure, and rose even further to 659 kilograms per hectare following the application of mineral fertilizer. In a year of normal rainfall, millet yields averaged 296 kilograms per hectare when the crop was grown using traditional methods, 969 kilograms per hectare following the adoption of *zai* pits and the use of manure, and reached 1,486 kilograms per hectare following the application of mineral fertilizer. Economically, the full package might have had the best return, at least in a good rainfall year, but the risk of a bad rainfall year and the cost of buying mineral fertilizer meant that farmers ended up adopting only *zai* pits and manure—simple, low-cost, low-maintenance techniques that increase yields demonstrably and without too much risk. Evidently the higher-tech improvements lacked the key elements of viability, including profitability, manageable risk, and accessibility (with limited or no barriers to entry).

Based on the experience to date, it is clear that improved agricultural water management under purely rainfed conditions can help overcome the effects of drought, boost productivity, and strengthen coping capacity under certain conditions. Farmers in dryland zones have shown themselves to be flexible, innovative, and ready to seize opportunities, including market opportunities, but they are also highly risk averse and resource constrained. Programs to support change are therefore needed to help farmers adapt technology that takes into account local situations and manages risks, and to involve land users as full partners in all stages of the project cycle. Programs must be sustained and accompanied by long-term results monitoring to ensure lasting impacts on livelihoods. It is vital to get the technical package correct, and technical innovation, flexibility, and down-to-earth adaptive research is key. Plant breeding is also important. The keys to adoption and to scaling up are increased incomes with managed risks and attention to barriers to adoption. The third element is stakeholder empowerment and indigenous knowledge. Successful interventions pay attention to empowerment of local people, local knowledge, and to building social capital. Finally, having a supportive policy framework is important. A market-oriented economy, pro-agriculture policies, and transport infrastructure help improve adoption.

Strengthening Resilience

A growing body of evidence from dryland zones in SSA makes clear that low-cost soil and water management practices using in-field rainwater management techniques can be developed on rainfed land. These practices can help improve the situation of the many farmers who have no access to water other than what falls from the sky onto their fields. In principle, this is an abundant resource. In the six Sahelian countries, for example, the amount of water arriving in the form of rain is five times greater than the amount available through internally resourced water resources (that is, the water available in water courses and aquifers). The main criteria for judging success are the level and sustainability of economic benefits and the manageability of risk and enhanced resilience. Resilience can certainly be increased. Hydraulic works such as gabion reinforcements or terracing can reduce exposure to floods and improve in-field soil and water management, helping to reduce weather-related risks and thereby lessening sensitivity to drought. To the extent that improved productivity allows farmers to generate market surpluses and increase their cash income, adoption of improved agricultural water management practices can also increase coping capacity, provided that the added level of financial risk can be managed. However, although these practices may help reduce weather-induced risk, they cannot eliminate such risk entirely, and agricultural intensification potential therefore remains limited under such practices compared to fully irrigated agriculture.

Improved Rainfed Agriculture: Water Harvesting and Watershed Management

Water harvesting and watershed management are techniques that allow farmers to bring additional water onto rainfed fields. In addition to providing a source of irrigation water, investment in water harvesting and watershed management has multiple benefits, including improved retention of moisture in the soil profile, improved soil fertility, recharged groundwater supplies, and reduced erosion. In some cases, water harvesting and watershed management techniques permit the growing of crops in places where previously this was not possible. In other cases, water harvesting and watershed management techniques allow farmers to bridge drought periods, increase yields, or provide a source of supplementary irrigation to extend the cultivation period into the dry season.

Experience with water harvesting in drylands is mixed. Burkina Faso promoted water harvesting starting in the 1960s. Government subsidies allowed for the construction of numerous small reservoirs, which were used mainly for watering livestock. In the 1980s, a second wave of government-supported construction took place, targeting mainly the irrigation of rice and other food crops. Today, more than 1,300 of these reservoirs exist. The quantity of water available in these reservoirs has often been lower than anticipated, due to the build-up of silt and a reluctance among water users' associations (WUAs) to carry out maintenance tasks. Recently, however, some of these reservoirs have experienced a revival, especially in areas where new markets for produce have opened up.

Farmers in dryland zones of Ethiopia have long practiced small-scale water harvesting, supported in recent years by the government. Where profitable urban cash crop markets are available, rapid development of water resources is now taking place. Niger has long supported investment in water harvesting and watershed management in the more than 13 million hectares of rainfed croplands in its drylands. Public programs from the 1980s onwards invested in these techniques, and up to 250,000 hectares were improved in what were essentially watershed management programs. At least some of these lands produce cereals at yields of 400–1,500 kilograms per hectare, with average yields of around 400 kilograms per hectare attributed to supplemental irrigation provided through water harvesting. However, two snags arose. Implementation was usually collective, but subsequent use was typically individual, and disputes arose over who should have access to land and water. Second, although many of the techniques appeared profitable, farmers rarely adopted them on their own accord. In the absence of a subsidy, the benefits did not outweigh the costs.[6]

Many lessons learned are similar to those for soil and water management. The difference is that interventions to improve water harvesting and watershed management extend beyond the fields of individual farmers, raising issues of collective action, land tenure, and externalities. Experience suggests that the best approach is often to work on a fully participatory basis. Because interventions go beyond the individual level, the participatory approach needs to be inclusive and built permanently into management arrangements. As for *in situ* soil and water conservation, profitability, manageable risk, and accessibility are central and sustainability depends on devising an appropriate incentive structure.

Strengthening Resilience

Adoption of water harvesting and watershed management techniques clearly has potential to increase the resilience of farmers living in dryland zones. Erosion control, reforestation, and soil and water conservation investments will reduce exposure to floods and landslides. Increasing soil moisture content will mitigate sensitivity to drought. Coping capacity can be strengthened by increasing the share of production that is marketed. However, these benefits have to be set against increased levels of risk associated with the required investments and with exposure to market fluctuations.

Small-Scale Irrigation

This section discusses forms of irrigation that are largely or entirely developed and managed by farmers themselves. Section "Individual Low-Cost Irrigation" looks at individual and low-cost irrigation, particularly individual pump irrigation. Section "Community-Based Small-Scale Irrigation" assesses experience with community-based small-scale irrigation.

Individual Low-Cost Irrigation

Individual low-cost irrigation has always existed throughout the drylands of SSA, being especially common in areas where a reliable source of water was available. Along the rivers of Western Africa, water was lifted by *shadouf* techniques to irrigate small plots located near the river banks. In Madagascar, local springs were tapped to provide water for paddy cultivation. The prevalence of individual low-cost irrigation changed beginning in the 1990s, when introduction of small diesel and electric pumps led to the rapid growth of individual, low-cost irrigation using pumps drawing water either from local surface water or from wells tapping underground water. The advent of this accessible technology coincided with the growth of domestic and export markets for horticultural products to create a significant new economic opportunity for individual farmers or small farmer groups. Wherever water is available and markets exist, this technology has seen very rapid growth all across the drylands, particularly in peri-urban areas and where there are export or industrial processing facilities. With relatively low investment costs and individual control over "just-in-time" water, the technology has proved popular. More recently, treadle pumps have proven to be a particularly accessible and low-cost technology that can have a cost-benefit ratio higher than motorized pumps, in addition to being much cheaper to acquire.

Market-oriented individual irrigation in the *fadama* lands in Nigeria's Kano and Sokoto Provinces took off with the introduction of washboring (low-cost shallow tube well technology combined with individual pumps), which triggered the development of productive and profitable market-oriented individual irrigation. Washboring has allowed farmers to practice dry season cropping of tomatoes, onions, and garlic, which is now a very important source of income. These successes have underwritten a follow-up to the national *fadama* development program.[7]

In Burkina Faso, motor pumps and markets are enabling new uses for old reservoirs. At Korsimoro reservoir, for example, more than 1,000 farmers now grow vegetables on 230 hectares upstream from a communal reservoir originally constructed to irrigate paddy fields located below the reservoir. The farmers irrigate by pumping water directly from the reservoir with small diesel pumps. The upstream area under vegetable production is now seven times larger than the downstream area used for growing paddy. The vegetables produced on this scheme find ready markets in Burkina Faso and in neighboring Ghana. One hectare of onions grown upstream can bring in US$5,000–15,000, whereas

1 hectare of paddy grown downstream may generate only one-fifth of that amount, that is, US$1,000–3,000.

Where water, markets, and functioning value chains are available, farmers in the drylands find pump technology profitable and the risks manageable. Individual pump irrigation has many advantages. It involves modest levels of investment, requires no communal organization, and needs little government support. Expansion potential is considerable, especially where markets exist. Due to the requirement of cash outlays on a recurrent basis, cash crops must be produced, so proximity of profitable markets is key.

This is not to say that individual pump irrigation does not face challenges. In many countries of SSA, supply chain inefficiencies reduce or prevent access to adequate equipment at reasonable prices. Commercial crop production is inherently risky, as many of the products are highly perishable. Adoption of individual pump technology risks rebalancing responsibilities within the household away from women. More broadly, although pumps are relatively affordable, poorer people continue to face barriers to entry. Environmental risks also come into play. When farmers pump from groundwater in an unregulated fashion (which is the case everywhere), water tables can drop. The same concern applies to surface water abstractions.

To encourage more sustainable development, improvements can be promoted along the value chain to increase profitability, and financing mechanisms can be devised to reduce barriers to access while favoring women and other disadvantaged groups. Market risk management instruments can also help (price information, increased market competition, etc.). Additionally, governments need to cooperate with local stakeholders to develop a regulatory framework and capacity to control abstractions and mitigate environmental externalities.

Pump irrigation can greatly increase resilience. With the full water control that pump irrigation brings, there is reduced sensitivity to weather shocks and the significant improvement in cash incomes raises coping capacity. Again, the downside is the increased level of risk associated with cash outlays and market exposure.

Community-Based Small-Scale Irrigation

Community-based small-scale irrigation has a long history in the drylands of SSA, and external support has expanded the number and area of schemes and improved their performance. Traditional small-scale irrigation in Ethiopia is responding to new markets. In Sudan, a wide variety of traditional small-scale irrigation schemes and practices exists (box 3.1). In Tanzania, partnerships between user associations and public agencies have improved the profitability and sustainability of small-scale irrigation. All across the Sahel, wherever water and market opportunities are available, a plethora of inventive production systems have sprung up using a variety of adapted technologies. All these experiences show that incomes from community-based small-scale irrigation can be at least as high as those from much higher-cost formal irrigation.

Box 3.1 Traditional Small-Scale Irrigation Practices Abound in Sudan

Sudan has a large number of community-based small-scale irrigation schemes along the Nile River and in savannah zones. Along the Nile, the predominant technology involves the use of communal pumps that draw water directly from the river. Elsewhere, a dizzying variety of practices flourish:

- *Basin irrigation* is practiced on lowlands inundated by the Nile during the flood season. Farmers organize themselves to plant food crops and vegetables when the floods recede. The crops grow on the residual moisture in the soil profile. In some cases, pumps provide supplementary irrigation.
- *Flood recession* systems include: (i) flood irrigation on residual moisture on river banks; (ii) flood recession farming on flood plains formed by seasonal rivers; (iii) farming on flooded islands after waters recede; and (iv) flood recession farming on the banks of large reservoirs (Roseires, Sennar) as they empty.
- *Spate irrigation* is practiced in the plains below the mountains of Kassala, Red Sea Province, and Kordofan. Farmer groups construct dikes and divert seasonal flood waters into rudimentary canal systems. Organization is largely along traditional tribal lines. Crops include food crops, such as vegetables, and the recent introduction of sunflowers as a cash crop.
- Planting directly in *seasonal stream water courses*, farmers use the residual end-of-season moisture to grow vegetables.

Source: Anderson and Burton (2009).

Community-based small-scale irrigation can be successful and sustainable in dryland zones of SSA, especially when farmers are able to form partnerships with outside agencies that can help finance the development of new sites and support the introduction of management practices to improve water use efficiency. The potential for continued development remains considerable. Across the drylands, small-scale irrigation schemes have proven popular, and many "community-driven development" programs have offered community-based irrigation as one of a range of possible investments. However, as water resources are increasingly developed and potential conflicts with other water users and environmental needs arise, small-scale irrigation needs to be brought inside the planning and regulatory framework.

Looking to the future, it will be important to maintain a balance between outside support and local institutions with internal autonomy, to avoid the emergence of a culture of dependence in the face of "top-down" and "engineering-led" approaches. Key factors for success include: (i) well-functioning water users' associations that have been trained in water management, general management, and administration; (ii) clustering small schemes together, reducing technology cost uptake by increasing the sales volumes; (iii) market opportunities and profitability; (iv) secure land tenure; (v) sufficient data on rainfall and hydrology; and (vi) light touch, preferably participatory, planning and regulation of water resources and integration within a basin approach to strengthen cooperation amongst communities drawing water from the same water course.

Strengthening Resilience

Community-based small-scale irrigation offers a wide range of opportunities to increase the resilience of farmers to weather-induced crisis and to increase their incomes and job opportunities. The water control offered by small-scale irrigation reduces sensitivity to shocks provided that the schemes are based on a sustainable water source and that water is managed efficiently and equitably. As with other forms of agricultural water management, cash crops and market orientation greatly strengthen coping capacity provided that water costs are not too high and commercial risks can be managed, through contract farming, for example.

Publicly Developed Large-Scale Irrigation

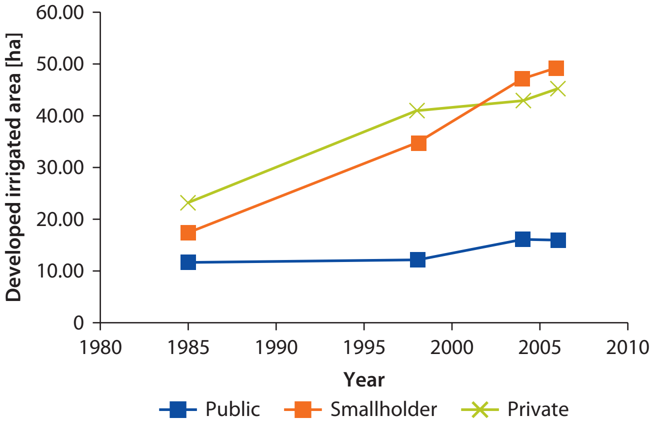
This section looks at the challenging topic of large-scale irrigation developed by governments and farmed by smallholders. The classic model of large-scale irrigation development in SSA has involved schemes financed and managed by public agencies, with smallholders doing the actual farming. Development based on large public irrigation infrastructure has the advantage of allowing smallholders grouped together on a large scheme to get to the required scale at which viable value chains can be established and sustained, as in the case of Mali's *Office du Niger*, Senegal's SAED scheme, or Niger's ONAHA scheme. At their best, these large-scale schemes' institutional improvements have been accompanied by supporting investments and policy reforms, resulting in more secure land and water rights, reliable irrigation service to users at a relatively affordable price, and farmer services that help producers to farm productively and profitably. Many large-scale schemes have, however, been plagued by technical and institutional problems, including poor conception and management that contribute to low farmer returns and inadequate cost recovery to ensure good water service. Table 3.6 lists some of the common causes of poor performance. The result is that, for many years, governments and donors struggling to get existing schemes to work were reluctant to embark on new schemes. For this reason, in recent years across SSA there has been a marked slowdown in the financing of publicly developed large-scale schemes and rapid growth in community-managed small-scale irrigation and individual private irrigation (figure 3.6 illustrates this pattern in Kenya).

Past results of large-scale irrigation development by governments for smallholders illustrate both problems and successes. Sudan's Gezira scheme is huge, but experiences low water use efficiency and low land and water productivity. Underfunding and poor management led to low performance and a cycle of

Table 3.6 Causes and Adverse Effects Affecting Performance in Large-Scale Irrigation Systems

Aspect	*Causes*	*Adverse effects*
Technical	• Weak environmental/hydrological assessments	• Less water than expected • Unsustainable groundwater schemes
Economic	• Poor markets, poor market assessments • Misjudgment of scheme and farmer profitability (high costs, lower than anticipated revenues) • Absence of agricultural support packages • Subsidies poorly targeted and giving no incentive to efficiency (for example, low water charges)	• Lack of markets/profitability for the higher-value crops needed to pay for irrigation • Schemes not financially sustainable • Farmers cannot farm to maximize productivity • Disappointing profits for farmers
Institutional	• Lack of a viable irrigation development strategy and accompanying policies • Weak links between irrigation strategy and other strategies (esp. agriculture and environment) • State-led, top-down approaches to planning, lack of linkages to private sector or farmers • Top-down planners' approach to scheme design • Weak public implementation and management capacity • Neglect of water governance to ensure water rights/allocations or avoid groundwater depletion • Issues of land tenure	• Overdesigned, expensive, hard-to-manage schemes • High capital and operating costs • Poor water service • Reduced incentives
Social	• Inadequate attention to building social capital needed for scheme operation • Underestimation of the time needed to adapt to new irrigated farming systems	• Weak buy-in from farmers • Scheme performance and farmers' incomes well below expectations

Figure 3.6 Growth in Smallholder, Public, and Private Irrigation Schemes, Kenya, 1980–2010



Source: Peacock and Ward (2007).

deterioration and rehabilitation on Ghana's publicly developed irrigation systems. In recent years, however, reform and rehabilitation have turned some schemes around. Mali's *Office du Niger* large-scale gravity irrigation scheme changed from disaster to success when physical investments to improve water service were matched with institutional and macroeconomic reforms. In Senegal, the transfer of scheme management by the government to smallholders brought sustained and improved returns to farmers in addition to reduced fiscal cost.

A large amount of potentially irrigable land exists in the drylands, for example, along the main rivers in the Sahel region that are technically suitable for large-scale irrigation. Large areas would only require conveyance and distribution systems and pumping equipment to bring water to farmers' fields. The constraints to bringing this land into profitable and sustainable production by smallholders are many. Lessons show that costs of development can be very high, and that decentralization, farmer responsibility, and full financing of management, operation and maintenance are essential but rare. Modernization of the water delivery system and reform of institutions must go hand-in-hand, but it takes long-term political and financial commitment and partnership with farmers and even then outcomes are uncertain. Profitable crops and market access are also key, but too often schemes have been planned without thought for the market.

To get large-scale irrigation to work for smallholders, a key factor is profitability, which provides incentives to farmers to invest in irrigated crop production and allows them to pay their share of the costs. Profitability depends not only on the existence of profitable market outlets, but it may also call for investments in value chain development, to allow farmers to be linked to input and output markets, generate value addition, and mitigate market risks. This may include attention to removing constraints in the value chain, for example, by providing affordable access to finance and ancillary market infrastructure.

Large-scale irrigation development also requires a government commitment to ensuring the sustainability and profitability of the scheme, along with viable institutional arrangements. The institutional set-up depends on local context, but it should be capable of: (i) allocating responsibility clearly and pragmatically amongst government, the managing agency, and farmers; (ii) ensuring full coverage of maintenance and operational management costs; (iii) building capacity at all levels, from planners and managers down to WUAs; and (iv) ensuring the essential outcome of irrigation—high-quality water delivery service. This will require professional scheme management (including consideration of contractual management, outsourcing of functions, etc.); modernized infrastructure capable of delivering a quality water service; engagement of farmers and effective farmers' organizations; and farmer knowledge and managerial capacity. Secure tenure of both land and water is also essential. When these factors are achieved, large-scale irrigation can be a powerful investment that drives farmer incomes and has pronounced impacts on the development of the local economy.

Strengthening Resilience

Well-functioning large-scale irrigation brings full water control, the potential for high productivity, and the capability to produce and sell at scale if profitable cash crop markets are accessible. Under these conditions, sensitivity to shocks is minimal and coping capacity is strong. Everything depends on the scheme's technical and institutional ability to deliver timely water and on farmers' ability to raise productivity to profitable levels and, through cooperatives, contract farming, etc., to manage commercial risk.

Large Farmer Irrigation and PPPs

This section considers the experience and lessons learned from commercial large farmer irrigation. The exercise is complicated by the fact that there has been limited experience to date in SSA in setting up PPPs that bring together government agencies with private investors and large-scale commercial farmers to develop and manage irrigation.

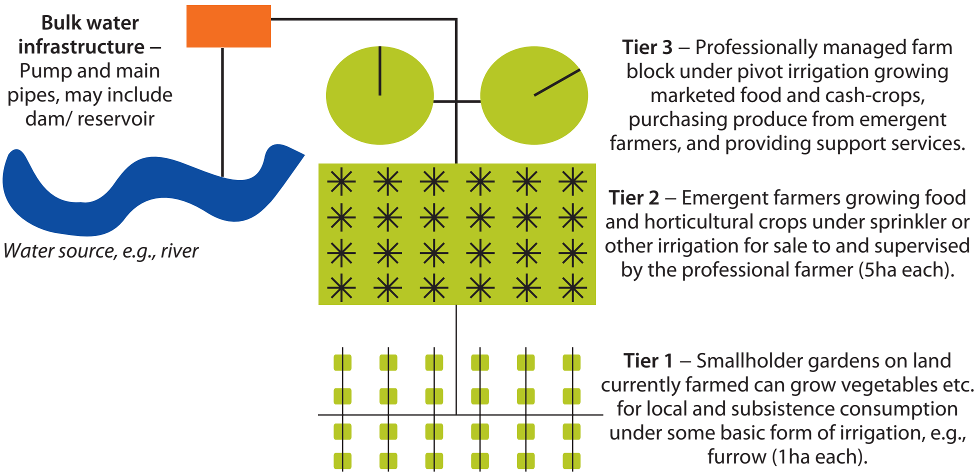
Large farmer commercial irrigation is generally high-tech and efficient. Examples of successful private commercial irrigation include an efficient private large-scale irrigation scheme at Kenana in Sudan and a multi-purpose reservoir in Ethiopia that irrigates large private farms on 65,000 hectares. All commercial irrigation involves some level of partnership between private enterprise and the state, and in recent years innovative partnerships have emerged, with some bringing smallholders into the picture.

Partnership arrangements involving smallholders include the Swaziland Lower Usuthu Smallholder Irrigation Project (LUSIP), and a PPP arrangement in Zambia that combines traditional smallholders, "emerging market-oriented farmers," and a professional operator or commercial farmer (see figure 3.7). In Ghana, the private sector is "anchoring" large-scale irrigation development, and working with surrounding smallholders as outgrowers. Development of larger-scale farming in Namibia directly benefits smallholders with water supply and outgrower contracts. A management contract in Ethiopia is designed to balance risks and ensure long-term sustainability of a large scheme for smallholders.

Commercial or commercially managed irrigation schemes in SSA have been generally profitable and water efficient. However, considerable barriers to entry exist, and there are risks for the private sector to engage without agreeing on risk-sharing with government. The risks are hard to manage, as many are subject to sovereign policy decisions. Governments are also typically reluctant to join in partnership with the private sector, particularly when it comes to irrigated agriculture, as governments typically see a conflict with higher-level public interest objectives such as food security and poverty reduction.

Despite these challenges, governments in several SSA countries have succeeded in establishing frameworks that encourage private commercial irrigation. Some have even begun to experiment with PPP models that include risk-sharing management contracts and co-investment contracts. Emphasis must be

Figure 3.7 Three-Way Partnership between Government, Commercial Firms, and Smallholders, Zambia



Source: World Bank (2011).

placed firmly on profitable market-oriented farming and on the development of autonomous, commercially viable institutions to achieve that. The experience (for example, at Ethiopia's Megech scheme) suggests that risk-sharing management contracts could help SSA countries develop large-scale irrigation for smallholders efficiently and sustainably without recurrent subsidy.

Notes

1. Note that this analysis is based on Food and Agriculture Organization (FAO)'s assessment of technical potential. International Food Policy Research Institute (IFPRI)'s new assessment of the economically realizable potential is discussed in chapter 4.
2. The notion of "irrigation potential" should be treated with caution: FAO figures are based largely on country returns and do not necessarily reflect the economic potential. See Xie et al. (2014a).
3. Note that these estimates of potential by livelihood zone are based on past studies. IFPRI modeled potential in a study prepared for this report (see Xie et al. 2014a). Chapter 4 presents the estimates of potential resulting from Xie et al.'s work.
4. 2.9 million hectares is the total of the "partial water control" and the "non-equipped" areas.
5. TerrAfrica was established in 2005 to respond to growing concerns over natural resource degradation in SSA by scaling up harmonized support for effective and efficient country-driven sustainable land and water management (SLWM) practices across sectors. Since its launch, TerrAfrica has created an enabling environment for effective mainstreaming, upscaling, and financing of SLWM strategies that are recognized as the precursor of climate-smart agriculture.
6. Ward (2007).
7. See: http://www.fao.org/docrep/w7314e/w7314e0v.htm

CHAPTER 4

Technical and Economic Scope for Expanding Irrigation in Sub-Saharan African Drylands

Background

A number of studies have assessed the potential for expanding irrigation in Sub-Saharan Africa (SSA). The conclusions of these studies have been somewhat variable, depending on the scale and type of irrigation being considered, as well as the assumptions made about a range of technical and economic factors including the productivity of irrigated cropping systems, current and future demand for irrigated crops, impacts of climate change, investment costs, and internal rates of return (for recent examples, see You et al. 2011; Xie et al. 2014b). Few if any studies have assessed the potential for expanding irrigation specifically in the drylands of SSA. As an input to the overall Africa Drylands study, a team from International Food Policy Research Institute (IFPRI) prepared a specific study to assess this potential (for details, see Xie et al. 2014a). Section "Methodology" presents a summary of the methodology used by the IFPRI team. Section "Potential for Irrigation Expansion in African Drylands" summarizes the results of the exercise, estimating the potential for irrigation development. Section "Costs and Benefits of Further Irrigation Development in the Drylands" discusses costs and benefits of irrigation development, and section "Key Findings from the IFPRI Assessment" presents policy implications.

Methodology

Most previous studies of irrigation potential across SSA have focused on technical factors, taking into account the availability of arable land and water resources. The IFPRI study took into account not only technical factors but also economic considerations, identifying areas in which irrigation is not only technically possible but also economically viable. The GIS-based approach (similar to the approaches used in You et al. (2011) and Xie et al. (2014b)) offers ample flexibility to incorporate multiple data and criteria in the assessment and allows for analysis at a high level of spatial resolution (10 kilometer × 10 kilometer pixels). It is important to note, however, that not all of the systems and technologies for improved agricultural water management discussed above and summarized in table 3.4 were included in the analysis. In particular, the focus was on formal irrigation, both large-scale and small-scale. Practices for improving water management in rainfed environments were not included.

The assessment was carried out using a two-step process consisting of ex-ante suitability analysis (section “Ex-ante Analysis”) followed by simulation of irrigation expansion (section “Irrigation Expansion Simulation”). The approach distinguished between small-scale and large-scale irrigation. In the case of small-scale irrigation, since different small-scale irrigation technologies are often close substitutes, no attempt was made to distinguish between technologies. Instead, the model was parameterized so as to approximate situations in which the adoption of any one of several common small-scale irrigation technologies could be accommodated (for example, pumps, small reservoirs).[1] In the case of large-scale irrigation, it was assumed that large-scale irrigation is associated with large, multipurpose reservoirs, the construction of which is generally driven by considerations other than irrigation, so that irrigation services are in effect a byproduct of the larger infrastructure investment. Barrages, run-of-the-river, and pump schemes were not considered. The assessment therefore excluded irrigation potential associated with schemes that simply divert river water (such as Gezira) or that rely on pumping from the river (such as Kenana). Information on the number, location, and capacity of existing reservoirs, as well as reservoirs that are scheduled to be constructed, was accessed from a World Bank database that had been compiled for an earlier study (see You et al. 2011). The reservoirs that are scheduled to be constructed (or in some cases rehabilitated) are at various stages of planning. Since the primary function of these reservoirs will be hydropower production, it was assumed that the initial construction costs will be recovered through hydropower generation, and only incremental operational and maintenance costs associated with providing irrigation services were considered in the analysis (You et al. 2011).

Sensitivity analyses were carried out to provide insights into how technical production parameters, investment costs, output prices, and other factors affect the potential for expansion.

Results of the assessment were then incorporated into a model of the agricultural economy to examine broader impacts on food prices, net trade in food, and calorie availability.

Ex-ante Analysis

For the ex-ante analysis, a set of physical criteria were used to assess the technical suitability for irrigation of every pixel located in the drylands, without taking into account potential economic constraints.

Before the physical criteria were applied, urban areas and protected rural areas were excluded, as were areas that are already under irrigation (since the purpose of the exercise was to assess the scope for expansion).

For small-scale irrigation, the criteria used for the ex-ante suitability analysis appear in table 4.1.

For every remaining pixel located in the drylands, a suitability score for small-scale irrigation was calculated as: SSI suitability score $(0 - 100) = [S_1 + \max(S_2, S_3) + S_4 + S_5]/4$. In cases where the actual value of a parameter fell outside the range indicated in table 4.1, that pixel was deemed unsuitable for small-scale irrigation and excluded from the analysis.

For large-scale irrigation, the assessment was based on an inventory of dams located throughout SSA (You et al. 2011). The inventory includes 373 large dams whose storage capacity exceeds 50 million MCM (millions of cubic meters). Of these, 253 dams are already operational and providing irrigation services, so they were not included in the assessment. The remaining 120 dams that are slated for construction (or in some cases, rehabilitation) were included in the assessment (table 4.2). In the absence of detailed information about the irrigation services being provided by the dams that are already operational, it was not possible to assess the potential for further expansion of large-scale irrigation around existing infrastructure, but the approach allowed the possibility of expansion in

Table 4.1 Criteria Used to Assess Potential for Small-Scale Irrigation

Criteria	*Range of parameter*	*Range of score*
Topography	0–10% slope	S_1: 100–0
Distance to surface water	0–5 km	S_2: 100–0
Groundwater depth*	0–250 m	S_3: 100–0
Travel time to market (hour)	0–3 h	S_4: 100–0
Distance to existing irrigation	0–10 km	S_5: 100–0

Source: Xie et al. (2014a).
Note: No groundwater data were available for Madagascar, so that particular criterion was dropped for Madagascar. The distance to existing irrigated area is derived based on the FAO Sirte irrigation map (www.sirtewaterandenergy.org). FAO = Food and Agriculture Organization.

Table 4.2 Current Inventory of Large Dams, SSA Dryland Countries

	Capacity threshold	
Dam status	*>50 MCM (#)*	*Full list (#)*
Operational	253	489
Planned	106	159
Rehabilitated	14	32
Total	**373**	**680**

Source: Xie et al. (2014a) based on Africa Infrastructure Country Diagnostic dams database.
Note: MCM = Million cubic meters; SSA = Sub-Saharan Africa.

small-scale irrigation in the vicinity of dams that are currently operational. Large-scale irrigation from the 120 dams that were included in the assessment was assumed to occur by gravity, with command areas up to 200 kilometers downstream of the dam, and with water elevation of 10 to 20 meters at the heads of the reservoirs. To avoid double counting, in a few cases dams located in close proximity to one another were combined, since they have highly overlapping command areas. Because of the assumption that command areas can extend 200 kilometers downstream from the dam, some dams that support irrigation in dryland zones are themselves not located in the drylands.

For large-scale irrigation, the criteria used for the ex-ante suitability analysis appear in table 4.3:

For every non-excluded pixel located in the drylands, a suitability score for large-scale irrigation was calculated as: LSI suitability score (0–100)= $[S_1+S_2+S_3]/3$. In cases where the actual value of a parameter fell outside the range indicated in table 4.3, that pixel was deemed unsuitable for large-scale irrigation and excluded from the analysis.

Irrigation Expansion Simulation

Once the ex-ante analysis had identified the areas in drylands that are suitable for irrigation, in the second step of the analysis, economic considerations were introduced, and the likely expansion pattern of irrigation with progressively higher levels of investment was projected.

The basic assumption underlying the projection of the irrigation expansion pattern is that irrigation development will be driven by suitability considerations, that is, the most suitable sites will be developed first. The methodology also assumed that within areas identified as being suitable for irrigation, land that is currently being planted to rainfed crops will be developed for irrigation before currently uncultivated land is brought under cultivation/developed for irrigation. In other words, land that is currently being planted to rainfed crops and that has a high irrigation suitability score will be converted to irrigation first, followed by land that is currently being planted to rainfed crops and that has a medium or low irrigation suitability score, followed by land that is not currently being cultivated and that has a high irrigation suitability score, and so on.

In projecting the irrigation expansion pattern, the model assumed that irrigation expansion is constrained by: (i) water availability; (ii) food demand in

Table 4.3 Criteria Used to Assess Potential for Large-Scale Irrigation

Criteria	*Range of parameter*	*Range of score*
Topography (slope)	0–10%	S_1: 100–0
Distance to main channel of river downstream of the dam	0–5 km	S_2: 100–0
Distance to existing irrigation	0–10 km	S_3: 100–0

Source: Xie et al. (2014a).
Note: The distance to existing irrigated area is derived based on the FAO Sirte irrigation map (www.sirtewaterandenergy.org).
FAO = Food and Agriculture Organization.

2050; and (iii) economic viability. Water availability for irrigation was assessed at the level of river basin using an SSA-wide Soil and Water Assessment Tool (SWAT) model (Xie et al. 2014b). For purposes of the assessment, SSA was divided into 1,231 river basins. The amount of water available for irrigation, as well as crop irrigation water use intensity of each river basin (expressed in millimeters of H_2O per hectare), were estimated using the SWAT model. Irrigation expansion in a river basin was limited to the level of water resources available for irrigation within the river basin. The estimated amount of water resources available for irrigation included contributions from surface runoff and groundwater; the latter was estimated according to groundwater recharge derived from the SWAT-based hydrologic simulation. It was assumed that 20 percent of surface runoff is preserved for environmental flow and other uses. Water availability constraints were imposed at the river basin level for the dry season. Food demand in 2050 was estimated using the International Model for Policy Analysis for Agricultural Commodities and Trade (IMPACT) maintained at IFPRI. It was assumed that within each country, irrigation expansion would be limited by national food demand in 2050, because once national food demand is met, additional production would have to be exported, and in most cases that would not be profitable due to the high cost of reaching regional and international markets. Economic viability was determined based on crop prices for irrigated crops, irrigation costs, and other production costs (for additional details, see Xie et al. 2014a).

An important factor affecting the projected irrigation expansion path is irrigation investment costs. When irrigation investment costs are high, the projected returns to irrigated crop production may not generate a minimum acceptable rate of return, making the investment unprofitable and hence economically irrational. Given the considerable uncertainty and wide range of irrigation technology and expansion costs, three sets of cost assumptions were considered in the analysis, ranging from US$8,000 to US$30,000 per hectare for large-scale irrigation and from US$3,000 to US$6,000 per hectare for small-scale irrigation (table 4.4). The medium-cost assumptions were considered baseline values.

In terms of sequencing, it was assumed that large-scale irrigation takes precedence where it is viable, so the expansion pattern of large-scale irrigation was projected first. The expansion pattern of small-scale irrigation then was

Table 4.4 Costing Assumptions for Large-Scale and Small-Scale Irrigation, Three Scenarios (US$ per hectare)

	Low cost scenario (US$/ha)		*Medium cost scenario (US$/ha)*		*High cost scenario (US$/ha)*	
Irrigation type	*Capital*	*O&M*	*Capital*	*O&M*	*Capital*	*O&M*
Large-scale irrigation	8,000	800	12,000	1,200	30,000	3,000
Small-scale irrigation	3,000	100	4,500	125	6,000	150

Source: Xie et al. (2014a).
Note: O&M = Operation and Maintenance.

projected in the remaining non-irrigated area. By sequencing the analysis in this way, it was possible to avoid double counting of irrigation potential.

Assessment of Impacts of Irrigation Expansion on Food Security

IMPACT is a partial equilibrium agriculture sector model that simulates changes in agricultural supply and demand in the presence of key drivers such as population increases, economic growth, and climate change. IMPACT was used to assess the likely impacts of irrigation expansion on a number of variables that are of interest to policy makers, such as food prices, food trade, and the number of people at risk of hunger.

Comparison of Results with Previous Scenarios

IMPACT assumes as part of its baseline scenario a constant underlying "rate of irrigation development." This constant underlying rate tracks the long-term trend and implicitly assumes that historical rates of investment in irrigation expansion will continue into the future. The assessment carried out for this study focusing specifically on irrigation development potential in dryland regions of SSA projects the likely expansion path under an enhanced level of investment, leading to an overall faster rate of irrigation expansion compared to the IMPACT baseline.

Potential for Irrigation Expansion in African Drylands

Results for Area Expansion

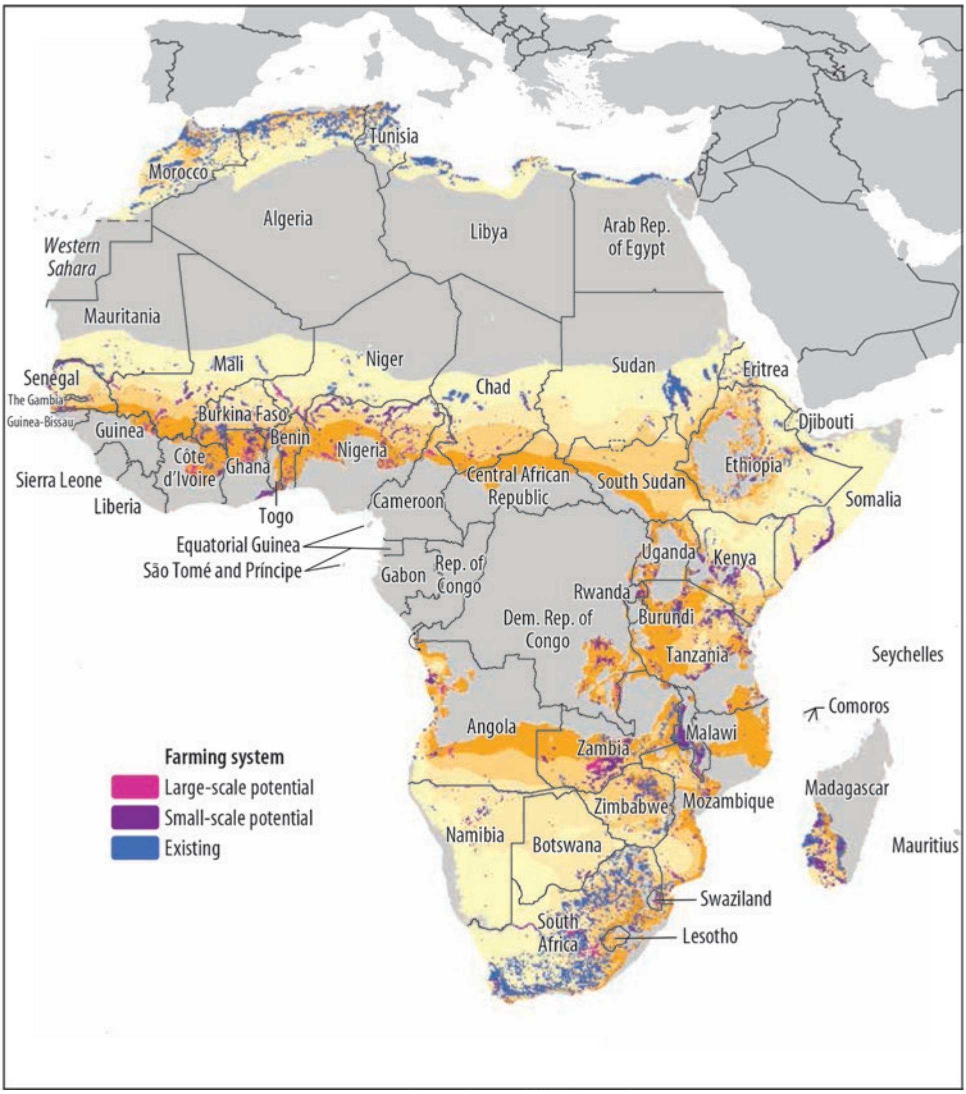
Currently, about 5.2 million hectares are irrigated in dryland regions of SSA (section "Current Adoption of Irrigation and Other Agricultural Water Management Practices" in chapter 3). According to the IFPRI assessment, an additional 14 million hectares could be economically irrigated in the drylands, depending on assumptions about costs and target rate of return. Table 4.5 summarizes the further dryland areas that the IFPRI simulation suggests might be economically converted to irrigation under three levels of investment costs and two internal rates of return (IRR). Map 4.1 presents the results for the baseline scenario (medium level of investment costs, 5 percent IRR). The potential for small-scale irrigation ranges from 5.2 million hectares under a high level of

Table 4.5 Irrigation Development Potential, SSA Drylands (Million Hectare)

Scenario	*Low cost*	*Medium cost*	*High cost*
		Large-scale irrigation	
IRR 5%	2.52	**1.60**	1.01
IRR 12%	1.44	1.15	0.85
		Small-scale irrigation	
IRR 5%	11.60	**9.07**	6.22
IRR 12%	11.48	8.54	5.16

Source: Xie et al. (2014a).
Note: Basic scenario of medium cost 5 percent IRR is in bold. SSA= Sub-Saharan Africa.

Map 4.1 Current Irrigated Area and Potential for Expansion, Whole SSA Drylands, Baseline Scenario



Source: Xie et al. (2014a).

Note: Even though the map presents areas in North Africa, only SSA countries are included in the analysis. SSA = Sub-Saharan Africa.

investment costs and an IRR of 12 percent to 11.6 million hectares under a low level of investment costs and an IRR of 5 percent. The potential for large-scale irrigation, which is determined in large part by the number of dams slated for construction or rehabilitation, is much smaller and ranges from 0.8 million hectares (high level of investment cost, 12 percent IRR) to 2.5 million hectares (low level of investment cost, 5 percent IRR).

Table 4.6 presents the same results broken down by aridity zone. Provided that investment costs can be moderated at the "medium" level of US$12,000 per

Table 4.6 Irrigation Development Potential by Aridity Zone, SSA Drylands ('000 Hectare)

		Large-scale irrigation		*Small-scale irrigation*					
Aridity zone	*Cultivable area (2000) ('000 ha)*	*Medium cost, 5% IRR ('000 ha)*	*Medium cost, 12% IRR ('000 ha)*	*Medium cost, 5% IRR2 ('000 ha)*	*Medium ICC, 12% IRR2 ('000 ha)*	*Total at 5% IRR ('000 ha)*	*% of crop area*	*Total at 12% IRR ('000 ha)*	*% of crop area*
Arid	21,920	198	161	403	421	601	2.7	582	2.7
Semi-arid	37,348	267	134	2,610	2,353	2,877	7.7	2,487	6.7
Semi-arid	29,318	419	310	2,693	2,638	3,112	10.6	2,948	10.1
Dry sub-humid	37,459	718	540	3,368	3,127	4,086	10.9	3,667	9.8
Grand total	**126,045**	**1,602**	**1,145**	**9,074**	**8,539**	**10,676**	**8.5**	**9,864**	**7.8**

Source: Cultivable area from Ramankutty et al. (2008); other columns: Xie et al. (2014a).
Note: SSA = Sub-Saharan Africa; IRR = internal rate of return.

hectare for large-scale irrigation and US$4,500 per hectare for small-scale irrigation (similar to the costs incurred in recent years under World Bank-funded projects), as much as 9–10 million hectares could be economically developed for irrigation with acceptable rates of return. This would represent conversion to irrigation of 7–8 percent of currently cultivated rainfed cropland and would have a transformational impact on drylands agriculture and livelihoods.

As a share of cultivable area, the potential for irrigation expansion is largest in aridity index (AI) zones 5 and 6 (covering part of the semi-arid zone and all of the dry sub-humid zone), representing about 10 percent of the cultivable area in those zones (table 4.6). In contrast, the potential for irrigation expansion is much lower in AI zones 3 and 4 (covering all of the arid zone and part of the semi-arid zone), representing about 2–3 percent of the cultivable land and 6–7 percent of the cultivable land in those two zones, respectively. The assessment found very limited irrigation potential in AI zones 1 and 2 (covering the hyper-arid zone), which were excluded from the working definition of drylands. In these two zones, the potential (totaling less than 100,000 hectares) is mainly for large-scale irrigation. At the other end of the spectrum, the study found considerable irrigation potential in AI zone 7 (covering humid, non-dryland areas), which was also excluded from the working definition of drylands.

Table 4.7 presents irrigation potential in dryland regions of SSA (the numbers in table 4.7 reflect the baseline scenario of medium-level investment costs and 5 percent IRR). The total area that could be developed for irrigation in drylands is significant, representing about 8 percent of the area that is currently being cultivated in drylands. Summarizing across all dryland regions in SSA, there is much more potential for development of small-scale irrigation than there is potential for development of large-scale irrigation. Out of a total area of around 10.6 million hectares that could be developed for irrigation in dryland regions, 9.1 million hectares (85 percent) are suitable for small-scale irrigation, whereas only 1.6 million hectares are suitable for large-scale irrigation.

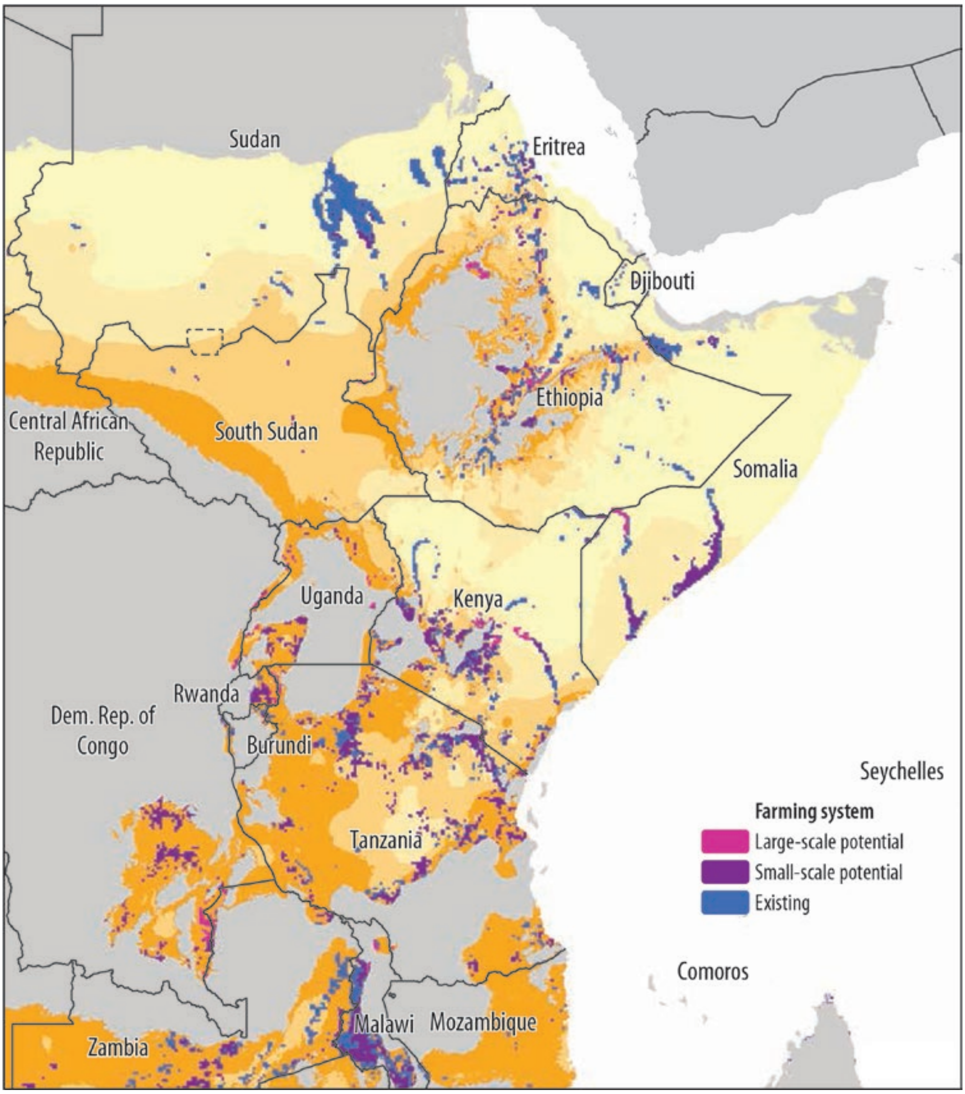
The geographic locations of potential irrigation under the medium-cost scenario and 5 percent IRR are shown in maps 4.2, 4.3, and 4.4. Fifty percent of the potential for large-scale irrigation and 57 percent of the potential for small-scale

Table 4.7 Potential for Expansion of Irrigated Area in Drylands, by SSA Region

Region	*Cultivable area ('000 ha)*	*Large-scale, medium cost, 5% IRR ('000 ha)*	*Small-scale, medium cost, 5% IRR ('000 ha)*	*Total ('000 ha)*	*As % of cultivable area*
Central Africa	4,353	87	180	267	6,1
Eastern Africa	37,739	326	2,358	2,684	7.1
Southern Africa	26,472	389	2,159	2,548	9.6
Western Africa	57,481	801	4,378	5,179	9.0
Total	**126,045**	**1,603**	**9,075**	**10,678**	**8.5**

Source: Cultivable area from Ramankutty et al. (2008) other columns: Xie et al. (2014a).
Note: SSA = Sub-Saharan Africa; IRR = internal rate of return.

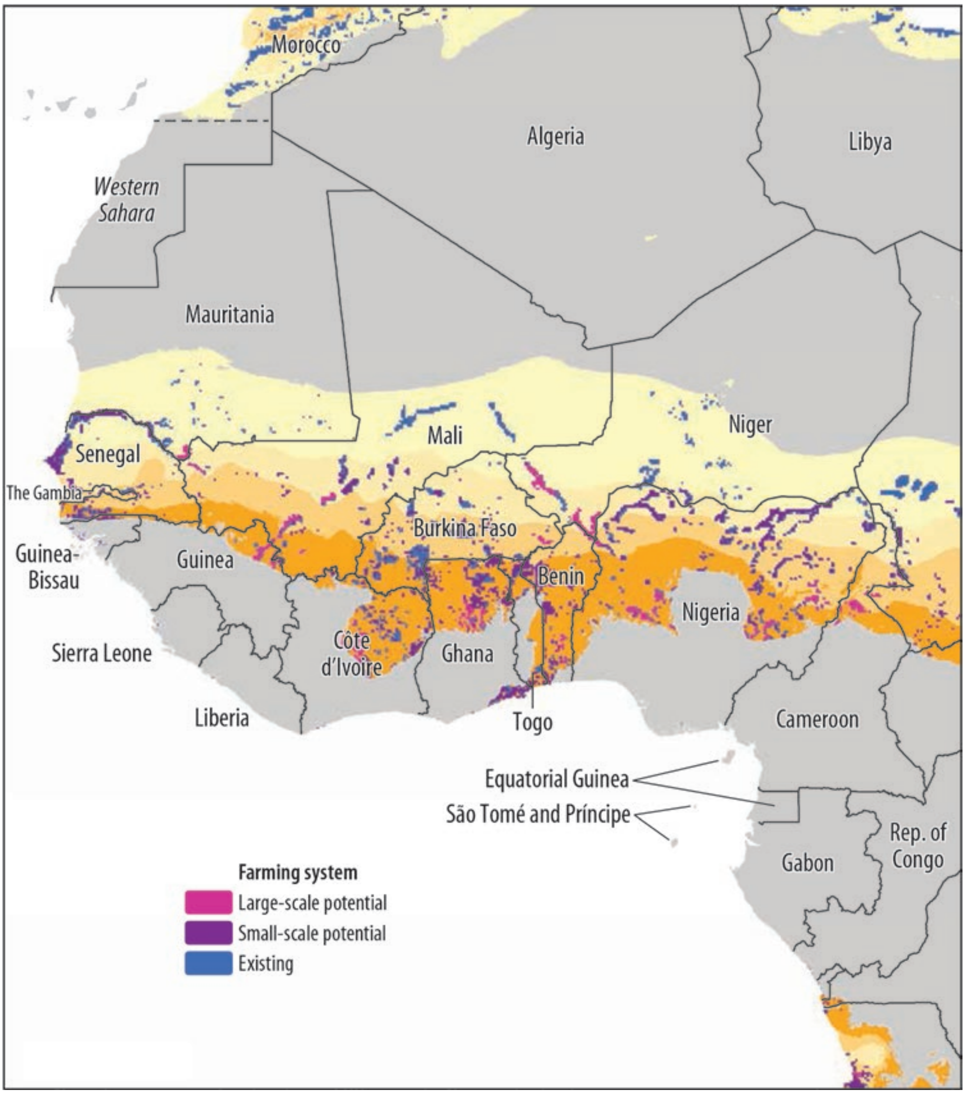
Map 4.2 Irrigation Development Potential in Drylands, Eastern Africa (Medium Investment Cost, 5 percent IRR)



Source: Xie et al. (2014a).
Note: IRR = internal rate of return.

irrigation is located in Western Africa. Twenty percent of the potential for large-scale irrigation and 26 percent of the potential for small-scale irrigation are located in Eastern Africa. The total potential is highest in Western Africa, with 5.2 million hectares, or 9 percent of the cultivable area. The potential is lowest in Central Africa with up to 267,000 hectares, or about 6 percent of the cultivable area. The region does not boast many new dams and has substantially more humid areas and overall smaller areas. In Southern Africa, the area with potential for

Map 4.3 Irrigation Development Potential in Drylands, Western Africa (Medium Investment Cost, 5 percent IRR)

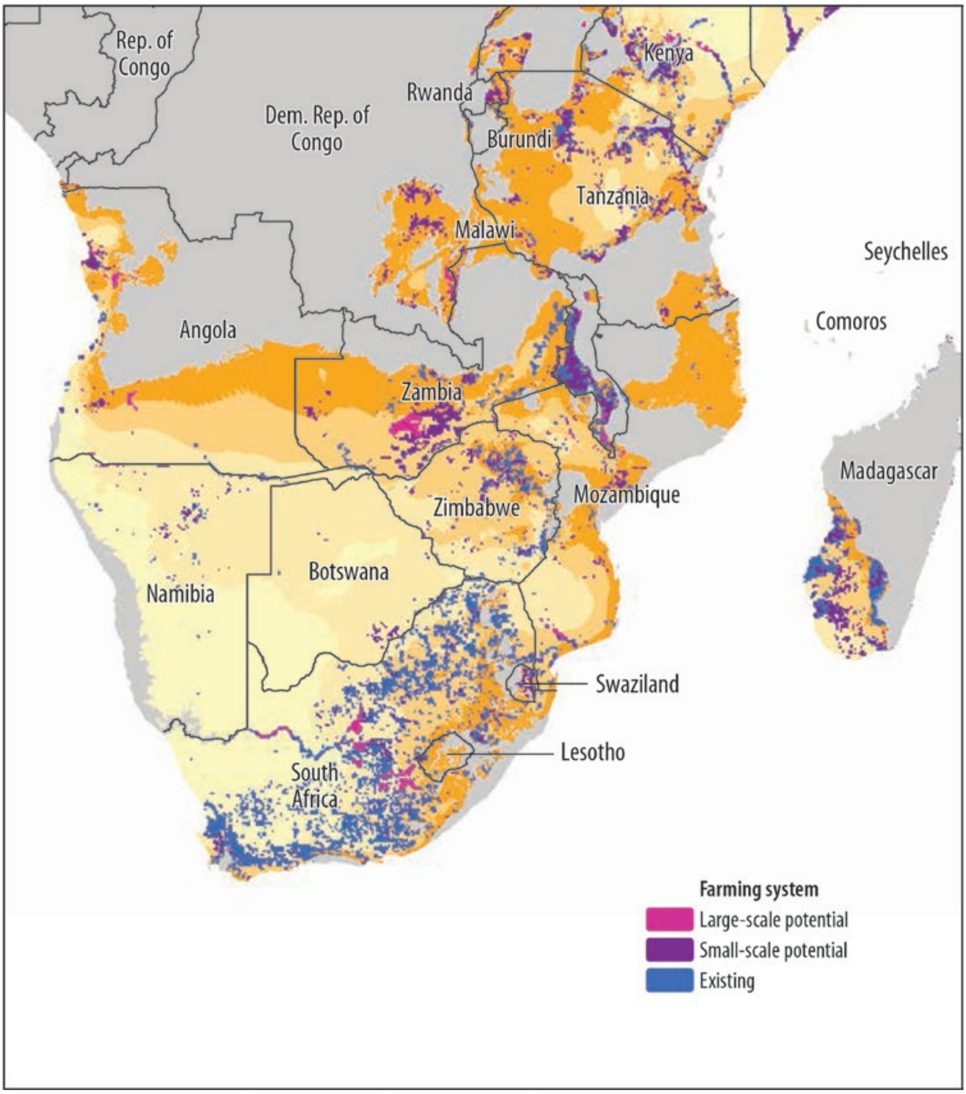


Source: Xie et al. (2014a).
Note: IRR = internal rate of return.

irrigation (2.6 million hectares, 10 percent of the cultivable area) is similar to the area in Eastern Africa (2.7 million hectares, 7 percent of the cultivable area). The area suitable for small-scale irrigation is somewhat smaller in Southern Africa because of the relatively dry climate in this region and because many dryland areas in Southern Africa are already irrigated.

As previously mentioned, irrigation development has lagged in dryland regions of SSA compared to other regions of the world, as only 5 percent of

Map 4.4 Irrigation Development Potential in Drylands, Southern Africa (Medium Investment Cost, 5 percent IRR)



Source: Xie et al. (2014a).
Note: IRR = internal rate of return.

cultivable land in the drylands is currently irrigated. Fully exploiting the irrigation potential in drylands could change that situation markedly, adding up to 10.6 million hectares to the existing 5.2 million hectares and raising the share of cultivable land in dryland regions that is irrigated to 13 percent (table 4.8). If the available irrigation potential were fully exploited, the share of land that is irrigated in dryland regions of Eastern Africa would more than double (from 6 percent of the cultivable area to 13 percent), as would the share of land that is

Table 4.8 Current and Potential Irrigated Area as a Share of Total Cultivable Area, SSA Drylands

SSA region	*Drylands cultivable area ('000 ha)*	*Current irrigated area ('000 ha)*	*As % of cultivable area*	*Potential irrigated area[1] ('000 ha)*	*Current plus potential irrigated area ('000 ha)*	*As % of cultivable area*
Eastern	37,739	2,330	6	2,684	5,014	13
Western	57,481	823	1	5,179	6,002	10
Southern	26,472	2,034	8	2,548	4,582	17
Central	4,353	0	0	267	267	6
Total	**126,045**	**5,187**	**4**	**10,678**	**15,865**	**13**

Source: Cultivable area from Ramankutty et al. (2008); current irrigated area from FAO AQUASTAT (Table 6); other columns: Xie et al. (2014a).

Note: [1]Medium cost scenario, 5 percent IRR. SSA = Sub-Saharan Africa; IRR = internal rate of return.

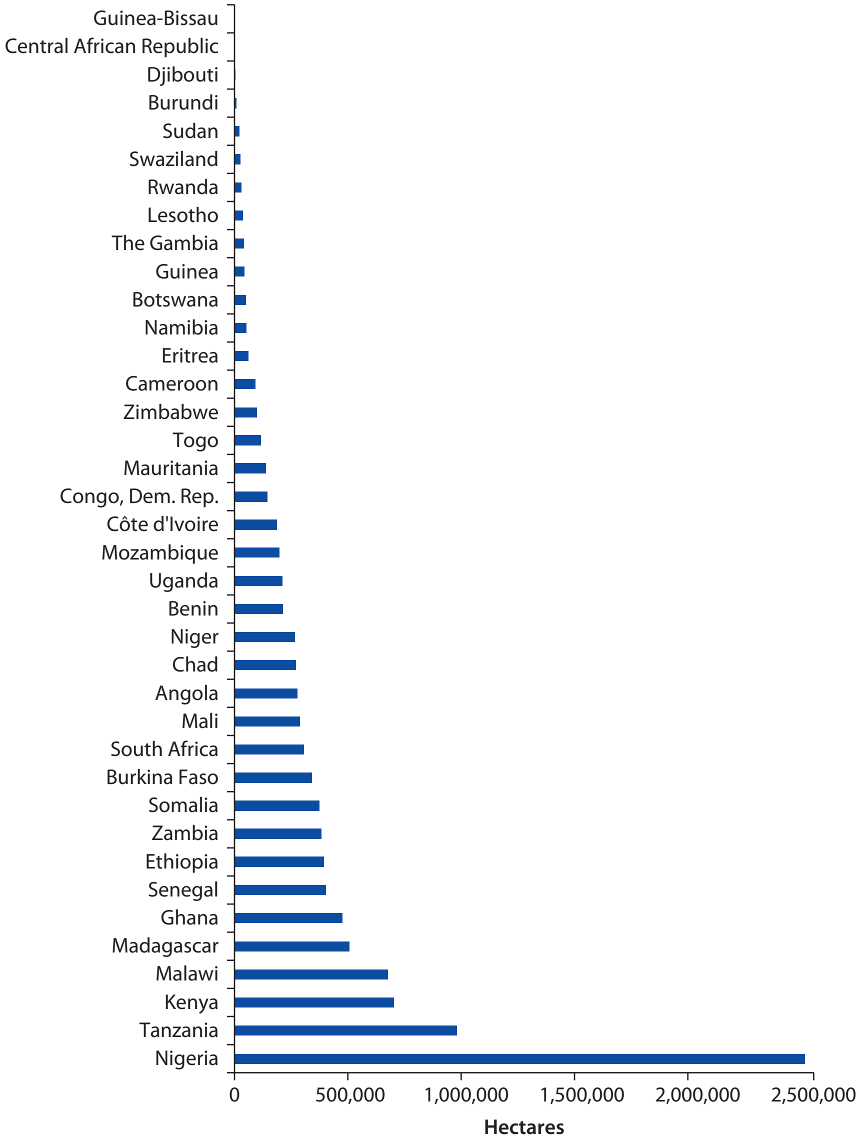
irrigated in dryland regions of Southern Africa (from 8 to 17 percent). The biggest relative increase would occur in Western Africa, where the share of land that is irrigated in dryland regions would increase from 1 to nearly 10 percent.

Figure 4.1 and table 4.9 present the results of the irrigation potential assessment for all countries for the baseline scenario (medium level of investment costs, 5 percent IRR). Not surprisingly, countries in which a large share of the cultivable land is located in more humid dryland zones have higher irrigation potential. More than 9 percent of the cultivable land found in dry sub-humid zones or more humid semi-arid zones (zones 5 and 6) could be developed for irrigation, compared to only 6 percent of the cultivable land found in semi-arid zones and arid zones (zones 3 and 4). Large areas of rainfed cropland provide fertile ground for conversion to irrigation, and those areas in zones 5 and 6 have higher soil moisture content in the dry season due to the overall enhanced precipitation. This allows for more stable production under small-scale irrigation schemes.

In several countries, the area that could be developed for irrigation makes up a significant share of the total cultivable area (table 4.9). In 17 countries, the area that could be developed for irrigation represents more than 10 percent of the cultivable area in drylands. In Tanzania and Ghana, the area that could be developed for irrigation in drylands represents more than one-quarter of the cultivable area in drylands, and in Malawi and Madagascar, fully 70 percent of the cultivable area in drylands could be brought under irrigation. In these countries, a focus on irrigation development in the drylands could have a transformational impact.

Approximately one-half of the dryland area with good potential for irrigation development is concentrated in just six countries (Ghana, Kenya, Madagascar, Malawi, Nigeria, and Tanzania). Nigeria, which is home to 16 percent of the total cultivable area in drylands in all of SSA, alone holds 2.5 million hectares of potentially irrigable land, almost one-fourth of the total for all of SSA. Tanzania and Kenya in Eastern Africa and Malawi in Southern Africa also have irrigation potential in dryland zones of more than 500,000 hectares. Another 15 countries

Figure 4.1 Irrigation Potential by Country (Medium Cost, 5 percent IRR)



Source: Xie et al. (2014a).
Note: IRR = Internal rate of return.

have irrigation potential of 200,000 hectares or more in dryland zones: Angola, Benin, Burkina Faso, Chad, Ethiopia, Ghana, Madagascar, Mali, Niger, Senegal, Somalia, South Africa, Uganda, and Zambia.

The least potential for irrigation development in dryland zones (less than 5,000 hectares) was found in Burundi, Central African Republic, Djibouti, and Guinea-Bissau, countries with relatively small areas of cultivable land located in dryland zones.

Table 4.9 Irrigation Expansion Potential in Drylands, by Region and Country (Medium Cost, 5 percent IRR)

SSA region and country	*Dryland cultivable area ('000 ha)*	*Irrigation expansion potential ('000 ha)*			*As % of dryland cultivable area*
		Large-scale	*Small-scale*	*Total*	
Eastern Africa					
Eritrea	518		61	61	11.8
Ethiopia	7,467	110	274	384	5.1
Kenya	4,316	127	559	686	15.9
Somalia	1,093	23	341	364	33.3
Sudan	16,729		21	21	0.1
Tanzania	3,503	26	932	958	27.3
Uganda	4,111	40	166	206	5.0
Djibouti	1		4	4	400
Sub-total	*37,738*	*326*	*2,358*	*2,684*	*7.1*
Western Africa					
Benin	2,540	44	164	208	8.2
Burkina Faso	4,348	21	312	333	7.7
Chad	3,527	5	260	265	7.5
Côte d'Ivoire	2,378	16	166	182	7.7
Gambia	261		40	40	15.3
Ghana	1,833	46	419	465	25.4
Guinea	31	42		42	135.5
Guinea-Bissau	17		2	2	11.8
Mali	4,531	52	229	281	6.2
Mauritania	820	5	129	134	16.3
Niger	13,809	199	62	261	1.9
Nigeria	19,801	370	2,087	2,457	12.4
Senegal	2,369		394	394	16.6
Togo	1,216		113	113	9.3
Sub-total	*57,481*	*800*	*4,378*	*5,179*	*9.0*
Southern Africa					
Angola	1,085	67	204	271	25.0
Botswana	828		49	49	5.9
Lesotho	226		35	35	15.5
Madagascar	682		495	495	72.6
Malawi	830	99	562	661	79.6
Mozambique	2,403	99	94	193	8.0
Namibia	812	10	41	51	6.3
South Africa	13,512	41	258	299	2.2
Swaziland	103		24	24	23.3
Zambia	2,677	64	309	373	13.9
Zimbabwe	3,313	8	89	97	2.9
Sub-total	*25,724*	*388*	*2,159*	*2,547*	*9.9*

table continues next page

Table 4.9 Irrigation Expansion Potential in Drylands, by Region and Country (Medium Cost, 5 percent IRR) *(continued)*

SSA region and country	*Dryland cultivable area ('000 ha)*	*Irrigation expansion potential ('000 ha)*			*As % of dryland cultivable area*
		Large-scale	*Small-scale*	*Total*	
Central Africa					
Burundi	97		7	7	7.2
Cameroon	1,270	52	37	89	7.0
Central African Republic	867		2	2	0.2
DRC	1,792	32	109	141	7.9
Rwanda	326	3	25	28	8.6
Sub-total	*4,352*	*87*	*180*	*267*	*6.1*
TOTAL	***126,045***	***1,601***	***9,075***	***10,676***	**8.5**

Source: Cropland 2000: Ramankutty (2008); irrigation potential from Xie et al. (2014a).
Note: SSA = Sub-Saharan Africa; IRR = internal rate of return.

Democratic Republic of the Congo, Equatorial Guinea, Gabon, Liberia, Sierra Leone, and Western Sahara have little or no cultivable land located in dryland zones, so they have no irrigation development potential.

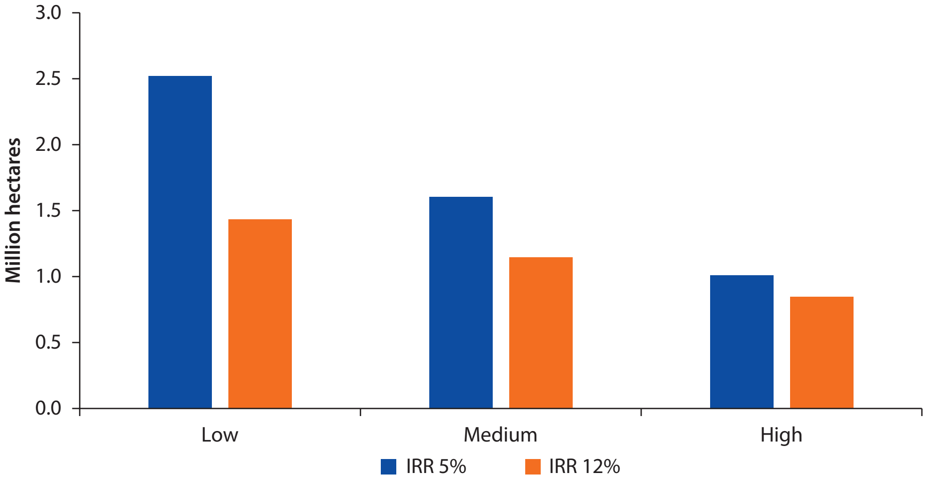
Likely Cropping Patterns

The assessment projected the cropping patterns likely to emerge in the presence of additional irrigation, based on supply and demand factors.[2] Across all countries with dryland areas, maize emerged as the dominant crop, grown on 4.7 million hectares (26 percent of the irrigated harvested area), followed by rice with 4 million hectares (22 percent), vegetables with 2.2 million hectares (12 percent), and sugarcane with 2.2 million hectares (12 percent). A series of other crops, such as millet, sorghum, and potatoes, are likely to be grown to a lesser extent on irrigated land in dryland zones. In terms of largest areas for specific crops, Madagascar has more than 700,000 hectares potential for rice cultivation, which includes double cropping on some of the irrigated area; Nigeria has 900,000 hectares potential for vegetables (which would still only meet domestic demand) and more than 700,000 hectares for sugarcane; and Tanzania has close to 400,000 hectares potential for rice.

Sensitivity to Costs and IRR Assumptions

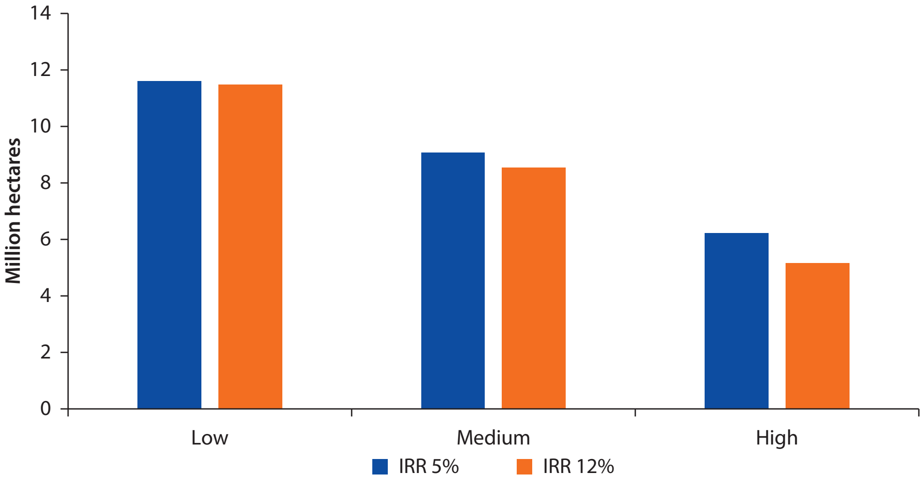
Changes in the assumptions made about levels of investment costs and IRRs affect the projections of irrigation development potential. This is particularly the case for large-scale irrigation, reflecting the much greater capital intensity. Figures 4.2 and 4.3 show the effects of changes in these key parameters. Assuming low levels of investment costs, when the minimum acceptable IRR is raised from 5 to 12 percent, the area in dryland zones with potential for large-scale irrigation decreases from 2.52 to 1.44 million hectares, a decline of

Figure 4.2 Sensitivity Analysis Results for LSI



Source: Xie et al. (2014a).
Note: LSI = large-scale irrigation.

Figure 4.3 Sensitivity Analysis Results for SSI



Source: Xie et al. (2014a).
Note: SSI = small-scale irrigation, IRR = internal rate of return.

75 percent. The declines are less dramatic when levels of investment costs are medium and high. Under medium levels of investment costs, the area in dryland zones with potential for large-scale irrigation decreases from 1.60 to 1.15 million hectares when the minimum acceptable IRR is raised from 5 to 12 percent (a 40 percent decline), and under high levels of investment costs, the area in dryland zones with potential for large-scale irrigation declines from 1.01 to

0.85 million hectares (a 19 percent decline). The upper bound of the potential for large-scale irrigation is 2.5 million hectares (low level of investment costs, 5 percent IRR), and the lower bound is 840,000 hectares (high level of investment costs, 12 percent IRR) (table 4.9).

For small-scale irrigation, which is generally more profitable due to the lower levels of investment costs, higher minimum acceptable IRRs impact potential most under the high-cost scenario. Assuming high levels of investment costs, when the minimum acceptable IRR is raised from 5 to 12 percent, the area in dryland zones with potential for small-scale irrigation decreases from 6.22 to 5.16 million hectares, a decline of 17 percent. Assuming medium levels of investment costs, when the minimum acceptable IRR is raised from 5 to 12 percent, the area in dryland zones with potential for small-scale irrigation decreases from 9.07 to 8.54 million hectares, a decline of only 6 percent. The upper bound of the potential for small-scale irrigation is 11.6 million hectares (low level of investment costs, 5 percent IRR), and the lower bound is 5.16 million hectares (high level of investment costs, 12 percent IRR) (table 4.9).

For both large-scale and small-scale irrigation, projected irrigation potential is sensitive to cost assumptions, confirming experience in SSA that capital cost is a key determinant of viability. When investment costs for large-scale irrigation increase from US$8,000 per hectare to US$30,000 per hectare, development potential in dryland regions decreases from 2.52 to 1.01 million hectares assuming a minimum acceptable IRR of 5 percent, and from 1.44 to 0.85 million hectares assuming a minimum acceptable IRR of 12 percent. When investment costs for small-scale irrigation increase from US$3,000 to US$6,000 per hectare, development potential in dryland regions decreases from about 11 million hectares to 5–6 million hectares, depending on the minimum acceptable IRR.

Costs and Benefits of Further Irrigation Development in the Drylands

Cost of Irrigation Expansion

What would be the cost of fully exploiting the potential for large-scale and small-scale irrigation in dryland regions of SSA?

Under the baseline scenario (medium level of investment costs and 5 percent minimum acceptable IRR), the total cost of fully exploiting the 1.6 million hectares with potential for large-scale irrigation would be US$19.2 billion (table 4.10). The lion's share of this cost would be incurred in Western Africa (US$9.6 billion, 50 percent of the total), with costs of US$4.7 billion in Southern Africa (24 percent) and US$3.7 billion in Eastern Africa (20 percent).

Using similar assumptions, the total cost of fully exploiting the 8.4 million hectares with potential for small-scale irrigation would be US$40.8 billion. Again, almost half this cost would be in incurred in Western Africa (US$19.7 billion, 48 percent of the total). Eastern Africa could invest US$10.6 billion (26 percent), and Southern Africa US$9.7 billion (24 percent).

Table 4.10 Estimated Cost of Fully Developing Irrigation Potential, SSA Drylands

	Large-scale irrigation at US$12,000/ha		*Small-scale irrigation at US$4,500/ha*		*Total (large-scale + small-scale)*	
SSA region	*Area ('000 ha)*	*Cost (US$ billions)*	*Area ('000 ha)*	*Cost (US$ billions)*	*Area ('000 ha)*	*Cost (US$ billions)*
Central Africa	87	1.04	180	0.81	267	1.85
Eastern Africa	326	3.92	2,358	10.61	2,684	14.53
Southern Africa	389	4.68	2,159	9.72	2,548	14.4
Western Africa	801	9.62	4,378	19.70	5,179	29.32
Total	**1,603**	**19.24**	**9,075**	**40.84**	**10,674**	**60.08**

Source: Xie et al. (2014a).
Note: SSA = Sub-Saharan Africa.

Combining the two estimates, the total cost of fully exploiting all irrigation development potential in dryland regions of SSA (10.6 million hectares) would come to approximately US$60.0 billion. Almost half of this cost would be incurred in Western Africa, where US$29.3 billion would be required to develop the total potential of 5.2 million hectares. Eastern and Southern Africa would require about the same investment envelope: US$14.5 billion to develop 2.7 million hectares in Eastern Africa, and US$14.4 billion to develop 2.5 million hectares in Southern Africa. The total potential of 267,000 hectares in Central Africa could be developed for about US$1.9 billion. The breakdown of potential and costs for each dryland country is discussed in section “Investment Costs and Phasing” in chapter 6, together with a discussion of their implications for country development plans.

The total estimated cost of US$60 billion to develop 10.6 million hectares (average cost US$5,700 per hectare) compares to earlier Economic Commission for Africa (ECA) estimates for SSA as a whole. ECA set the target of doubling the irrigated area in SSA as a whole (not just in the drylands), which would add a further 6.2 million hectares, and estimated that this would cost US$35 billion (at an average cost of US$5,600 per hectare). In addition, ECA counted the cost of extra storage of 89 BCM for a further cost of US$10 billion (at a cost of US$0.11 per cubic meter stored). Thus ECA’s total bill for 6.2 million hectares would be US$45 billion, or US$7,300 per hectare. Without the storage cost, the cost per hectare would be very similar to that calculated here (US$5,700 per hectare). Thus ECA estimated potential at only two-thirds as much as the current assessment, but reckoned the investment cost on an identical per hectare cost.

One significant result emerging from the current assessment is the much larger potential in drylands for development of small-scale irrigation, with its lower costs, more decentralized approaches, and likely higher levels of farmer participation, both in kind and in cash. Government strategies, action plans, and investment programs therefore would be well advised to give priority attention to small-scale rather than large-scale irrigation.

Benefits from Irrigation Expansion

Impact on Production

IMPACT was used to assess the likely impact of irrigation expansion in drylands zones of SSA on production of cereals (rice, maize, and wheat), other grains, pulses and root crops (millet, sorghum, groundnut, potato and sweet potato), and other cash crops (vegetables). Under the baseline scenario, production in dryland zones could increase by as much as 41 percent (189 million metric tons or MT) (table 4.11). The increase likely to occur in cereals production amounts to 59 million MT or 52 percent. Similar to the other results of the assessment, these projections are sensitive to assumptions made about productivity parameters, costs, prices, and the minimum acceptable IRR.

Economic Returns

The baseline scenario used for the assessment assumed a minimum acceptable IRR of 5 percent and medium levels of investment costs. Empirical studies suggest that historical rates of return on investments in irrigation in SSA have been highly variable (see table 4.12). Irrigation projects that have recorded high rates of return have tended to exhibit one or more of four key characteristics: (i) low investment costs (especially common in projects designed to rehabilitate existing infrastructure, as opposed to developing new infrastructure); (ii) good access to markets and high-performing value chains; (iii) high productivity; and (iv) empowerment of farmers and streamlining of project agencies. On the whole, projects that have supported small-scale irrigation have done better than projects that have supported large-scale irrigation. Higher rates of return generated by projects during the 1990s are explained by the fact that the majority of the irrigation

Table 4.11 Projected Incremental Crop Production in SSA Drylands due to Irrigation Investment (Medium Cost, 5 percent IRR)

	Cereals (rice, maize wheat)		*Other grains, pulses and root crops (millet, sorghum, groundnuts, potato and sweet potato)*		*Other cash crops (vegetables and sugarcane)*		*Total for all crops*	
Region	*Annual increment (million MT)*	*Acceleration ratio*	*Annual increment (million MT)*	*Acceleration ratio*	*Annual increment (million MT)*	*Acceleration ratio*	*Annual increment (million MT)*	*Acceleration ratio*
Eastern Africa	21.9	1.79	15.7	1.34	13.6	1.92	51.3	1.57
Central Africa	4.7	1.64	2.8	1.16	3.3	1.55	10.8	1.36
Southern Africa	11.9	1.32	14.8	2.40	3.9	1.20	30.6	1.46
Western Africa	20.2	1.50	37.2	1.20	38.9	1.91	96.4	1.36
Total	**58.8**	**1.52**	**70.5**	**1.27**	**59.7**	**1.72**	**189**	**1.41**

Source: Xie et al. (2014a). Acceleration ratio is the ratio between projected productions in 2050 at specified investment scale and in the case of lacking sufficient irrigation investment.
Note: SSA = Sub-Saharan Africa; IRR = internal rate of return; MT = metric ton.

Table 4.12 Rates of Return on Externally Financed Irrigation Projects, SSA, 1970–1999

	1970–74	*1975–79*	*1980–84*	*1985–89*	*1990–94*	*1995–99*
Number of projects	3	9	11	15	4	3
Cost/ha (US$)	4,700	24,500	11,300	7,700	8,300	8,300
Average IRR (%)	10	2	8	16	17	30

Source: Peacock and Ward (2007).
Note: SSA = Sub-Saharan Africa.

Box 4.1 Costs and Benefits of Small-Scale Irrigation in Niger

Niger's small-scale private irrigation program has proved an affordable and profitable model for farmers, and benefits have been widespread. The development of affordable, low-cost equipment like the treadle pump, which is fabricated, installed, and serviced by trained local artisans, has greatly increased the accessibility of irrigation, even for poor farmers.

Investment costs for small-scale private irrigation are relatively low: CFA franc (CFAF) 500,000 to 1.5 million per hectare, depending on the technology. The existence of a range of technologies allows farmers to start with the simplest and least risky, and to work their way up as they succeed.

Yields in irrigated horticulture have improved considerably: between 2001 and 2006, onion yields rose from 26 to 41 tons per hectare, and yields of peppers went up from 11 to 19 tons per hectare. Income per hectare from onions and peppers rose by 80 percent. Onions are the most profitable crop, but others (potatoes, tomatoes, cabbages, peppers, and lettuce) run a close second.

Rates of return are high and farmers make good money from the investments. Typical economic returns from motor pump irrigation range from 49 percent for potatoes to 74 percent for onions. Returns are higher to pedal pumps than to motor pumps (typically over 100 percent), and the gap is growing with the rise in energy costs.

Benefits are broadly distributed. With plot sizes averaging only 0.5 hectares, over 26,000 families have benefited. This translates into a substantial income increase for some 150,000 Nigeriens, the vast majority of whom were poor. The project thus has made a substantial contribution in terms of accelerating growth, boosting exports, raising household income, and reducing poverty.

Source: Ward (2007).

projects financed during that period supported small-scale irrigation, including community-based schemes and individual irrigation (box 4.1) (IWMI 2005; Peacock and Ward 2007).

Impact on the Dryland Population

An additional 10.0 million hectares of irrigated production could support up to 60 million rural people, assuming that one hectare of irrigated production produces on average 9 tons of incremental produce, including a mix of both two-thirds food crops and one-third other cash crops, can provide adequate stable income for one family. Fully exploiting the irrigation development potential in the drylands of SSA thus could help up to one-quarter of the rural population of the drylands become resilient (264 million people).

Impact on Net Trade

Based on the IMPACT projections, under all scenarios involving irrigation expansion in dryland zones of SSA, net imports of cereals to the region decline. For example, under the baseline scenario (medium level of investment costs, 5 percent minimum acceptable IRR), net imports of cereals into the region are projected to fall from 133 to 76 million metric tons. Irrigation development in the drylands is projected to improve the trade balance by 57 million metric tons annually, reducing net imports by over one-third (43 percent) (table 4.13).

One-half of this change will occur in Eastern Africa, where irrigation is projected to add 22 million metric tons annually to the trade balance in cereals, reducing net imports from a projected 35 to 22 million metric tons (IFPRI 2014, Table 3.8). Cereal imports into Southern Africa would decline by one-third. Accelerated investment in irrigation in dryland zones of SSA could thus reduce cereal net imports by more than one-third.

For root crops (potato and sweet potato), the impacts on trade would be even more dramatic. If the potential for irrigation development in drylands is fully exploited, the dryland countries would shift from being net importers to being net exporters. For SSA as a whole, a 2050 net import position of 17 million metric tons projected in the absence of irrigation development would change to a net export position of about 29 million metric tons.

According to the IMPACT projections, irrigation development in the drylands would also bring about a large change in the net trade position for vegetables. Across the entire region, net imports of 36 million metric tons annually would be turned into 3 million metric tons of exports in 2050. Vegetables are generally higher value and thus less affected by higher costs or higher IRR. The Western Africa region contributes almost all vegetable exports, which changes its trade

Table 4.13 Projected Changes in Cereals Trade due to Irrigation Development, 2050

Crop	*Rice, wheat, and maize*	
SSA region	*million MT*	*% change*
Eastern Africa	(13)	62
Central Africa	(4)	52
Southern Africa	(23)	32
Western Africa	(35)	36
Total	**(75)**	**43**
Additional trade due to irrigation development	57	

Source: Xie et al. (2014a).
Note: SSA = Sub-Saharan Africa; MT = metric ton.

position from net imports of 13 million metric tons to net exports of 17 million metric tons. The change in vegetable imports is 4 million metric tons in Eastern Africa and 2 million metric tons in both Central and Southern Africa (which also becomes a net exporter).

Finally, for sugar, the IMPACT projections show that irrigation development in the drylands would allow SSA as a whole to shift from a 2050 net import position of 9 million metric tons to a net export position of about 9 million metric tons, with most dramatic changes occurring in Eastern and Western Africa.

Impacts on Food Security

The IMPACT model was used to explore the likely impacts of irrigation development in dryland regions of SSA on two indicators of food security: (i) the number of malnourished children; and (ii) the population at risk of hunger.[3]

The assessment found that irrigation development in dryland regions of SSA could lead to reductions in child malnutrition on the order of 0.6–1.7 percent (equivalent to 230,000–680,000 children). Projected reductions range from 2.1 percent for Western Africa, 1.3 percent in Eastern Africa, 2.4 percent in Southern Africa, and 0.96 percent in Central Africa.

The baseline generated by the IMPACT model suggests 272 million people will be at risk of hunger in SSA in 2050. Close to one-third of these people will be found in Central Africa (92 million people), with smaller numbers located in Eastern Africa (67 million people), Western Africa (57 million people), and Southern Africa (approximately 56 million people). If the potential for irrigation development in drylands is fully exploited, the population at risk of hunger could be reduced by as little as 1.3 percent (3.6 million people) and by as much as 5.4 percent (14.8 million people), depending on the assumptions made about levels of investment costs and minimum acceptable IRRs.

Key Findings from the IFPRI Assessment

The IFPRI assessment generated a number of key findings.

- *Considerable potential*. The IFPRI assessment provides an objective look at the technical and macroeconomic scope for irrigation expansion in dryland regions of SSA. Like any modeling exercise, the methodology requires numerous assumptions about technical and economic parameters, but even so provides compelling evidence that there is considerable potential for irrigation development in the drylands—10 million hectares of new irrigation. In some countries, 10 percent or more of the cultivable land could be converted to irrigation, which would have a significant impact on the livelihoods of millions of rural households.
- *Benefits for up to 60 million people—and a multiple of that for the local economy*. Progressively developing this irrigation potential could have a transformative impact on the lives of up to 60 million dryland dwellers, one-quarter of the

total rural population of the drylands. Given the usual multiplier effect of irrigation, the total impact on local economies could be up to three times the direct income effect.

- *Improved resilience*. Expanded irrigation would substantially improve resilience of dryland farming systems and of farm families by allowing diversification, higher productivity, and increased monetary income and by proofing against climatic risks.
- *Planning predominantly for small-scale irrigation*. Given that the potential is largely (85 percent) for small-scale irrigation, a system more easily accessible to smallholders, of lower cost, and less demanding in terms of finance, operation and maintenance, and "top-down" investment, the priority for development in most areas and countries is likely to be for small-scale irrigation rather than large-scale irrigation. This predominance of small-scale irrigation in the overall potential has some significant advantages for dryland countries, particularly: (i) the lower entry cost, as small-scale irrigation does not rely on the construction of a dam for multi-season or multi-year storage as large-scale irrigation does; (ii) the more divisible nature of the investments—the average small-scale scheme has an average investment cost of US$1 million or less (for a 200 hectares scheme) versus US$25 for a 2,000 hectares large-scale irrigation scheme; and (iii) the more decentralized local accessibility of small-scale irrigation, compared to large-scale irrigation, which requires considerable government planning and investment.
- *Cost matters*. All irrigation development is high cost, with an average cost across all systems estimated here at US$5,700 per hectare. Since viability as measured by the IRR is sensitive to cost, keeping costs down is essential. In addition, investment costs need to be kept to the minimum if they are to be affordable by farmers and by poor dryland countries.
- *The challenges and high rewards of* large-scale irrigation. The potential for development of large-scale irrigation of up to 1.6 million hectares (medium level of investment costs, 5 percent IRR) would mainly comprise large-scale, conventional river basin development below multi-purpose dams. The large, up-front investment, the necessary involvement of government money (and usually of public agencies) and the challenging requirements of cost-effective development and efficient sustainable operations (recall section "Publicly Developed Large-Scale Irrigation" in chapter 3) are likely to constrain the pace of investment in large-scale irrigation. However, the rewards in terms of transformation and sustained resilience not only of the lives of local people but of the local and national economies are comparatively high. There are significant lessons from experience on how to get large-scale irrigation right in Africa, and over time countries are likely to progressively invest in developing their large-scale irrigation potential.

Groundwater sustainability. Much of the small-scale irrigation potential is either groundwater-based or uses groundwater as a complement to surface water sources. Strong advantages to groundwater prevail in terms of year-round availability, excellent water control, and local or individual responsibility for development, management, operation and maintenance (MOM), and financing. As in every groundwater-based environment, the challenge is to ensure equitable access and sustainable extraction, for which a measure of regulation—public or community-based—is essential, a condition that has proved hard to meet.

Notes

1. See the range of technologies in section "Why is Agricultural Water Management So Important in the Drylands?" in chapter 3.
2. Appendix Table 3.2 to Xie et al. (2014a) presents the crop area for the medium-cost scenario with 5 percent IRR.
3. To incorporate additional socioeconomics and food security indicators in the analysis, the six *expanded irrigation scenarios* in the drylands were simulated in IMPACT (see section "Assessment of Impacts of Irrigation Expansion on Food Security"). Food security indicators are estimated for African regions using IMPACT, with the impact estimated as the difference of the African drylands irrigation expansion scenario and the IMPACT baseline expansion scenario as explained in the methodology section. As some of the irrigated crops in the irrigation expansion simulation are not yet grown in some of the African countries in the IMPACT baseline (for example, rice), the study aggregated the IMPACT results to the regional level, where all crops can be found.

CHAPTER 5

Key Challenges: Exploiting Irrigation Development Potential and Strengthening Resilience

Historical Perspective

Chapter 3 discussed the status of irrigation in the Sub-Saharan African (SSA) drylands. With the exception of Madagascar's millennium-long tradition of Indonesian-style irrigated paddy cultivation and some large-scale irrigation developments during the colonial period (notably on the Nile River in Sudan and on the Niger River in Mali), irrigation in SSA is a fairly new phenomenon. At the farmer and community level, there is little experience in the technology of water development and distribution and in the institutional patterns of cooperation that characterize older irrigation socio-economies. The zealous expansion of publicly financed large-scale irrigation following independence encountered serious problems of planning, design, economics, and institutions, and failed or low-yielding schemes in many countries gave irrigation a bad name. In Kenya, for example, the failure of the Bura large-scale irrigation scheme in the drylands bordering the Tana River in the east of the country led policy makers and development partners to pause further large-scale irrigation development for two decades.

Today, demographic pressures, climate change, expanding markets, the growing vulnerability of the dryland population, and the legitimate desire for a more stable and prosperous future for the 270 million rural dryland dwellers all indicate the need for development paths for agricultural water that are viable and sustainable and can increase incomes and enhance resilience. This chapter discusses how these pathways can be opened up, while chapter 6 looks at the policies and programs that could put them into practice.

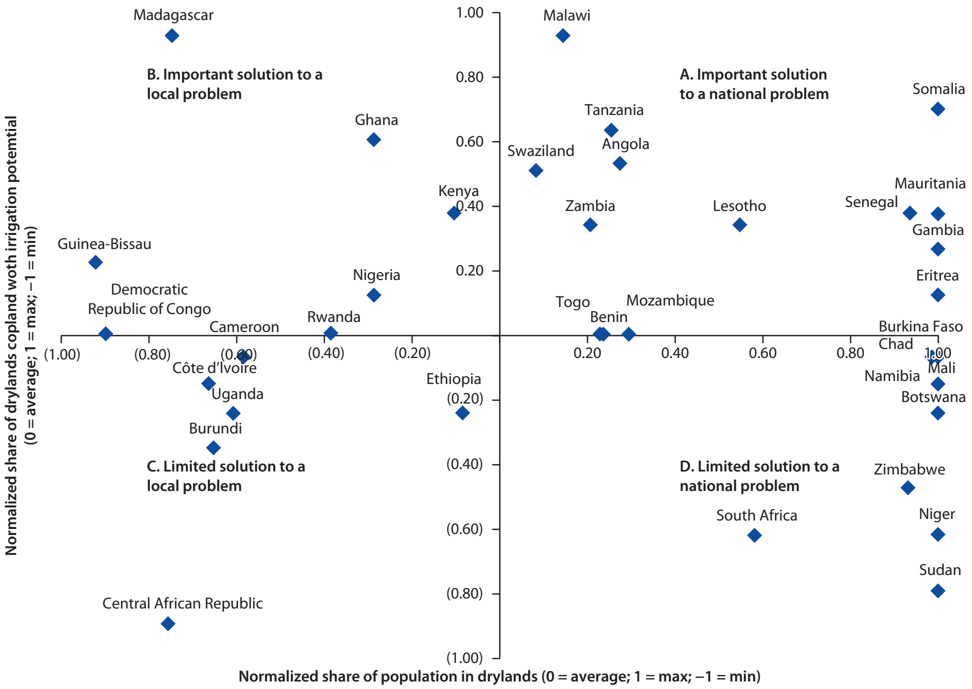
Where Does Irrigation Expansion Matter Most for Drylands?

To assess the relative importance of the drylands challenge by country and to evaluate the potential significance of irrigation in responding to that challenge, a simple classification scheme was devised that links the relative share of population living in drylands in each country to the country's irrigation potential. This is intended to identify the particular constraints facing each of these groups of countries and promote discussion of corresponding policy measures.

Figure 5.1 illustrates this simple classification scheme. Countries were mapped into one of four quadrants obtained by normalizing the country's share of population living in drylands (0 is the regional average of about 50 percent, 1 is the maximum, and –1 is the minimum) and the country's irrigation potential expressed as a share of dryland cropped area (again, 0 is the regional average of about 8 percent; 1 is the maximum, and –1 is the minimum).

In 14 countries, irrigation expansion could be an important solution to a national problem (table 5.1). These countries share two characteristics: more than the average share (50 percent) of their population lives in the drylands and their potential for further irrigation expansion is higher than average. Thus, irrigation expansion could be an important part of strategies to build resilience and reduce poverty and food insecurity in a range of countries, including Mauritania (on 134,000 hectares), Senegal (on 394,000 hectares), Malawi (on 661,000 hectares), and Zambia (on 373,000 hectares). The total potential for all 14 countries amounts to 3.4 million hectares, and development of this area for

Figure 5.1 Varying Importance of Irrigation Expansion in SSA Dryland Countries



Source: Cervigni and Morris (2016).
Note: SSA = Sub-Saharan Africa.

Table 5.1 Quadrant A—Irrigation Expansion Could Be an Important Solution to a National Problem

Country	*Cultivable area ('000 ha)*	*Irrigation expansion potential ('000 ha)* *Large-scale irrigation*	*Small-scale irrigation*	*Total*	*Potential irrigated area as % of cultivable area*
Eritrea	518	–	61	61	11.8
Somalia	1,093	23	341	364	33.3
Tanzania	3,503	26	932	958	27.3
Benin	2,540	44	164	208	8.2
Gambia	261	–	40	40	15.3
Mauritania	820	5	129	134	16.3
Senegal	2,369	–	394	394	16.6
Togo	1,216	–	113	113	9.3
Angola	1,085	67	204	271	25.0
Lesotho	226	–	35	35	15.5
Malawi	830	99	562	661	79.6
Mozambique	2,403	99	94	193	8.0
Swaziland	103	–	24	24	23.3
Zambia	2,677	64	309	373	13.9
Subtotal: Quadrant A	*19,644*	*427*	*3,402*	*3,829*	*19.5*

Source: Cervigni and Morris (2016).
Note: The dash indicates negligible.

irrigation could build resilience of and lift from poverty some 4 million farm families, or up to 25 million people.[1]

In all 14 countries, there is more potential for small-scale irrigation, so irrigation and agricultural strategy should focus on mechanisms to help smallholders develop this potential through multiple local schemes. Large-scale irrigation (LSI) potential also exists in several of these countries, including Zambia (64,000 hectares), Malawi (99,000 hectares), and Mozambique (99,000 hectares).

Seven countries (table 5.2) have potential for irrigation expansion as great as the first group (3.4 million hectares), but a smaller proportion of the population lives in the drylands; therefore, the focus of national development efforts will be less focused on the realization of this potential. Amongst these countries are three larger, more diversified economies: Kenya (irrigation expansion potential of 686,000 hectares); Ghana (potential of 465,000 hectares); and Nigeria (a vast potential of 2.5 million hectares). For these three countries, irrigation expansion in the drylands will take its place amongst a whole range of development initiatives aimed at poverty reduction. Madagascar is a less diversified economy and a very poor country where the historic predominance of irrigated agriculture across the country could help spur further development of the potential in the drylands as a means of relieving the poverty and improving the resilience of its very poor and vulnerable population. Generally speaking, for these countries, irrigation expansion could help to reduce poverty and build resilience for 4 million or more farm families, or up to 25 million people.

Table 5.2 Quadrant B—Irrigation Expansion Could Be an Important Solution to a Local Problem

		Irrigation expansion potential ('000 ha)			
Country	*Cultivable area ('000 ha)*	*Large-scale irrigation*	*Small-scale irrigation*	*Total*	*Potential irrigated area as % of cultivable area*
Kenya	4,316	127	559	686	15.9
Ghana	1,833	46	419	465	25.4
Guinea-Bissau	17		2	2	11.8
Nigeria	19,801	370	2,087	2,457	12.4
Madagascar	682	–	495	495	72.6
DRC	1,792	32	109	141	7.9
Rwanda	326	3	25	28	8.6
Subtotal: Quadrant B	*28,767*	*578*	*3,696*	*4,274*	*14.9*

Source: Cervigni and Morris (2016).
Note: The dash indicates negligible.

In these countries, the potential is again largely for small-scale irrigation, but large-scale irrigation potential also exists, for example, in Nigeria (370,000 hectares), Kenya (127,000 hectares), and Ghana (46,000 hectares).

For nine countries in the region, a large proportion of the population lives in the drylands but irrigation potential is considerably lower, with less than 3 percent of the drylands used as cropland on average (table 5.3). For these countries, irrigation could still be an important solution to the problems of poverty and vulnerability, but a range of other solutions will also be vitally important. For the better-off countries (Botswana, Namibia, and South Africa), diversification and alternative livelihoods will inevitably be a prime solution. For the poorer countries of Western Africa, focus will be on developing preexisting irrigation potential, which is not negligible. Burkina Faso has a potential of 333,000 hectares; Chad, 265,000 hectares; Mali, 281,000 hectares; and Niger, 261,000 hectares. These countries already have well-established irrigation histories and support programs that can be further developed and refined. Expansion of the irrigated area to full potential in these countries could lift up to 2 million farm families permanently out of poverty.

In some situations, more people could benefit, particularly where irrigated plots are small, complementary to other components of a diversified rainfed, irrigated, or pastoral farming system that characterizes much of the drylands. Most of the potential is again in small-scale irrigation, but major dams are planned or under construction that command potential large-scale irrigation perimeters in Mali (52,000 hectares) and Niger (199,000 hectares). In these countries, too, there is considerable existing experience with improving water management in purely rainfed areas where there is no irrigation potential. These approaches, typically part of integrated area development programs or community-driven development (CDD) funds (see chapter 3), will also be prime development mechanisms to strengthen resilience. Diversification and promotion of alternative non-agricultural livelihoods will be essential as well.

Table 5.3 Quadrant D—Irrigation Expansion Could Be a Limited Solution to a National Problem

Country	*Cultivable area ('000 ha)*	*Irrigation expansion potential ('000 ha)* *Large-scale irrigation*	*Small-scale irrigation*	*Total*	*Potential irrigated area as % of cultivable area*
Sudan	16,729	–	21	21	0.1
Burkina Faso	4,348	21	312	333	7.7
Chad	3,527	5	260	265	7.5
Mali	4,531	52	229	281	6.2
Niger	13,809	199	62	261	1.9
Botswana	828	–	49	49	5.9
Namibia	812	10	41	51	6.3
South Africa	13,512	41	258	299	2.2
Zimbabwe	3,313	8	89	97	2.9
Subtotal: Quadrant D	*61,409*	*336*	*1,321*	*1,657*	*2.7*

Source: Cervigni and Morris (2016).
Note: The dash indicates negligible.

Table 5.4 Quadrant C—Irrigation Could Be a Limited Solution to a Local Problem

Country	*Dryland cultivable area ('000 ha)*	*Irrigation expansion potential ('000 ha)*	*Potential irrigated area as % of cultivable area*
Ethiopia	7,467	384	5.1
Uganda	4,111	206	5.0
Cote d'Ivoire	2,378	182	7.7
Burundi	97	7	7.2
Cameroon	1,270	89	7.0
Central African Republic	867	2	0.2
Subtotal: Quadrant C	*16,190*	*870*	*5.4*

Source: Cervigni and Morris (2016).

The final group of six countries (table 5.4) has a smaller share of both population living in the drylands and of croplands with irrigation potential (just 5 percent on average). For these countries, irrigation expansion is only one amongst a range of development options, although three countries still have considerable potential in area terms: Ethiopia has a potential of 384,000 hectares; Uganda, 206,000 hectares; and Côte d'Ivoire, 182,000 hectares. Although potential is largely for small-scale irrigation (SSI), large dams also create the potential for large-scale irrigation development, including in Ethiopia (110,000 hectares) and in Côte d'Ivoire (16,000 hectares).

These countries will certainly pursue irrigation expansion, and this could strengthen the resilience of up to 1 million farm families and lift them out of poverty. However, given the small potential for irrigation relative to total croplands, complementary solutions to the challenges of poverty and vulnerability will be needed. The challenge may be greater for Ethiopia because of its high level of poverty and difficult topography and communications. Here, a focus on improving the productivity of rainfed agriculture will be a prime part of the strategy to build resilience and reduce poverty.

Agricultural Water Management in Rainfed Agriculture: Challenges and Opportunities

Across all dryland countries, the large majority of farmers cannot have access to full irrigation. In only nine countries (Somalia, Tanzania, Angola, Malawi, Swaziland, Ghana, Guinea, Djibouti and Madagascar) can irrigation be developed for more than 20 percent of the drylands cropped area, and in only four of these (Malawi, Madagascar, Guinea and Djibouti) is irrigation a possibility for more than half of the dryland cultivable area. In all other dryland countries, the great majority of farm families will continue to rely on rainfed agriculture for their livelihoods, and the challenge will be to improve resilience within these systems.

In particular, the very poor countries of the Sahel have relatively limited irrigation potential. On average, 91 percent of dryland cropland in Western Africa has no irrigation potential, and the situation is worst for the poorest countries: Burkina Faso (93 percent), Chad (93 percent), Mali (94 percent), and Niger (98 percent). These countries are faced with the enormous challenge of reducing poverty and enhancing resilience by improving productivity and the management of risks in rainfed agriculture—a major challenge for agricultural water management.

Reasons for Investing in Agricultural Water Management in Rainfed Environments

Although historical investment in agricultural water management has principally been in irrigation proper, and policy makers have shown less interest in this area, improving agricultural water management in rainfed systems in the drylands represents an accessible, low-cost, and highly geared investment that can strengthen resilience for large numbers:

- There is high potential to improve productivity through agricultural water management, and the potential is in principle the greatest where yields are lowest. In the drylands, the potential is large, as water is a principal limiting factor and observed yields are less than one-third of the maximum attainable (Molden 2007).
- As the predominant system, accounting for 96 percent of the dryland farmed area and 90 percent of production, the impact of a given improvement in productivity is very high in drylands compared to irrigated agriculture. A 1 percent increase in productivity in rainfed zones would produce as much extra production as a 10 percent increase in productivity in irrigated zones.
- Smallholder rainfed farmers are generally poor and vulnerable, so improving rainfed agriculture, although never transformational, must form part of a poverty reduction and enhanced resilience strategy.

- Smallholder rainfed farmers are the most exposed to the risks of climate change, so improving agricultural water management for these farmers would help reduce sensitivity to shocks.
- The costs of agricultural water management improvement are generally low compared to the costs of developing irrigation. Investment costs are typically US$50–250 per hectare developed; and US$2–5 per 1,000 cubic meters of water harnessed (Molden 2007).
- The conception and planning of improvements: (i) can be achieved either with or by farmers themselves; (ii) can build on existing farming systems (rather than revolutionize them); (iii) can draw on local knowledge about resources, climate, and farming; and (iv) can be flexibly adapted to conditions during implementation and operation.
- Many investments are labor-intensive and can be made by farmers without heavy external subsidies or engineering design, and operation and maintenance are generally financed and executed by farmers themselves.
- Environmental impacts of improving rainfed are generally positive, or at least lack the considerable risks attached to irrigated developments (Molden 2007).

What Is "Improved Rainfed Agriculture"? What Sort of Intensification?

Section "Improved Water Control in a Rainfed Environment" described a range of improvements that can be made to improve water use efficiency and water productivity in rainfed farming systems in the drylands which, if integrated with improvements in soil management and crop husbandry, can increase production and farmer incomes and strengthen resilience. Table 5.5 summarizes these improvements (Molden 2007).

Chapter 3 also emphasized that investments are needed not only in technical improvements on-farm but also within the wider farming system and in institutions and infrastructure. The "package" would need to be identified and developed locally and in concert with farmers. Best practice approaches discussed in chapter 3 included:

- *Sustained, long-term programs*: Make a long-term commitment to a demand-driven program. Adopt a program rather than a project approach and plan on commitment for at least a decade.
- *Profitable, integrated packages for land/crops/water*: Construct packages jointly with local people to take account of local situations and to be profitable with managed risks. Develop integrated packages that address all aspects of the land, crop, and water cycle and are integrated within the overall farming system. Wherever possible, build in possibilities for cash crops and help foster market linkages.
- *Flexible, adaptive approach*: Adopt an innovative and adaptive approach to identifying conditions needed for success. Start with a participatory action research program and maintain the action research throughout. Base innovations on a combination of research results, especially plant breeding, adaptive research, participatory "action-research," and local indigenous knowledge. Build

Table 5.5 Agricultural Water Management Strategies, Techniques, and Structural Measures for Improving Rainfed Productivity

Aim	*Agricultural water management strategy*	*Purpose*	*Techniques and structural measures*
Improve WUE by increasing water available to the plant roots	Soil and water conservation	Concentrate rainfall around crop roots	Bunds, ridges, broad-beds and furrows, micro basins, runoff strips
			Planting pits
		Maximize rainwater infiltration	Terracing, contour cultivation, conservation agriculture, dead furrows, staggered trenches
	Evaporation management	Reduce non-productive evaporation	Dry planting, mulching, conservation agriculture, intercropping, windbreaks, agroforestry, early plant vigor, vegetative bunds
	Water harvesting	Mitigate dry spells with supplemental irrigation, protect springs, recharge groundwater, enable off-season irrigation, permit multiple uses of water	Surface micro dams, subsurface tanks farm ponds, percolation dams and tanks, diversion and recharging structures
Improve water productivity by increasing productivity per unit of water consumed	Integrated soil, crop and water management	Increase proportion of ET flowing as productive transpiration and so obtain "more crop per drop"	Increase plant water uptake capacity through conservation agriculture, dry planting (early), improved crop varieties, optimum crop spacing, soil fertility management, optimum crop rotation, intercropping, pest control, organic matter management

Source: Adapted from Molden (2007).
Note: WUE = water use efficiency; ET = evapotranspiration.

long-term monitoring and evaluation (M&E) into the approach from the very start and ensure that findings are systematically fed back into programs.

- *Empowerment, ownership, and social capital for inclusion and sustainability*: Empower local people as owners throughout and pay attention to building social capital. The participatory approach needs to be inclusive and built into permanent participatory institutions for management.
- *Incentives for sustainability and equity:* Build in incentives for sustainability and replication by prioritizing profitability and manageable levels of risk, but ensure that the incentive structure also addresses questions of individual versus common benefits, social and gender equity, and upstream versus downstream benefits.
- *Scaling up*: Keep the conditions for scaling-up constantly in view. Prepare mechanisms for sharing demonstrated success and for technology transfer and financing.

Technical, Economic, and Institutional Constraints

Despite the best practices recorded above, improving agricultural water management in rainfed environments faces considerable constraints. Technical solutions exist for most production environments, but they must take account of local physical and socioeconomic conditions and be developed flexibly through constant trial and error as part of an integrated approach to improving productivity and managing risk. Adoption is most often constrained by economics. Improvements need to demonstrably increase incomes with managed risk and to ensure that poor farm families can hurdle economic barriers to adoption such as affordability and working capital. The existence of accessible markets is often a game-changer. Institutions are also vital. At the local level, rules and cooperation over resource management and collaborative development are key. At the national level, and this is important for scaling up, there needs to be consistent policy and investment and a coherent agency responsible for local area development that integrates with agencies responsible for natural resource management. It is also important to integrate programs that enhance agricultural water management into broader support programs such as community-driven development (CDD) funds, that a learning loop exists, and that a long-term development horizon is taken.

Political Economy Constraints

Several dryland countries have made extraordinary efforts over the last three decades to improve rainfed agriculture and there have been some signal successes (recall section "Improved Water Control in a Rainfed Environment"). Nonetheless, there is some hesitance on the part of governments and donors with a bias toward hardware investments with more obvious footprints such as irrigation schemes. By contrast, the small scattered investments in rainfed improvement sometimes do not have much to show and often give small returns. Some programs have been initiated but then abandoned, and there has been a reluctance to engage in the necessary sustained commitment to programs over many years.

More generally, agricultural water management tends to slip between the cracks of sectoral strategies and programs. Water management agencies focus on resources and allocations, agricultural agencies focus on soil conservation, and no agency has responsibility for agricultural water management or for joint soil and water management. The limited interest in sustaining watershed management programs is witness to this. Where there are departments for soil and water, they tend to be junior to their larger, better resourced irrigation brethren (Molden 2007). Solving this constraint requires a consistent and sustained voice for rainfed farmers, commitment from development partners, and demonstration of success on the ground backed up by empirical studies.

Trade-offs and the Results

The sometimes marginal improvements in rainfed productivity demonstrate that even successful programs rarely catalyze a quantum leap out of poverty. A strategy targeting improvement in rainfed productivity is unlikely to achieve dramatic short-term gains, but it will improve the livelihoods of the large majority of rural dryland people who depend only on rainfall. The tradeoff is: (i) one of gradual poverty reduction for many against fast growth for a few; (ii) between promoting the general but modest advancement of the vast majority against large improvements in income for relatively few; and (iii) between investing US$250 per hectare in rainfed agriculture to achieve an increment of 250 kilograms per hectare of cereals against investing US$5,000 to achieve an increment of 2 tons (Molden 2007).

Long-term investment in improvements in rainfed agriculture in the drylands will bring significant results in time. Molden (2007) examined two scenarios for rainfed production in SSA through 2050 in the context that food demand in the region is likely to triple between 2000 and 2050. The low-case scenario was characterized by: (i) low rates of water harvesting adoption; (ii) modest yield improvements; (iii) the largest increase coming from area expansion of 53 percent;[2] and (iv) some increase in imports. In the high-case scenario: (i) there is widespread water harvesting and some supplemental irrigation; (ii) cereals yields grow by 72 percent;[3] (iii) area expands by 7 percent; and (iv) SSA remains largely self-sufficient in staples. Table 5.6 shows the projected yields per hectare in the two scenarios (Molden 2007).

Improved Agricultural Water Management in Rainfed Agriculture Strengthens Resilience

Although improvements will come only slowly and in relatively small increments, over time investment and rising productivity will strengthen the resilience of dryland populations, albeit with increased market risk. Where actual outcomes are toward the higher-yield scenario (table 5.6), this would strengthen the resilience of the dryland population to shocks, particularly if investment in agricultural water management and drylands agriculture is accompanied by investment in education and health. Structural investments in water and erosion control and increases in soil fertility combined with increases in farm output and with diversification in crops and the farming system would reduce sensitivity to shocks. The resulting increases in incomes and assets would strengthen capacity to cope with shocks. On the other hand, investment in market-oriented production brings an

Table 5.6 Yield Scenarios for (Improved) Rainfed Agriculture, SSA Drylands (Tons per Hectare)

Crop	*Actual yield 2000 (t/ha)*	*Maximum potential yield (t/ha)*	*Low-yield scenario 2050 (t/ha)*	*High-yield scenario 2050 (t/ha)*
Wheat	1.3	3.4	1.9	3.2
Rice	1.0	4.0	1.5	3.2
Maize	1.4	6.6	2.1	4.1

Source: Molden (2007).
Note: SSA = Sub-Saharan Africa.

increased exposure to market risks—a trade-off that keeps many farmers from investing too much in improved agricultural water management technologies.

Actual experience in the SSA drylands shows how these results can be achieved. One soil and water conservation program in Burkina Faso triggered a process of agricultural and pastoral intensification with lasting benefits. Here, government and donors worked alongside local people for over two decades (1980–2002) in the dryland Central Plateau to invest in soil and water conservation. This triggered a process of agricultural intensification and agro-silvo-pastoral development leading to: (i) substantial tree cover; (ii) increased yields on millet and sorghum (up from 440–450 to 620–670 kilograms per hectare); (iii) increased fodder, allowing livestock intensification and producing manure as a useful byproduct; and (iv) diversification into a range of cash crops (sesame, cowpeas, and vegetables) for local and regional markets (Côte d'Ivoire, Ghana, and Nigeria). No rate of return was ever calculated. The main evaluation criteria used to justify continuing the program were farmer adoption and sustainability. In dryland cropping, it is hard to separate cost and benefit streams as elements are often complementary in integrated mixed farming systems. Simple investment in water harvesting can also generate several benefit streams. Hence, calculating internal rate of returns (IRRs) can be tricky. Often it is simply adoption rates that indicate whether the benefit-cost ratio is acceptable to the farmer. The main criteria for judging success from farmers' viewpoints are: (i) long-term increases in productivity; (ii) sustained increases in household income and returns to family labor; and (iii) demonstrated increase in resilience of the production system. Farmers will also factor in their appreciation of risk and of the potential for increase in resilience. Farmers themselves will apply rule-of-thumb cost-benefit calculations and gauge contributions to resilience. For example, gabion reinforcements or terracing may not only improve infiltration and water retention by the soil around plant roots, but they may also improve resilience to shocks such as floods. Box 5.1 illustrates how farmers are the best judges (FAO 2011; Molden 2007).

Where costs, benefits and rates of return have been calculated they can be high, but returns to specific components of an integrated package are still hard to capture. For example, at the core of a program carried out in Niger's Illela District was the introduction of *zai* or *tassa*—improved traditional planting pits. The pits require an initial investment of 40–60 days of labor per hectare (a total investment of about US$250 per hectare) and require annual maintenance. *Zai* return on average a net of US$65 per hectare each year after deducting maintenance costs and are very cost-effective when combined with manure. This technique increases resilience by improving incomes and allowing for better management of rainfall risks. Farmers have continued to maintain the *zai*, demonstrating the profitability from their perspective, and they have proved especially rewarding in drought years by allowing farmers to manage rainfall risk. The ERR at project completion in 1995 was estimated at 20 percent, but this covered

Box 5.1 In Niger, Farmers Assess Costs, Benefits, and Risks and Reject Technologies that Fail the Test

In the past, Niger invested in water harvesting on a large scale with generally positive results. Public programs from the 1980s onward invested in these techniques, and up to 250,000 hectares were improved in what were essentially watershed management programs. A recent study found at least some of these lands producing cereals at yields of 400–1,500 kilograms per hectare, with average yields of around 400 kilograms per hectare attributed to supplemental irrigation provided through water harvesting.

Many of the techniques appear profitable, yet farmers rarely adopt them spontaneously. On paper the main techniques—*tassa*, half-moons, check dams—show promising financial results. Costs are low, from US$30 to US$400 per hectare. The Niger national rural development strategy notes "water harvesting increases yields by an average of 50 percent for very little investment." Yet there have been only modest rates of spontaneous adoption, and even investments made by the state and handed over are often not maintained.

Various reasons explain the lack of spontaneous adoption. One is the problem of collective versus individual interests. Whose land is it? Who will benefit? Another is the relationship between investments upstream—say, work on a hillside to reduce erosion and improve infiltration—and downstream effects on groundwater replenishment or reduced siltation. How can the benefits be apportioned fairly and what is the mechanism for delivering the benefits?

A third reason is economic arguments, and this applies also to structures on private farms. The benefits are perhaps too little compared to the costs. Or, the investments are too short-lived. Or, the cost of making or reworking the structures is beyond the capability or labor availability of farmers. Or, very importantly, there is a risk of crushing failure in a bad year.

Farmers quickly come to a fine appreciation of the costs, benefits, and risks, showing their disdain for technology that does not meet their criteria. But only sustained action-research and long-term trial and error can come up with packages that raise farmer incomes sustainably and improve household resilience.

Source: Ward (2007).

a wide range of investments and public as well as private benefits, so is less revealing about the private profitability of the *zai* than about farmers' continued use of the technique. Elsewhere in Niger, under other support programs, farmers adopted improved *tassa* planting pits that allowed them to achieve millet yields of up to 480 kilograms per hectare compared to 130 kilograms per hectare without the technology. The approach has proved sustainable and replicable because it gives quick results with available labor and manure, presents low risks, and improves food availability for households by 20–40 percent (http://www.unesco.org/most/bpik10.htm; Peacock and Ward 2007).

Individual Smallholder Irrigation and Small-Scale Community-Based Irrigation: Challenges and Opportunities

As discussed in chapters 3 and 4, private smallholder irrigation is at present the predominant form of irrigation in the SSA drylands, and both individual irrigation and small-scale, community-based irrigation are experiencing rapid growth and have potential for expansion.

Individual Smallholder Irrigation

Individual smallholder irrigation is expanding fast due to the availability of low-cost pumps drawing water from both groundwater and surface sources. This form of irrigation has sprung up around towns and cities and wherever there is a market for higher-value produce. In Ethiopia, Kenya, and Tanzania, individual irrigators are able to sell into profitable export markets for fresh fruit, vegetables, and flowers. Private pumps can also provide supplementary irrigation to predominantly rainfed systems to relieve stress at critical points in the growing period and private pumped groundwater can provide "conjunctive use" on irrigation schemes along with canal water.

The prospects for this technology are excellent across the drylands wherever there is perennial surface water or a groundwater source. The enormous advantages of individual smallholder irrigation are that: (i) it is normally very profitable for farmers, provided the water source is accessible (for example, groundwater is not too deep) and markets are available; and (ii) it does not usually require public intervention or communal organization.

The biggest negative risk is the impact of unregulated extractions of surface and groundwater on water resources. In the Nairobi water supply area, for example, the Kenyan government is having to transfer water from other basins to make up for the unregulated appropriation of water resources by 50,000 private irrigators. Given the relatively sparse population, generally quite modestly sized population centers, and weak transport links, limits to market access and fragmented value chains in many dryland locations increase risk and reduce profitability. Finally, cost is a barrier to entry for many, which raises the issue of equity for governments trying to promote pro-poor technologies. At present, poorer people and women generally have limited access to the capital and support needed to invest. Lower-cost technology such as the treadle pump goes some way to addressing this issue. Clearly this accessible technology is an excellent response to the challenge of the drylands and should be promoted wherever it is viable and sustainable.

In some countries, government has taken a very hands-off approach. In Kenya for example, the vibrant market economy has largely eliminated the need for government-supported individual smallholder irrigation. Even in this context, however, governments may provide incentives to irrigators by a simple touch on the incentive structure; for example, removing tariffs on imported pumps can provide incentives to pump irrigation. And there are risks to such a laissez-faire approach, such as environmental risks of unmanaged groundwater depletion. The government has a necessary minimum role to ensure that individual smallholder irrigation is regulated within a water resources management framework, even if this is some form of delegated self-regulation to local water users' associations.

Elsewhere, governments have taken a more proactive role in supporting the development of private irrigation. In Niger, for example, the successful spread of small private irrigation resulted from an innovative government program in partnership with the private sector (see box 5.2).

Community-Based Irrigation

Small-scale, community-based irrigation has long existed and has expanded in recent decades, responding to new markets and support from development programs. The advantages of this form of irrigation are that it is essentially farmer-managed and adapted to both the biophysical and socioeconomic

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Box 5.2 Niger's Government Tremendously Boosted the Spread of Small-Scale Private Irrigation

Beginning in 1996, the Nigerien government supported the growth of small-scale private irrigation and encouraged the establishment of an apex organization for the private irrigation profession. A pilot project tested out approaches from 1996 to 2001, and a full-scale project followed.

The two projects worked on development of a wide range of improvements designed not only to equip irrigated farming but also to put in place the institutional basis for future growth. The projects supported technology acquisition and promoted changes in husbandry and cropping patterns through high-productivity technology packages. They helped to create an artisanal industry with drillers, well technicians, pump makers, and repairers. Accessible microfinance, private sector farming advisory services, and farmer-run input supply have been promoted. The projects also supported the development of autonomous farmer organizations at local, regional, and national levels. Additionally, they helped improve post-harvest practices and promoted market development, including organization, infrastructure, and market information.

Farmer organizations have multiplied rapidly, with nearly 4,000 producer associations working with the project. The second project has reached almost 40,000 farmers and helped install or improve irrigation on 15,900 hectares in over 3,000 subprojects, mostly for water users' groups. Private advisory services have been established, and input supply stores (*boutiques d'intrants*) and local savings and loan organizations are popular (27 *boutiques* are operational and over 29,000 farmers have joined savings and loan organizations).

Source: Ward (2007); World Bank (2009).

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contexts in which it arose. Considerable scope remains for further development, in fact, community-based small-scale irrigation represents by far the largest potential for irrigation development in the SSA drylands, of about 8 million hectares according to the International Food Policy Research Institute (IFPRI) assessment.

The key constraints to developing this considerable potential are again technical, economic, and institutional. Some countries, for example Madagascar and Sudan, have a long tradition of irrigation and local people have the technical know-how and organizational skills to develop and manage small irrigation perimeters. In other countries, the technology is not as well mastered, for example in the *perimetres de contre-saison* in Niger or the use of crude diversion "cuts" in the river bank in Kenya and Uganda. The main economic challenges are the relatively high investment requirements (up to US$5,000 per hectare or more), which puts the investment beyond the reach of the poor, and the need to access nearby product markets to make the investment viable. The twin institutional challenges are: (i) the need for farmers to organize themselves collaboratively with agreed sets of rules for land and water management; and (ii) achieving the right balance between outside support and community and individual responsibility and ownership.

In a purely laissez-faire economy, the government's role may be restricted to establishing the enabling environment, providing public goods like research and road infrastructure, and regulating land and water rights and impacts on land, water, and the broader environment. There is scope, however, for governments to pursue important policy objectives of equitable growth and poverty reduction by structured interventions. Experience has shown that community-based irrigation can be supported by government either through dedicated small-scale irrigation development programs like those in Madagascar or Niger, or within broader rural development programs or CDD funds that integrate other complementary investments.

Table 5.7 sets out a schematic allocation of responsibilities between government and smallholder farmers on community-based schemes, taking into account the potential for smallholder farmer organizations to play an intermediary role between government and farmers.

Individual Irrigation and Small-Scale Irrigation Strengthen Resilience

Investment in water control will reduce both exposure and sensitivity to shocks by reducing or eliminating the risks from damaging floods, and by providing timely water to avoid crop water stress to achieve higher levels of productivity. The high levels of cash income associated with fully irrigated production will allow households to cope with shocks, with the proviso that high dependence on marketed production needs careful commercial management to avoid negative impacts from market risks.

Table 5.7 Responsibilities in Developing Community-Based Small-Scale Irrigation

Responsibility	*Actor*
Policies	
• Setting overall supportive framework (tax regime, trade policy, business friendliness, PPP framework)	Government
• Linking irrigation and water resources management within a basin framework	Government
• Integrating irrigation and agricultural policies and programs	Government
• Articulating policies of growth, poverty reduction, and gender equity through support to private irrigation	Government
Research	
• Developing and transferring research and technology	Government with farmers/farmers' organizations
Development	
• Investing in storage, diversion and irrigation network development	Farmers (with possible government support)
• Investing in related infrastructure (roads, etc.)	Government
• Regulating land tenure and water rights	Government
• Regulating environmental impacts	Government
Operations	
• Establishing efficient decentralized management arrangements involving stakeholders	Farmers' organizations with government support
• Financing MOM and supplying water	Farmers
• Capacity building (training, WUA development)	Government with farmers' organizations
• Supporting efficient farming with guidance on water management, crop mix and husbandry, post-harvest	Government with farmers/farmers' organizations
• Ensuring availability of working capital	Farmers' organizations with government support
• Ensuring efficient and profitable market outlets	Farmers' organizations with government support

Source: Molden (2007).
Note: PPP = public-private partnership; MOM = management, operation and maintenance; WUA = water users' association.

Large-Scale Irrigation for Smallholders

The Case for Large-Scale Irrigation

Scale is important in large-scale irrigation in terms of: (i) cost of developing the infrastructure, headworks and main canals can serve large areas; (ii) efficiency, as huge volumes of water can be moved around in an economically rational way; (iii) operating costs, which are typically low per unit, especially when the scheme is gravity-fed and pumping costs are limited or nonexistent; (iv) integration with water resource planning, as firm water allocations can be made, or varied, within a basin planning framework; and (v) stimulating viable value chains through the size of demand for inputs and services and volumes of output.

More Irrigation or Better Irrigation?

The potential for new large-scale irrigation development in the SSA drylands is up to 2.5 million hectares, depending on development costs and targeted rates of return, largely located in the plains adjacent to rivers. These lands can be irrigated either from storage dams that also regulate flows available to an irrigation scheme, or from simple diversion weirs that raise the height of the river above the level of the irrigation command area, a cheaper approach but one that does not bring the benefits of flow regulation or flood control.[4]

Across the drylands in SSA there are areas commanded by over 350 operational or planned dams over 50 meters in height. Dams command a considerable undeveloped irrigable area.

Typically, the benefits from irrigation alone are not enough to justify storage and irrigation is often a secondary benefit to other primary benefits (for example, hydropower and flood control). This limits the scope for irrigation development but improves the economics of irrigation, as the costs of storage and water control may be considered sunk costs.

Costs of large-scale irrigation expansion are higher in SSA than elsewhere because of the challenging environment and difficult terrain and soils, the generally higher construction costs than elsewhere, and the relatively smaller scale of developments (Molden 2007).

The subsection on "strengthening resilience" in chapter 3 assessed the underlying causes of past poor performance of many large-scale irrigation schemes in SSA. Although each scheme has its own characteristics, the general problems have been essentially a combination of:

- Weak underlying economics, lack of a market-driven approach, and incomplete or deficient value chains which resulted in low farmer incentives and schemes' lack of financial viability.
- Technical flaws that resulted in poor water service and diminished water use efficiency (WUE) and crop productivity.
- Lack of a viable institutional model to provide efficient low-cost construction and subsequent management of schemes and to engage farmers as full partners.

Because initial investment costs are so high, the conclusion has to be that irrigation improvement on existing schemes may be a better initial investment. If new large-scale irrigation is to be developed, projects have to meet some tough conditions of entry. The following subsection discusses the contrasting challenges of irrigation improvement on existing schemes and new large-scale irrigation development.

Irrigation Improvement on Existing Schemes

One option often discussed, not only in SSA, is to focus first on improving performance on existing large-scale irrigation schemes. In principle, potential gains from enhancing productivity in current irrigation could be greater than gains from expanding irrigation, especially as costs are low—typically only one-quarter of the cost of new scheme development. Modernization of irrigation schemes combined with institutional change could increase yields considerably (table 5.8): wheat yields and water productivity (kilograms per cubic meter of evapotranspiration, ET) could go up by 75 percent; and rice and maize yields and water productivity could double. Typically, economic returns on improvement projects are much higher than on new development. There could also be scope for bringing back into production some of the more than 1 million hectares in the drylands equipped for irrigation but not currently being irrigated (Molden 2007).

Modernization of the 5.2 million hectares currently irrigated in the drylands, together with extra storage and institutional change, is estimated to cost about US$2,700 per hectare, one-quarter of the cost of new development, and with the advantage of an existing institutional base, a working farming system, and relatively experienced irrigation farmers (Molden 2007).

Irrigation Improvement: Technical Considerations

Improving the reliability and flexibility of water service to the field will allow farmers to plan for irrigation. Improved service should also ensure adequate service of the entire scheme, with particular attention to serving tail-enders. The technical components of improved water service might include more effective diversion and conveyance works, conversion to piped delivery and/or pressurized delivery, and on-farm or intermediate storage reservoirs. In addition, extra resources may be harnessed through increased upstream storage, conjunctive use of canal and ground water, and drainage water reuse.

Improving water use efficiency will increase the water available to the plant roots and the share of water evaporated through crops (ET, the pathway to increasing yields). Here the key measure is on-farm water management by the farmer. The technical components might be: improved irrigation intervals, including deficit irrigation; drainage and leaching; land leveling; and precision irrigation such as pressurized drip or sprinkler irrigation. Protected agriculture, such as plastic houses, would also increase water use efficiency.

The route to improved water productivity is twofold. At the farm level, the farmer can improve his irrigated farming through measures to increase the harvest index (that is, obtain more kilograms or dollar per unit of water evaporated). This could include choice of more responsive planting material, improved

Table 5.8 Yield Scenarios for (Improved) Irrigated Agriculture, SSA Drylands (Tons per Hectare)

	Yield (t/ha)				*Water productivity (kg/m3 ET)*	
Crop	*Actual 2000*	*Maximum potential*	*Worldwide average 2000*	*Scenario 2050*	*Actual 2000*	*Scenario 2050*
Wheat	3.0	5.8	3.4	5.3	0.37	0.53
Rice	1.8	7.2	3.4	4.1	0.18	0.31
Maize	2.8	10.5	6.1	7.9	0.36	0.70

Source: Molden (2007).
Note: SSA= Sub-Saharan Africa; ET = evapotranspiration.

fertility and soil management, land preparation techniques, plant spacing, planting time, adoption of weeding and pest management procedures, and diversification into more responsive and higher-value crops. In addition, value can be increased at the harvest, post-harvest, and marketing stages.

The second route, scheme-level water productivity, could be improved by building in multiple uses, such as domestic water supply, irrigation of home gardens, fisheries, livestock, flood protection, groundwater infiltration, etc. This may require additional or changed infrastructure to incorporate small dams, fisheries, flood control, etc. (Molden 2007).

Irrigation Improvement: Institutional Considerations

The objectives of institutional modernization are threefold: (i) to provide the institutional basis to complement technical improvements aiming at improved water service; (ii) to ensure that farmers are properly skilled in on-farm water management and irrigated production; and (iii) to ensure efficiency and sustainability of the scheme through full financing of maintenance, operation, and management.

Institutional improvement would typically follow two best practice principles: decentralization to the lowest feasible level (subsidiarity) and more direct farmer involvement. The array of options to implement these two principles ranges from full farmer ownership and operation through contracted professional management to joint management by a public agency and farmer groups. In all cases, government has to maintain oversight of service provision and safeguard water resources and the broader environment. Typically, bulk water supply would remain a government responsibility because of the multiple functions and public good aspects of water (Molden 2007).

New Development of Large-Scale Irrigation

The scope for developing new large-scale irrigation is considerable. IFPRI's estimate of the economic potential for new large-scale irrigation development in the drylands is in the range 1 to 2.5 million hectares, with the base case (medium cost, 5 percent IRR) equal to 1.60 million hectares (Molden 2007). However, the economic, institutional, and technical conditions are demanding.

Given the poor record from the past, experience shows that the following are conditions for optimal investment (recall the subsection on "strengthening resilience" in chapter 3):

- A major new scheme is best set within the right enabling environment and incentive structure: Ideally, development would take place in an environment of balanced macroeconomic management, pro-enterprise policies, investment in transport infrastructure, and trade and market policies and practices that are not biased against agriculture and ensure food security without introducing market distortions, such as requiring production of low-value cereals when higher-value crops are needed to make the scheme economically viable and profitable for farmers.

- The allocation of water resources to a new scheme would be part of a set of water allocations and investments optimized at the basin scale, and within a water resources and environmental management framework that both protects the investment from upstream events and ensures that the investment protects public goods and the rights of other users and the environment.
- Clarity on the respective roles and responsibilities of public and private actors is needed. Ideally, the allocation of responsibilities between government, the private sector, and farmers should be based on a clear assessment of risks and assignment of responsibilities with built-in incentives, transparency, and accountability.
- The economics of the scheme are vital. Part of this is technical—an efficient, least-cost design that: delivers a good water service and ensures water use efficiency; has multi-functionality built in wherever possible to maximize economic benefits; and has affordable capital and operating costs. Part of it is commercial; a value chain that ensures input and output markets are efficient and that production is profitable for farmers. Value chain development may be needed to effectively link farmers to both input and output markets, creating enough value from the additional investment and mitigating the market risks.
- The institutional model needs to be clear and efficient from the outset. It needs to provide for:
  - Strategy, economic analysis, and reasoned decision making in the choice of investment: This is an essential role for government, with public participation.
  - Strong capacity for project design and implementation: This may best be outsourced, perhaps under a public-private partnership (PPP) arrangement.
  - An inclusive approach from the outset, with farmers as partners and owners of the project: Includes (i) a bottom-up approach from identification onward and the gradual building of institutional capital that will form water users associations and (ii) farmer knowledge and managerial capacity with the skills necessary to operate and maintain irrigation systems and manage water at their level while developing competitive agricultural production.
  - Arrangements for efficient maintenance, operation, and management: Again, this may best be outsourced, perhaps under a PPP arrangement with ultimate handover to a farmer-owned management agency (as at Megech in Ethiopia).
  - Full financing of maintenance, operation, and management costs: In principle this should be paid for by farmers and their capacity to pay is a litmus test of scheme viability. If they cannot afford water charges, the scheme is probably not economically viable.
  - Benchmarking, M&E, and accountability: What you cannot measure, you cannot manage, and efficient management and accountability are only possible with regular reporting against benchmarks.

- Tenure of both land and water is essential to securing producers' on-farm investments and allowing them to reach the required intensification level to ensure the economic and financial viability of irrigation investments.
- Efficient and productive farming is needed. To justify the high costs, water service has to be good, on-farm water management and crop husbandry have to be well done, and harvest and post-harvest operations have to maximize value added. Project design has to be clear and detailed on how farming will work and what support is needed (research, extension, etc.).

Large-Scale Irrigation Can Strengthen Resilience

Well-designed and well-managed large-scale irrigation has the potential to be the most efficient and profitable form of farming and to be the system that contributes the most to resilience. Assured water service eliminates exposure to drought and high-productivity cash cropping transforms livelihoods and considerably reduces sensitivity. Coping capacity is strengthened by secure cash incomes. Thus, vulnerability can, under the best conditions, be virtually eliminated, especially where the scale of production allows for the minimization of market risks, for example through contract farming or marketing cooperatives. The problem is the high cost and the limited number of potential beneficiaries.

Irrigation for Large-Scale Farmers and Public-Private Partnerships

Irrigation for Large-Scale Farmers

Private commercial irrigation is found both in large-scale schemes and in intensive horticultural operations. Experience has shown that larger commercial farmers are generally highly efficient and will invest in improved conveyance and on-farm water application technology. There is potential for further development of private commercial irrigation if governments decide to pursue this growth path.

Given that the priority of governments in drylands is to reduce poverty and improve resilience of poor farmers, larger farmer irrigated agriculture by itself is unlikely to be a major pathway, although it could be an option when lands are located far from markets and when only a large industrial crop operation (like Kenana Sugar Estate) could generate the necessary economies of scale. However, partnership arrangements involving both larger and smaller farmers have much greater potential.

Public-Private Partnership Models

All commercial irrigation involves some level of partnership between private enterprise and the state. At minimum, private commercial producers must acquire land and water rights and operate within national policy, fiscal, and regulatory frameworks. Most commercial irrigation in fact goes further and involves some measure of co-investment. For example, government may finance water storage and grant water rights to a private enterprise, or commercial and governmental investors may actually co-invest in an irrigation scheme.

Despite the risks, experience in Zambia, Ghana, and elsewhere shows that private commercial irrigation can be associated with smallholder irrigation, such as supply of irrigation water, outgrower contracts, etc., provided that this is clearly agreed up front and the corresponding incentives and risk management measures are built in. In addition, the experience in one project suggests that risk-sharing management contracts could help SSA countries develop large-scale irrigation for smallholders efficiently and sustainably without recurrent subsidy.

Success in all partnerships between public and private sectors requires clear assessment and assignment of risks and agreed contractual arrangements, with adequate incentives and safeguards for all (see box 5.3).

Public-Private Partnerships Can Strengthen Resilience

The resilience profile of PPP models is similar to that of large-scale irrigation generally: reduced exposure and sensitivity, and enhanced coping capacity. The probable better water service, integrated inputs, advisory packages, and more assured marketing outlets under PPP arrangements are likely to improve resilience further (see box 5.4).

Box 5.3 An Efficient, Privately Run, Large-Scale Irrigation Scheme in Sudan

Kenana Sugar Estate is a well-managed public-private large-scale irrigation scheme in Sudan. The scheme resulted from an agreement between the Sudanese government and the multinational Lonrho. Financing was provided by a group of 11 largely public sector investors. The Government of Sudan, with a 35 percent shareholding, is the largest. Other shareholders include the Government of Kuwait (30 percent), the Government of Saudi Arabia (11 percent), the Arab Investment Company (7 percent), and the state-owned Sudan Development Corporation (5 percent).

Construction on this US$1 billion project started in 1976. The scheme is located in the central clay plain of Sudan, near Rabak about 300 kilometers south of Khartoum on the eastern bank of the White Nile River. The total command area is 70,000 hectares, with about 45,000 hectares effectively cultivated. Six pumps are connected in a series along the main canal to lift water 46 meters above the river level.

Production began in 1981, initially for domestic consumption. Exports began in 1991. Management is efficient, with modern technology adopted in seed bed preparation and laser land leveling. Irrigation practice has evolved over many years, with the water ration based on observed ET. In 2002, the open channel furrow system was changed to a closed system of gated pipes, which today cover about 75 percent of the scheme. One problem has been pollution of Nile River water stemming from discharge of factory effluent. Kenana Factory is constructing a wastewater treatment plant to address this problem.

Source: Anderson (2009).

Box 5.4 A Management Contract in Ethiopia Is Designed to Balance Risks and Ensure Long-Term Sustainability of a Large Scheme for Smallholders

The Megech-Seraba Irrigation and Drainage Scheme aims at developing a 4,040 hectares smallholder farming agricultural area on the northern shore of Lake Tana in Ethiopia. The project is financed by an IDA credit. In view of the lack of capacity and experience in managing large public irrigation schemes in the country, the Government of Ethiopia requested the World Bank's help in designing a PPP approach.

A new PPP model was designed and tailored to the specific challenge of a government-financed LSI scheme where the government lacked the capacity to develop it efficiently, but also aimed for managerial autonomy and self-financing in the longer term. The model therefore pursues the threefold objective of: (i) ensuring high quality of construction; (ii) delivering adequate and reliable irrigation and drainage service to beneficiary users; and (iii) building the capacity of the water users and managers to ensure long-term sustainable scheme O&M. The transaction is specifically tailored to optimizing the risk allocation between the government, the private operator, and farmers, with each stakeholder involved where it can bring the most value for money.

The main features of this innovative model are based on a clear understanding of risks and a fair allocation of responsibilities between the public and private sectors. They provide for:

- A private operator competitively contracted to oversee the development of the infrastructure and thereafter to manage the primary and secondary infrastructures for eight years. Incentives are built into the contract to foster a high standard of construction and subsequent water service delivery.
- Empowered water users' associations responsible for the operation and maintenance of the tertiary block units.
- In a target eight years, an autonomous operation and maintenance entity owned by the water users' associations will assume management of the scheme.
- The government retains responsibility for financing the construction of the scheme, setting the irrigation service fee and delivering extension services to beneficiary farmers.

Several SSA countries (Ghana, Malawi, Zambia, to name a few) embarking on PPP irrigation initiatives are testing different transaction models such as concession and BOT (Build-Operate-Transfer). The Ethiopian experience will bring an original transaction model (with management contract) that could be replicated in other contexts where a project includes high risks (new schemes with low presence of commercial farming, low capacity, and willingness to pay, etc.) and cannot be transacted as a concession or another transaction model that allows transfer of investment risks to the private sector.

Elements of this solution could also inspire the reform of large public irrigation. In particular, the empowerment of WUAs and the use of performance remuneration for O&M services may contribute to transparency and higher service quality in existing schemes, resulting in improved O&M and higher cost recovery.

Notes

1. Assuming irrigated plots of an average of 1 hectare per farm family.
2. The land does exist: in SSA, the currently cropped area is 228 million hectares, and the total area suitable for cropping is 1,031 million hectares, but land suitability drops rapidly at the margins, and there are strong environmental disadvantages to expansion (table 3.6 CA 102).
3. CA estimates that average rainfed water productivity in SSA could increase by 75 percent by 2050 to 0.28 kilograms per cubic meter (compared to 0.50 kilograms per cubic meter for irrigated) (table 3.13, Molden 2007).
4. Note that the IFPRI simulation summarized in table 4.3 does not consider potential for run-of-the-river or pumped schemes.

CHAPTER 6

Priorities and Actions to Develop the Potential of Agricultural Water Management to Increase Resilience

Desirable Economic and Policy Characteristics to Develop Agricultural Water Management in Drylands

The economic and policy environment within which the development of drylands is set varies widely across Sub-Saharan Africa (SSA), helping to explain why, for example, publicly developed irrigation in Kenya has performed poorly and led to a 20-year moratorium on public investment in large-scale irrigation whilst private irrigation has prospered and spread rapidly.

Three conditions proven conducive to agricultural water management success globally and in SSA can guide countries contemplating major expansion in the drylands: (i) supportive policies and institutions; (ii) economic incentives and opportunities; and (iii) access to needed resources. As a background to the discussion of strategic options later in this chapter, this section reviews each of these conditions and suggests the possible implications for government policy.

Supportive Policies and Institutions

The most successful agricultural water management in SSA has been in countries with balanced macro-management and pro-enterprise policies (Kenya, Namibia, South Africa, Swaziland) and judicious poverty reduction approaches. The exchange rate policy, tax regime, trade policy, business friendliness, approach to foreign direct investment (FDI) and public-private partnerships (PPPs), and, above all, development policy (growth, poverty reduction, gender equity, subsidies) all influence what farmers may or may not do. Additionally, these policy aspects all influence the incentive structure that drives farmer behavior and is particularly important in the high-risk market environments that characterize the drylands.

- *Policy implications*: SSA governments targeting agricultural water management expansion in the drylands should ensure the best fit of investments and interventions within the overall enabling environment and incentive structure.

Agricultural water management lies at the intersection of water resources management, agriculture, and environment, and agricultural water management interventions and practices need to be set within the policies for these three sectors.

- *Policy implications*: agricultural water management initiatives, particularly in the fragile environments of the drylands, need to be integrated with government policies on water resources management, agriculture, and the environment.

A key problem with historical SSA irrigation development has been a lack of transparency in public and private sector roles. In most countries nowadays, market-driven economic activity is recognized as the private sector's role, subject to any necessary regulation or correction of market failure by governments. A second institutional lesson of past experience (chapter 3) is that sustainable development of agricultural water management is better conducted on a bottom-up, participatory basis rather than top-down. Linked to this is a third institutional lesson from experience in SSA: farmer contributions are essential to demonstrate their ownership and help with financing.

- *Policy implications*: SSA governments need to: (i) establish a transparent framework setting out the roles and responsibilities of all actors in agricultural water management; (ii) ensure that local people are involved as empowered actors and "owners" in agricultural water management programs (both rainfed and irrigated) from day one; and (iii) require that all investments, once implementation is complete, be operated and financed by farmers themselves—or in the case of large-scale irrigation, at least that practical arrangements are in place for recovery of maintenance, operation, and management costs.

Water is part of a cycle and its management generally has common property aspects. On the positive side, experience in the drylands, particularly in rainfed programs, has shown that building in facilities for livestock watering, domestic uses, or water for home gardens to an agricultural water management investment can greatly increase both economic returns and community acceptance. On the risk side, increased water consumption among farmers is likely to affect other users and sectors. In addition, water forms part of the natural environment, and agricultural water use has to ensure protection and sustainability of both the quantity and quality of water resources.

- *Policy implications*: All agricultural water management investments should integrate multi-functionality wherever possible, ranging from access for washing or drinking water up to flood control or groundwater recharge at the basin scale. Governments also need to work with farmers to ensure that agricultural water use fits with water resource management and environmental protection plans. Ideally this should be done within a river basin framework, as practiced in Tanzania, for example.

Creating Incentives and Opportunities

Irrigation is expensive, and SSA governments need to be highly selective in programming investments to avoid the problems of the past. The key determinants of high economic returns (and of profitability for farmers) are: (i) lower per hectare investment cost; (ii) access to profitable markets; (iii) big increases in productivity; and (iv) sound institutional design that empowers farmers and minimizes government recurrent outlays. Economic analysis should also take account of the many second-round and associated benefits of irrigation, including: (a) increased resilience; (b) jobs, poverty reduction, and gender equity; (c) second-round multiplier effects on the local and national economy; and (d) environmental costs and benefits and externalities (for example, groundwater recharge, flood control).

- *Policy implications*: Governments and investors can identify priority investments by a quick screening, but need to apply rigorous economic analysis to rank larger agricultural water management investment options, ensuring that second-round and associated benefits and costs and any externalities are taken into account.

The more successful agricultural water management investments have been responsive to farmer demand and need. An advantage of empowering farmers through participatory processes is that the fit of development programs to actual farmer situations and needs is generally better. Programs developed collaboratively with farmers will be: (i) demand-driven, with farmer knowledge incorporated; (ii) with constraints identified and eased, particularly water supply and land tenure; (iii) resulting in enhanced diversity of livelihoods and reduced risk and vulnerability; (iv) well-adapted to the shifting biophysical and socioeconomic contexts faced by farmers; (v) profitable and market-oriented; and (vi) decentralized, managed locally by farmers or with strong farmer involvement.

- *Policy implications*: Governments should ensure that agricultural water management investments are designed together with farmers and with them constantly in mind, and that designs respond to farmers' needs and constraints and reflect the leading characteristics of successful past investments from farmers' viewpoints.

Water is an input amongst others and agricultural water management has to form part of a total productivity package adapted to the situation and building on farmer knowledge. Water use efficiency is at the heart of agricultural water management and can certainly contribute to growth. However, other conditions need to be satisfied, particularly in the challenging production conditions of the drylands. On the input side, an integrated approach is needed for soil, crop, and water management to ensure that other inputs working together with water are present, such as soil amendments and fertilizers, land preparation, the correct crop and varietal choice, high-yielding planting material, land preparation techniques and equipment, and weed and pest control. Additionally, farmer knowledge is important, both of soil and water management as well as agronomic aspects. In the case of complex systems such as the agro-silvo-pastoral systems often found in drylands, agricultural water management improvements have to be integrated within the entire system.

- *Policy implications*: A good productivity package needs to accompany investments in agricultural water management, both in irrigated agriculture and in the lower-yielding rainfed farming systems. Where necessary, governments and regional and international agencies should invest in research, including basic research such as varietal development and adaptive and action-research, with an emphasis on building upon existing farming systems and indigenous knowledge. Governments also need to ensure that (preferably market-based or cooperative-type) input supply institutions are in place.

Boosting Access to Needed Resources

Even the simplest improvement in agricultural water management requires investment and working capital, and this is particularly important for the SSA drylands, where the population is very poor and risk-averse and lacks access to capital. Facilities are available from governments through programs, including community-driven development (CDD) funds, or by the market (including microfinance and savings and credit cooperatives), or both—but they are essential, particularly to ensure equity in programs and to ensure that the poor and women are included.

- *Policy implications*: SSA governments can ensure that access to capital is not a barrier to entry by putting in place support programs or credit schemes and investing in associated public goods and services that are accessible on an equitable basis.

Without markets and a functioning value chain, investment in agricultural water management is often not attractive to farmers, particularly the risk-averse vulnerable farmers of the drylands. There are barriers to access on the input side (for example, barriers for poorer people or women to accessing pump irrigation) and governments can help reduce these (by supporting improvements in the efficiency of equipment supply and repair markets, promoting pump rental, developing lease or hire purchase options, etc.; Niger's successful program is a beacon for this approach). On the output side, infrastructure to evacuate products to market and/or to process them as well as information and institutions that allow farmers to access profitable output markets and to manage market risk are needed.

- *Policy implications*: Governments can help improve efficiency of markets all along the value chain, in particular by ensuring transport infrastructure and an enabling environment for ensuring market access and the development of risk-management institutions (such as outgrowers contracts) (IFAD 2008).

At almost every level of technology and cost of improved agricultural water management, farming systems need not only to become market-oriented, but farming must be profitable for farmers and with manageable risk. Farmers must be sure of covering all their increased costs, including the opportunity cost of labor, and outlays for acquiring, managing, and maintaining water supply systems and of other inputs. They must be able to manage risks (particularly market and climate risks), and they must be sure of making an adequate return after costs. In rainfed systems, risks are also great, particularly climate risk, and resilience is limited, so all packages need to incorporate risk management strategies.

One key aspect in the growth of profitable markets is demand. Markets for maize, wheat, and rice will grow at least in line with population growth (that is, faster than 2.5 percent per year). The region is currently a net importer and this is expected to continue (see chapter 4), so that prices will remain linked to the higher import parity level. For other grains and pulses, the region may switch from net importer to net exporter, so prices may move downwards towards export parity. Vegetables are generally of higher value but are also perishable and so are predominantly for the expanding local market; whether countries are net exporters or not, incentives are likely to remain high. Sugar is likely to remain a profitable crop for many situations, even if the region becomes a net exporter (section "Costs and Benefits of Further Irrigation Development in the Drylands" in chapter 4).

- *Policy implications*: Investments in agricultural water management should be promoted only in situations where economic incentives are attractive. Governments and agencies need to ensure that the economic/financial implications of improvement packages are exhaustively tested, and that farmers, particularly poor rainfed farmers, are not exposed to unmanageable risk.

Strategies for Agricultural Water Management in Drylands

Improve Rainfed Agriculture or Promote Irrigation?[1]

Chapter 4 assessed the scope for expanding irrigated agriculture but did not address the question of potential for improving productivity and strengthening resilience in the vast areas of the SSA drylands where irrigation is not feasible. In a recent comparative assessment of the global scope for productivity improvements and area expansion in agriculture, only in SSA is there both a high scope for improved productivity in rainfed areas and for irrigated area expansion.[2] These advantages, which stem from the large yield gaps and limited irrigation development in the region, make SSA unique in the world. But they also pose the question of choice and priority between improving rainfed agriculture or promoting irrigation.

At present, rainfed agriculture produces 90 percent of SSA's staple food needs. The region is largely self-sufficient in major staples such as maize, coarse grains (sorghum and millet), sweet potatoes, cassava, and other roots and tubers. These "home-grown" staples, which account for 91 percent of SSA's food consumption, are grown almost entirely under rainfed conditions. By contrast, irrigated supply provides only 5 percent of SSA staples, with the food crops produced using irrigation being largely higher-value cereals (wheat and rice). Irrigated production of staples constitutes only 5 percent of SSA food consumption.[3] Most of these irrigated cereals are produced in just three countries (Madagascar, South Africa, and Sudan). Other dryland countries produce very little irrigated cereals.

The high cost of irrigation has in the past made it generally less profitable to produce staples under irrigation, and SSA irrigated production often cannot compete price-wise with imports. In other regions, particularly in Asia, higher population densities create strong local markets for staples, and the abundance of labor and the scarcity of land make it profitable to invest in irrigated cereals, particularly rice, using large amounts of labor to intensify production. Thus, although the International Food Policy Research Institute (IFPRI) assessment results suggest that maize could be a dominant crop in an expanded SSA drylands irrigated area, it is likely that farmers would grow higher-value crops wherever possible, especially vegetables, rice, and sugar cane. Where double cropping is possible, farmers may grow both higher-value cash crops and staples (box 6.1).

FAO projects that irrigated production is likely to contribute at most 10 percent of staples consumption in SSA as a whole up to 2050, and this would be of the higher-value tradables such as rice and wheat, which are consumed by better-off city dwellers. The proportion is likely, however, to be higher in the drylands, particularly in the landlocked countries of the Sahel where import prices are higher.

FAO has registered steady increases in cereals production in SSA as a whole over the last half century (table 6.1), and forecasts continued growth, with four-fifths of the increase coming from intensification on existing rainfed lands, and the remainder largely from area expansion and—at the margin—from irrigated production (FAO 2011).

The area under rainfed cereals in SSA as a whole nearly doubled between 1980 and 2007, and the scope for further area expansion is limited. The challenge for rainfed farmers therefore will be intensification through a combination of improved water management, varietal improvement, soil fertility,

Box 6.1 Double Cropping of High-Value and Staple Crops

In Zimbabwe, farmers invest in irrigation infrastructure to provide supplemental irrigation needed to establish high-value summer crops, especially tobacco and cotton. Then in the winter (dry season) they use the same irrigation systems to grow wheat (assuming they have enough water stored in their on-farm reservoirs), because wheat is the only crop that will tolerate cold weather. Following the same pattern but with a reverse order of priorities, farmers in neighboring Zambia invest in irrigation to grow wheat in winter and use the same system for supplemental irrigation of maize or soy beans in summer.

Source: Personal communications from Michael Morris and Francois Onimus.

Table 6.1 Cereals Production, SSA, 1960–2030

Period	*Millions of tons*
1964/6	32
1974/6	40
1984/6	48
1997/9	71
2015 (forecast)	114
2030 (forecast)	168

Source: FAO (2011).
Note: SSA = Sub-Saharan Africa.

power sources, and crop husbandry—exactly the agenda discussed for rainfed agriculture in section "Improved Water Control in a Rainfed Environment" in chapter 3.

Cereals yields are typically lower in dryland areas but the production area is vast (125 million hectares), and even assuming a yield of 400 kilograms per hectare—less than one-third of the average yield for SSA as a whole—the drylands would account for annual production of 50 million tons, almost half of the total SSA cereals production (2013 production was 114 million tons). Investment to improve dryland yields by just one-tenth would thus produce an additional 5 million tons of cereals.

Given the economics of staple production in the drylands, the optimal strategy for the coming decades—for nations, consumers, and farmers—could be to invest in improved rainfed production of most staples and in irrigation for higher-value crops, including horticulture and industrial crops. If costs can be kept down, it may also be cost-effective to invest in irrigated production of the higher-value food grains (maize, rice, wheat) as a cash crop for markets that can remunerate the higher production costs. In many production situations, irrigation investment may be justified for a rotation of higher-value and staple crops. This strategy is consistent with the comparative assessment referred to above, which supports: (i) investment in the drylands to improve the productivity of rainfed agriculture with an emphasis on poverty alleviation and strengthening resilience; and (ii) an increase in the area under irrigation, mainly through small-scale irrigation to produce higher-value cash crops (fresh fruit and vegetables, sugar, cotton, etc.) (Molden 2007).

Agricultural Water Management in the Overall Landscape of the Drylands Economy

Contributions of Small-Scale and Large-Scale Irrigation in Overall Farming Systems

When governments assess options for developing irrigation potential, they must consider the different characteristics of large-scale irrigation and small-scale irrigation as drivers of local development and strengthened resilience. Many sites have potential for small-scale irrigation, and these are spread broadly across the drylands in local valleys, along smaller watercourses, or situated over exploitable aquifers. These sites can play a key role in local development and sell their surplus into local markets. The potential needs to be assessed from a local perspective. Small-scale irrigation should not, however, be considered in isolation and separate from rainfed cropping. Small-scale irrigation can benefit large numbers of farmers who can link it to rainfed cropping activities on their farms and to livestock rearing to yield a more diverse—and thus resilient—system (many farmers having one irrigated plot among other rainfed plots and with pasture and rangeland).

On the other hand, a relatively small number of corridors and regions in the drylands have potential for large-scale irrigation based on dammed rivers. This potential is thus concentrated and developing it brings with it economies of scale that increase efficiency and result in high yields. Farms will be more specialized and more commercially oriented, and many farmers will cultivate only irrigated plots. The concentration of a large number of specialized producers will create its own dynamic, prompting development of commercial value chains for these products. There will also be second-round effects on the local and national economy, as commerce, services, and urban centers spring up around this focus of economic growth—a phenomenon common to successful large-scale irrigation schemes across the world and observable in the best large-scale irrigation schemes in the drylands (for example, at Mali's 60,000 hectares *Office du Niger* scheme or Kenya's Mwea scheme).

Thus, in regions where mixed irrigated/rainfed systems dominate, small-scale irrigation will provide opportunities for large numbers of poor households to increase their income and reduce production variability. In the corridors and regions where irrigated agriculture dominates, commercial value chains will emerge, assisted by economies of scale, which will provide producers with higher and fairly stable cash incomes that will considerably reduce their vulnerability to shocks.

Irrigation, Population Growth, and Employment

Irrigation development plays a role in the broader agricultural and rural development agenda for the drylands, particularly with respect to demographic trends and the need to generate employment. The population living in the SSA drylands is predominantly rural and will remain so for the foreseeable future, and this is where the poverty and vulnerability will be concentrated. Population growth in rural areas will be mitigated to some extent by migration to urban areas, but employment opportunities created in urban areas are unlikely to keep up with population growth. Therefore, increasing resilience will require creation of employment opportunities in rural areas. Irrigation can play an important role in creating this employment, since irrigated agriculture has the potential to absorb labor and to generate opportunities for crop transformation (see Losch et al. 2012).

Action Plans and Investment Programs for Agricultural Water Management

This section asks the question: How should dryland countries turn the evident potential into productive investment? The discussion looks first at how action plans and investment programs might best be prepared where promoting agricultural water management in a rainfed environment is top priority, and then at countries and areas with significant potential for development of irrigation.

Action Plan for Agricultural Water Management in Rainfed Environments

Several countries with large dryland populations have comparatively little potential for irrigation expansion and yet are faced with significant problems of poverty and vulnerability. Most of these countries are in the Sahel—Burkina Faso, Chad, Mali, Niger, and Sudan. Zimbabwe and South Africa also have large dryland populations and relatively little scope for further irrigation development. For all these countries, emphasis will be on developing what irrigation potential exists, but improvement of rainfed production within broader rural development programs has to be a principal strategy for enhancing resilience. In Niger, for example, there is potential for some 260,000 hectares of irrigation—but almost 14 million hectares of rainfed dryland cropland. This section aims to identify the best options for developing agricultural water management in these conditions.[4] The section looks first at what sort of policy and strategic framework could be most conducive to promoting agricultural water management in rainfed production in these conditions, and then at the strategies and investment programs that would best enhance resilience through agricultural water management.

Setting the Investment Framework for Agricultural Water Management in Rainfed Environments

It is important that the policy framework is conducive to pro-poor agricultural water management development in the drylands. Based on experience, farmers have most readily adopted improvements in agricultural water management in drylands when there is a market-oriented economy, when land tenure and water rights are clear and stable, and when development policies support pro-poor growth (for example, on poverty reduction, gender equity, subsidies) and development of rural infrastructure, especially roads. Strategies for water resources management, agriculture, and the environment also need to be supportive and coherent amongst themselves.

Institutional set-ups will inevitably vary by country, but experience in promoting agricultural water management for rainfed farmers in the SSA drylands has shown that two good practice principles apply. First, there is a need for a coherent development delivery agency, a public interest agency organized on integrated lines to deliver technology, investment, and institutional support in a consolidated program. In the Sahel, this has taken the form either of regional development agencies or of specific long-term development programs, including CDD programs. The second good practice principle is that empowerment and responsibilization of farmers is key. Experience across all Sahel countries (chapter 3) has shown that sustainable development of agricultural water management has to be conducted on a bottom-up, participatory basis rather than top down. Participation of farmers as owners and actors is vital, best organized through empowered farmer groups or users' associations. Strengthening local institutional capacity is essential to developing sustainable programs adapted to local natural resource and socioeconomic situations, and is vital for ownership and sustainability.

What Agricultural Water Management Strategy, for Which Farmers?

In poor rainfed areas of the drylands, poverty, food insecurity, and vulnerability to shocks are very high, and spontaneous development of improved agricultural water management is unlikely for two reasons: (i) agricultural water management alone is unlikely to resolve the range of constraints farmers face and it needs to form part of a broader productivity and risk-management package; and (ii) farm households are too poor and lacking in knowledge about technological options to be able to invest to resolve problems by themselves. Therefore, a proactive role for the state is indicated, with programs of rural development and technological change, largely on a subsidized basis. This approach is particularly valid for the poorest countries, particularly the very poor Sahelian countries, and for all dryland areas where irrigation options are not available (85 percent of the total dryland farmed area). Table 6.2 suggests how governments might adapt their strategies to different types of farmers and farming systems.

Optimizing Investments

Investment in drylands will inevitably be heavily constrained and economic, socioeconomic, and equity criteria can help dryland countries to prioritize amongst opportunities for improving agricultural water management. Economic criteria include giving priority to zones where population is denser, so that

Table 6.2 Adapting Agricultural Water Management Strategies to Farmer Types

Farmer type	*Typical strategy for government intervention*
For the highly vulnerable	Largely social programs; economic programs to add value to any assets (including labor); upgrading of farming systems if water and land are available. Fully subsidized.
For less vulnerable, traditional farmers	Services and investment to improve agricultural water management in rainfed farming and to develop irrigation if water is available. Subsidized or on a cost sharing basis but with sustainable, self-financed operation and maintenance.
For emerging, market-oriented farmers	Enabling environment and limited support services; support to development of sustainable financial institutions; interventions to remove barriers to access for target groups (women, the poor); regulation of water resources and the environment. Credit or limited government cost sharing, but with sustainable, self-financed operation and maintenance.
For large commercial farmers	Enabling and regulatory environment; possible co-investment; risk-sharing contracts, including for service provision to smallholders.

markets and labor availability are likely to be less constraining, and to areas where past successes and learning suggest a higher potential for profitable and sustainable water development or improved management. Socioeconomic criteria might include giving priority to locations where farming systems and farmers are more ready in terms of knowledge, incentives, and assets for stepping up agricultural water management, and where there is the social capital needed for collaborative development and management. Equity criteria might include giving priority to areas where rural poverty, vulnerability, and/or food insecurity are most prevalent and to opportunities where investment (or policy or institutional change) might improve distribution and remove barriers to entry for the marginalized, women, etc. Of course, some of these criteria will produce conflicting priorities, particularly the trade-off between higher economic potential and poverty reduction, and other subjective criteria like political interest will intervene, but the criteria at least provide an objective platform from which to start.

Preparation of drylands investment programs in support of agricultural water management can start by downscaling the simulation of potential to the various farming/livelihoods systems in the country to reconcile potential with facts on the ground: who lives there, what is the socioeconomic profile, etc.? This step allows planners to identify zones where potential meets the economic, socioeconomic, and equity criteria adopted, and to list and rank sites for further investigation. Within those areas, appropriate agricultural water management practices and technologies for improving rainfed agriculture can then be identified (table 6.3).

The final and most important step is to set out how an essentially top-down "planners'" national strategy can be integrated into a bottom-up, demand-driven, livelihoods-adapted, environmentally sustainable set of context-specific, targeted interventions that will raise dryland farmers' incomes permanently, strengthen

Table 6.3 Typology of Agricultural Water Management Systems in Nonirrigated Areas and Main Technologies

Agricultural water management system	*Main technologies*
Pure rainfed cropped area	• Soil and water conservation • Improved on-farm water management • Agronomic improvements • Watershed management
Improved rainfed	• Small reservoirs • Run-off/run-on techniques • Bottomlands, wetlands, drainage • Soil and water conservation • Improved on-farm water management • Agronomic improvements

resilience, and reduce poverty and malnutrition. This step requires a method for working from the bottom-up to match farmers' aspirations and capabilities, the reality of natural resources, and socioeconomic and institutional facts on the ground to the *prima facie* potential identified. It is essentially a participatory planning process that will validate the potential and match it with what local people are willing and able to do. Participatory planning approaches are well documented and tested. One that is particularly appropriate and was developed specifically for agricultural water management in SSA is described in FAO (2012), which identifies investments that are adapted to:

- Farmers and their socioeconomic conditions;
- The agro-ecological zone (AEZ) and the existing farming/livelihoods system;
- The sustainability of the resource base (soil, water); and
- The likelihood of the investment raising farmers' incomes sustainably and reducing poverty.

Box 6.2 summarizes the methodology, which has already been tested and used to develop agricultural water management country investment briefs for Burkina Faso, Ethiopia, and Ghana.

Immediate Steps for Governments to Take in Rainfed Environments

Developing the potential for improved agricultural water management in the drylands is a key pathway towards strengthening resilience in all dryland countries, but particularly in: (i) the countries where a large proportion of the population depends on drylands agriculture but irrigation potential is limited—essentially the Sahel countries; and (ii) the poorer Eastern African countries where drylands are less prevalent but significant parts of the population still live there and where there is less potential for developing irrigation—notably Ethiopia and Uganda.

Box 6.2 Moving from Strategy to Context-Specific, Targeted Interventions for Agricultural Water Management

International Fund for Agricultural Development (IFAD) and FAO set out a five-step participatory approach to move from strategy to targeted interventions:

1. Mapping livelihoods zones by: (i) livelihoods basis; (ii) farmer typology; (iii) density of population; (iv) poverty rates; (v) main development constraints; (vi) dependence of livelihoods on water; and (vii) agricultural water management potential for improving livelihoods.
2. Identifying where agricultural water management can have most impact on livelihoods, where: (i) rural population density is highest; (ii) water is a key constraint for livelihoods; and (iii) water is available for agricultural water management options.
3. Assessing suitability by types of agricultural water management investment. This step involves four parts: (i) assessing biophysical suitability (water access, market access, AEZ); (ii) gauging strength of livelihoods-based demand; (iii) ranking potential according to biophysical suitability and livelihoods-based demand; and (iv) factoring in hydrological/sustainability/risk constraints.
4. Assessing the investment costs.
5. Validating the process.

Source: FAO (2012).

All of these countries have policies, strategies, and investment programs that address the issue of improving agricultural water management in rainfed areas within an integrated rural development context. Some of these are very developed, such as the *Strategie Nationale de Developpement Rural* (SNDI) of Niger. Therefore, an appropriate initial step would be to review existing strategies and investment plans against the findings and recommendations of this report, and to prepare updates. This review would most appropriately be carried out with the participation of all national stakeholders, especially farmer groups and representatives, and with the collaboration of development partners interested in financing the resulting programs.

Action Plan to Develop Irrigation in Drylands

The IFPRI assessment identified a number of SSA countries with significant potential for irrigation development in their drylands. The largest potential is in Nigeria (almost 2.5 million hectares) and Tanzania (almost 1 million hectares). In several countries, irrigation could have a transformational impact on the drylands as irrigation potential is high relative to the total dryland cropped area: more than 20 percent in two Eastern African countries (Tanzania, 28 percent; Somalia, 33 percent) and in four Southern African countries (Malawi, 80 percent;

Madagascar, 73 percent; Angola, 25 percent; Swaziland, 23 percent). Potential relative to dryland area is also high in Ghana (26 percent). Many other countries have sizable potential that is more than 10 percent of their dryland cropped area, including Mauritania and Senegal in Western Africa, and Kenya and Zambia in Eastern Africa.

This section looks at how the identified irrigation potential could best be developed, highlighting any differences from the approaches described above for promoting agricultural water management in rainfed production.

Setting the Framework for Irrigation Investment in Drylands

Many policy considerations for irrigation development are the same as for rainfed agricultural water management: market-oriented economy, clear land tenure and water rights, and supportive and coherent strategies for water resources management, agriculture, and the environment. Factors that take greater prominence for irrigation reflect the fully commercialized nature of most irrigated agriculture: trade and tariff policy; the business environment; the incentive structure, including the tax regime; policy on investment subsidies; energy policy; approach to FDI and PPP; and infrastructure and logistics, including roads, airports, transit facilities, and storage.

Public agencies are essential for irrigation policy, strategy, and investment planning, for regulation, and for monitoring and evaluation (M&E). Implementation of public programs may be the direct responsibility of public agencies or can be done in partnership with private agencies (as in Zambia, Ghana, ANPIP in Niger, Swaziland, etc.) or under a risk-sharing contract with the private sector (as at Megech in Ethiopia). Where public agencies are employed, particularly for large-scale irrigation development, they need adequate capacity, and programs will be needed for institutional strengthening and capacity building, as for example, the support provided to Kenya's National Irrigation Board under the World Bank-financed Water Security and Climate Resilience Project.

At the local level, empowering farmers, assigning them responsibilities, and holding them accountable are as important for irrigation schemes as for purely rainfed environments. Best practice is to work with farmers organized into water users' associations (WUAs) from the outset and to hand over developed schemes to the WUAs for sustainable management of assets created, whether this is maintenance of simple structures for small-scale irrigation or—on a large-scale scheme—paying water charges and perhaps ultimately becoming responsible owners of a management company. Again, strengthening institutional capacity at the local level is essential to sustainable investment in agricultural water management.

Although small farmers may be able to afford the costs of individual irrigation (for example, the cost of a pump), not all can, particularly women and the poorest (section "Individual Low-cost Irrigation"). Generally, the costs of developing small-scale, community-managed schemes (US$4,500 per hectare medium cost) are also beyond the financial capacity of poor farmers—and those of large-scale irrigation (US$12,000 per hectare medium cost) are quite out of reach. Therefore, most countries in SSA already practice some form of investment cost sharing, but always with the stipulation that operation and maintenance (O&M) should be sustainable and self-financed. To realize the potential for expansion, programs for cost sharing or credit will be required to remove barriers to access, including for special target groups such as women or the poorest.

Optimizing Investments

In designing the investment program for irrigation expansion, the economic, socioeconomic, and equity criteria used for rainfed investments apply but with greater scrutiny of the prospects for economic viability, as the investment costs are high and the risks of unsustainability are greater if the scheme does not generate adequate cash flow.

Table 6.4 illustrates technologies for investment in irrigation.

Table 6.4 Typology of Irrigation and Main Technologies

	Agricultural water management system	*Main technologies*
Small-scale irrigation (individual, community-based)	Individual low-cost irrigation	• Motor pumps • Small reservoirs • Soil and water conservation • Improved on-farm water management • Wastewater and grey water reuse • Agronomic improvements
	Community-based irrigation	• Stream or river diversion • Small reservoirs • Bottomlands, wetlands, drainage • Soil and water conservation • Improved on-farm water management • Agronomic improvements • Piped irrigation; drip, sprinkler; protected (greenhouse) agriculture
Large-scale irrigation	Large-scale public irrigation for smallholders	• Dams or weirs; surface canals; furrow irrigation • River diversion • Soil and water conservation • Improved scheme water service • Improved on-farm water management • Agronomic improvements
	Large farmer commercial irrigation and PPPs	• Piped irrigation • Drip, sprinkler • Protected (greenhouse) agriculture

Note: PPP = public-private partnership.

Immediate Steps for Governments to Take for Expanding Irrigation

Although the extra irrigation potential in the drylands represents only one-tenth of the currently cropped area, this one-tenth has the potential to produce three times as much as non-irrigated land and to create three times as much employment. Investment in sustainable, profitable irrigation is therefore a priority as a means of reducing poverty, strengthening resilience, and creating a growth dynamic.

Countries with the highest potential relative to the dryland population have particular interest in strengthening planning to realize the potential immediately, notably:

- *Tanzania*, where 60 percent of the population lives in the drylands and almost 30 percent of the drylands cropland (958,000 hectares) has irrigation potential;
- *Mauritania*, where almost the entire population are dryland dwellers and more than 16 percent of drylands cropland (134,000 hectares) could be converted to irrigation;
- *Zambia*, with 60 percent of the population in the drylands and about 14 percent of the drylands cultivated area (373,000 hectares) with irrigation potential; and
- *Malawi*, with 60 percent of the population in the drylands and a massive 80 percent of the drylands cultivated area (661,000 hectares) with irrigation potential.

Other countries with relatively high proportions of their population living in the drylands (more than 50 percent) and with more than 10 percent of their drylands cropland with irrigation potential are Angola, Lesotho, Senegal, Somalia, and Swaziland. In these countries, development of the irrigation potential would be a priority to reduce poverty and improve resilience in the drylands.

To develop this considerable potential, countries first need to downscale the IFPRI simulations and to identify and prioritize sites. As for rainfed area development, a first next step would be to review existing strategies and investment plans against the findings and recommendations of this report and to prepare updates. Again, this review would most appropriately be carried out with the participation of all national stakeholders, especially farmer groups and representatives, and with the collaboration of development partners interested in financing the resulting programs.

Countries with existing large-scale irrigation schemes could examine whether the returns on investment on rehabilitation and modernization of existing schemes may justify investing in modernization of infrastructure and reform of institutions. Given the high costs and demonstrated risk of large-scale irrigation investment in SSA, getting better returns from the existing schemes and testing sustainable and efficient institutional models before investing in further costly large-scale irrigation may be the optimal sequencing. For example, in Kenya's drylands, getting the Bura and Hola schemes to run efficiently and profitably for farmers could be the first step before embarking on major expansion of large-scale irrigation. Similar considerations could apply in Niger (proving a sustainable economic and management model on *amenagements hydro-agricoles*) and in Mali (completing the ongoing modernization of infrastructure and institutions at the *Office du Niger*).

Investment Costs and Phasing

The overall investment cost to realize the full potential for irrigation expansion is considerable at US$60 billion (table 6.5). Almost one-half of the total cost (49 percent) would be for investment in the Western African countries. Of this, a large share (23 percent) would be in Nigeria.

One-third of the total investment (32 percent) would be in large-scale irrigation. This would develop just 16 percent of the potential area—1.6 against the 9.1 million hectares potential for small-scale irrigation. The cost of large-scale irrigation per hectare is almost three times that of small-scale irrigation and the returns from large-scale irrigation would have to be commensurately higher and free of risk before large-scale irrigation would be the priority for most countries. In addition, several countries might first modernize infrastructure and institutions in their existing large-scale irrigation schemes before embarking on expansion plans.

Exceptions could be countries where there is good large-scale irrigation potential but limited small-scale irrigation potential. In particular, the very poor Niger has limited small-scale irrigation potential (62,000 hectares) but much greater potential for large-scale irrigation (199,000 hectares) from dams being planned and constructed on the Niger River. Clearly, large-scale irrigation could have a transformational impact on Niger's poverty and vulnerability, provided that a sustainable, efficient economic and institutional model could be developed. The same logic applies to Ethiopia, another very poor country that has a large irrigation potential in the drylands. Recent development of new large-scale

Table 6.5 Estimated Costs of Developing the Irrigation Potential in the SSA Drylands

		Large-scale irrigation		*Small-scale irrigation*		
SSA region	*Total irrigation potential ('000 ha)*	*Potential ('000 ha)*	*Cost (US$ millions @ US$12,000/ha)*	*Potential ('000 ha)*	*Cost (US$ million @ US$4,500/ha)*	*Total cost (US$ millions)*
Eastern Africa	2,684	326	3,917	2,358	10,610	14,527
Western Africa	5,179	800	9,617	4,378	19,699	29,317
Southern Africa	2,547	388	4,665	2,159	9,717	14,381
Central Africa	267	87	1,041	180	808	1,850
Total	**10,674**	**1,601**	**19,236**	**9,075**	**40,834**	**60,076**

Source: Xie et al. (2014a).
Note: SSA = Sub-Saharan Africa.

irrigation in Ethiopia suggests good prospects for its profitable and sustainable operation. In addition, several countries might find opportunities for lower-cost, high-return development of large-scale irrigation downstream of new dams coming on stream (including Angola, Ghana, Guinea, Nigeria, Malawi, Mozambique, and Zambia).

Costing and Phasing Considerations: Eastern Africa

In the Eastern African drylands, there is very considerable potential for expansion of small-scale irrigation: 2.7 million hectares that could benefit up to 14 to 15 million dryland dwellers, at a total cost of US$14.5 billion, or about US$1000 per capita (table 6.6). Around urban centers in most of these countries, much of this small-scale irrigation development would be in the form of individual pumped irrigation, largely or entirely at the cost of farmers themselves. Development of small-scale community-managed schemes would likely be on a cost sharing basis, but would require some contribution from government under programs to develop small-scale irrigation. Some schemes, however, would be developed and financed by farmers themselves, with government in only a planning, advisory, and regulatory role. It is thus likely that a fair share of the potential can be developed without excessive cost to governments, but governments could promote more rapid and efficient development through financial and technical support programs. Governments will in all cases need to have institutional capacity for planning and advising farmer organizations on small-scale irrigation development, and for regulating resource development and use.

The large-scale irrigation potential is also considerable, particularly in Ethiopia, Kenya, Somalia, Tanzania, and Uganda. To develop this potential would, however, incur a much higher cost: US$3.9 billion to develop 326,000 hectares. On the

Table 6.6 Estimated Costs of Developing the Irrigation Potential in the Drylands: Eastern Africa

		Large-scale irrigation		*Small-scale irrigation*		
Country	*Total irrigation potential ('000 ha)*	*Potential ('000 ha)*	*Cost (US$ millions @ US$12,000/ha)*	*Potential ('000 ha)*	*Cost (US$ millions @ US$4,500/ha)*	*Total cost (US$ millions)*
Eritrea	61			61	273	273
Ethiopia	384	110	1,319	274	1,234	2,553
Kenya	686	127	1,524	559	2,516	4,040
Somalia	364	23	279	341	1,535	1,814
Sudan	21			21	96	96
Tanzania	958	26	313	932	4,193	4,506
Uganda	206	40	480	166	748	1,228
Djibouti	4			4	16	16
Total	2,684	326	3,915	2,358	10,611	14,526

Source: Xie et al. (2014a).
Note: The empty cells indicate negligible.

assumption of one hectare per family, the per capita cost would be US$2,000, three times that of small-scale irrigation. In addition, most of the financing burden would be at the public expense. Governments would therefore be advised to adopt prudent stances: selecting the lowest capital cost sites where the benefit-cost ratio is highest; ensuring that the economic and institutional model is workable and that high farmer incomes and sustainability of scheme operations are assured; and testing out PPP models to ensure efficient implementation and operations and bringing in private capital to the extent possible. Again, several countries may wish to start with getting existing large-scale irrigation schemes up to speed.

The above reasoning suggests a phasing of immediate planning and development for small-scale irrigation, and a cautious scheduling of large-scale irrigation opportunities, following the dam construction program but investing only where the conditions outlined above are in place.

Costing and Phasing Considerations: Western Africa

The Western African drylands have the highest potential for expansion of irrigation, almost half of the potential for expansion of both small-scale irrigation (50 percent) and large-scale irrigation (49 percent).

The potential for expansion of small-scale irrigation is some 4.4 million hectares at a total cost of US$19.7 billion. The extreme poverty and vulnerability of the rural populations of several of these countries, notably those of the Sahel, make development of small-scale irrigation (SSI) a top priority. The potential for small-scale irrigation expansion in Burkina Faso (312,000 hectares), Chad (260,000 hectares), and Mali (229,000 hectares) indicates a major opportunity to strengthen resilience and reduce poverty. These countries will therefore likely look to strengthen their existing small-scale irrigation and rural development programs to develop this potential. The downside is the cost. For Burkina Faso, the cost would be almost US$1.4 billion; for Chad, US$1.1 billion; for Mali, US$1.0 billion; and for Mauritania, US$0.6 billion (table 6.7). Financing from development partners for accelerated programs is clearly indicated. Of course, more than just financing is required: the experience of accelerated programs such as that in Niger has shown the vital need for strong institutional and technical capacity and development to accompany investment.

In other countries of Western Africa, small-scale irrigation is also likely to be an important solution to a national drylands problem: Benin, Gambia, Senegal, and Togo all have more than half their population living in dryland areas and all have significant potential for small-scale irrigation expansion. Nigeria has a huge potential of 1.6 million hectares. These countries, too, will likely program an accelerated rate of support to development of community-based small-scale irrigation and foster the development of individual pumped

Table 6.7 Estimated Costs of Developing the Irrigation Potential in the Drylands: Western Africa

Country	*Total irrigation potential ('000 ha)*	*Large-scale irrigation*		*Small-scale irrigation*		*Total cost (US$ millions)*
		Potential ('000 ha)	*Cost (US$ millions @ US$12,000/ha)*	*Potential ('000 ha)*	*Cost (US$ millions @ US$4,500/ha)*	
Benin	208	44	532	164	737	1,269
Burkina Faso	333	21	254	312	1,404	1,658
Chad	265	5	58	260	1,170	1,228
Cote d'Ivoire	182	16	193	166	749	942
Gambia	40			40	182	182
Ghana	465	46	547	419	1,885	2,433
Guinea	42	42	509			510
Guinea-Bissau	2			2	9	9
Mali	281	52	626	229	1,029	1,655
Mauritania	134	5	62	129	581	643
Niger	261	199	2,386	62	280	2,666
Nigeria	2,457	370	4,446	2,087	9,391	13,837
Senegal	394			394	1,774	1,774
Togo	113			113	509	509

Source: Xie et al. (2014a).
Note: The empty cells indicate negligible.

irrigation in peri-urban areas, although the latter may require some guidance and support and will certainly require regulation of abstractions if it is to be equitable and sustainable.

Western Africa's large-scale irrigation potential is located along the great rivers that flow through the region, particularly in Niger (199,000 hectares) and Nigeria (370,000 hectares). As discussed above, development of this potential is of vital importance for Niger, which lacks significant small-scale irrigation potential. Ongoing dam construction on the Niger River provides the opportunity, but the challenge will be to ensure that the economics are right and that the institutional model provides for efficient water service and sustainable and affordable O&M.

Costing and Phasing Considerations: Southern and Central Africa

The countries of Southern and Central Africa present a contrast (tables 6.8 and 6.9). Several are relatively poor and have a large proportion of their populations living in dryland areas, particularly Malawi (661,000 hectares), Madagascar (495,000 hectares), and Zambia (373,000 hectares). Others have higher per capita incomes (particularly South Africa and its immediate neighbors) or lower potential for irrigation expansion relative to their drylands area (for example, Zimbabwe). Most of the potential for the three countries highlighted (Malawi, Madagascar, and Zambia) is in small-scale irrigation, and these countries will likely accelerate development of this potential, building on their existing programs. With its millennium-long tradition and its irrigation development programs over the last 50 years, Madagascar has all the experience needed.

Table 6.8 Estimated Costs of Developing the Irrigation Potential in the Drylands: Southern Africa

Country	*Total irrigation potential ('000 ha)*	*Large-scale irrigation*		*Small-scale irrigation*		*Total cost (US$ millions)*
		Potential ('000 ha)	*Cost (US$ millions @ US$12,000/ha)*	*Potential ('000 ha)*	*Cost (US$ millions @ US$4,500/ha)*	
Angola	271	67	808	204	916	1,725
Botswana	49			49	220	220
Lesotho	35			35	158	158
Madagascar	495			495	2,226	2,226
Malawi	661	99	1,183	562	2,529	3,711
Mozambique	193	99	1,194	94	423	1,617
Namibia	51	10	120	41	186	305
South Africa	299	41	493	258	1,159	1,653
Swaziland	24			24	109	109
Zambia	373	64	771	309	1,391	2,163
Zimbabwe	97	8	97	89	399	496
Total	**2,547**	**388**	**4,666**	**2,159**	**9,716**	**14,383**

Source: Xie et al. (2014a).
Note: The empty cells indicate negligible.

Table 6.9 Estimated Costs of Developing the Irrigation Potential in the Drylands: Central Africa

Country	*Total irrigation potential ('000 ha)*	*Large-scale irrigation*		*Small-scale irrigation*		*Total cost (US$ millions)*
		Potential ('000 ha)	*Cost (US$ millions @ US$12,000/ha)*	*Potential ('000 ha)*	*Cost (US$ millions @ US$4,500/ha)*	
Burundi	7			7	29	29
Cameroon	89	52	630	37	166	795
Central African Republic	2			2	10	10
DRC	141	32	381	109	490	871
Rwanda	28	3	31	25	113	145
Total	**267**	**87**	**1,042**	**180**	**808**	**1,850**

Source: Xie et al. (2014a).
Note: The empty cells indicate negligible.

Constraints will be finance, markets for cash crops, and the challenges of groundwater irrigation, on which much of the potential is based.

Notes

1. Some of the discussion in the section draws on data or refers to approaches for Sub-Saharan Africa (SSA) as a whole, due to the difficulty of reviewing topics such as country demand or regional demand where most countries or regions contain a mix of drylands and non-drylands.
2. The assessment is in the excellent and comprehensive assessment edited by David Molden (2007).

3. This is in contrast to the average of 60 percent of staples produced under irrigation for developing countries as a whole; the balance of 4 percent of SSA food consumption is imported.
4. The discussion of course applies to all countries addressing the challenge of improved agricultural water management in a rainfed environment, but the focus is on countries with less potential for irrigation development.

CHAPTER 7

Conclusions

Natural conditions in the Sub-Saharan Africa (SSA) drylands are harsh and are likely to deteriorate with climate change, whilst dryland populations have low levels of resilience. Agricultural water management can play a significant role in reducing vulnerability and strengthening resilience for these populations.

The IFPRI assessment carried out for the Africa Drylands study suggests that there is technical and economic justification for tripling the irrigated area in the drylands, adding another 10 million hectares of irrigation development to the current 5 million hectares. Overall, the development of irrigation could have a great, even transformational, impact on farming systems and resilience, although the level of environmental and financial risk increases. The potential identified is concentrated in small-scale irrigation, with its lower costs, more decentralized approaches, and likely higher levels of farmer participation. It is thus likely that government strategies, action plans, and investment programs for developing irrigation potential will focus largely on small-scale irrigation.

Considerable potential also exists for large-scale irrigation development (1.6 million hectares), concentrated along corridors below dams. Large-scale irrigation development costs are three times as high, but the value added and employment created are three times as great. However, large-scale irrigation poses technical, economic, and institutional challenges and risks, so investment in larger schemes is likely to proceed more slowly as sustainable and profitable models are worked out. For some countries, investment in improving existing large-scale irrigation schemes may pay higher returns than starting new sites.

Both small and large schemes can have significant but somewhat different contributions to make to increased resilience. Small-scale irrigation development will often increase resilience as a complement to a mixed rainfed or pastoral system rather than as a stand-alone activity, providing opportunities for large numbers of poor households to increase their income and reduce production variability. By contrast, large-scale irrigation development is likely to create specialized production, economies of scale, and its own value chains, strengthening household resilience through cash incomes that will considerably reduce vulnerability to shocks. Large-scale irrigation is also likely to create greater employment opportunities that will enhance resilience for a broader segment of the rural population.

At the same time, development strategies will need to focus on the much larger area and population where irrigation development is not possible. Many techniques for improving agricultural water management in rainfed environments are available, and they can help increase the incomes and resilience of the more than 90 percent of dryland farmers who cannot have access to irrigation.

A main driver of strategy will be the fact that investment in full irrigation in SSA will normally only be viable economically if higher-value cash crops are produced for market. This would suggest a broad strategy of "rainfed for most staples, irrigated for higher value cereals, horticulture, and industrial crops," and an investment program that focuses on: (i) improved agricultural water management as part of a total livelihoods package in drylands areas where irrigation is not possible, with an emphasis on poverty alleviation and increased resilience; and (ii) where water and markets are available, developing irrigation for higher-value, market-driven production, with an increase in the area under irrigation mainly through small-scale and individual irrigation to produce higher-value cash crops.

In all approaches, the emphasis will be on farmers as partners rather than beneficiaries. Bottom-up, participatory approaches will be essential to ensure sustainable, equitable, and profitable agricultural water management development.

For poor dryland countries and populations, cost will be a major barrier. At per ha costs of US$4,500 for small-scale irrigation and US$12,000 for large-scale irrigation, investment in irrigation will have to be supported largely by the state. Investment in rainfed systems is much cheaper (around US$200 per hectare and up) but also requires sustained support. Keeping costs down will be an imperative, and prioritizing and phasing will be essential. External support will be required. The first step will be to update development strategies and to prepare phased investment programs based on downscaled estimates of potential and on results validated with local stakeholders to turn potential into feasible projects.

Of course, agricultural water management alone cannot make all the difference. Essentially, an integrated approach is required that enhances agricultural risk management and promotes resilience of agricultural production value chains within the potential and constraints of the local natural resource and socioeconomic setting. Alongside development of agricultural water management, action and investment are needed in research and technology development and transfer, livestock development, and rangeland management, as well as other measures to improve productivity and strengthen value chains and with investment in infrastructure and human capital and improvement of the overall enabling environment and incentive framework.

Taken together, these developments can make a contribution in varying degrees to increased resilience, through increased productivity, increased and more stable levels of production, and more labor use. The results can include reduced household vulnerability, increased coping capacity, improved household food security and nutrition, increased disposable income, and reduced poverty at household level.

APPENDIX A

Public and Private Roles and Investments by Farmer Type and Farming Livelihood Systems

Farmer type	*Typical policy/public sector role and strategy*	*Typical agricultural water management investments and source of finance*
Highly vulnerable/ survival (10–15%)	• Predominantly social programs to reduce vulnerability and provide basic services • Employment creation schemes • Subsidized support to any farming/ livestock operations	• Improved agricultural water management in situ • (Possibly) water for livestock • (Possibly) small-scale water harvesting • (Possibly) small-scale irrigation schemes • (Possibly) individual or group pump schemes • Finance on highly subsidized basis—but with sustainable, self-financed O&M
Traditional vulnerable farmers (smallholders, mainly subsistence) (75–80%)	• Enabling and support services for developing and operating: (a) water harvesting; (b) improved agricultural water management in rainfed in situ; (c) livestock watering; and (d) small-scale and individual irrigation (including support to WUAs) • Enabling and support services for profitable farming (including extension, research, land tenure, credit, market development and access, rural roads)	• Water harvesting • Improved agricultural water management in rainfed agriculture in situ • SSI schemes • Individual or group pump schemes, with finance on cost-sharing basis • Small-scale water harvesting • Water for livestock • Finance on cost-sharing basis but with sustainable, self-financed O&M
Emerging, market-oriented smallholders (10%)	• Enabling and regulatory environment (including water rights) for water resources development within WRM/basin plans • Enabling and support services for developing and operating small-scale and individual irrigation (including support to WUAs)	• Water control for peri-urban producers • SSI schemes

table continues next page

Farmer type	*Typical policy/public sector role and strategy*	*Typical agricultural water management investments and source of finance*
	• Enabling and support services for profitable farming including: extension; research; land tenure; credit; market development; linkages to higher-value markets including exports; and market access including rural roads • Interventions to remove barriers to access by women, the poor, etc.	• Individual or group pump schemes • Improved existing irrigation on large-scale irrigation schemes for smallholders • Finance on credit or cost-sharing basis but with sustainable, self-financed O&M
Commercial farmers (mainly large-scale) (<1%)	• Improved political, fiscal, and legal environment • Improved market and trade environment • Financing through functioning capital markets/banking system; possible co-investment • Development of possible PPP arrangements, including financial arrangements, outgrower schemes, etc. • Water allocation and regulation within WRM/basin plans • Oversight within agriculture/irrigation strategy	• Hi-tech and larger-scale infrastructure investments • Finance by private sector, with possible cost-sharing with public sector for public good services (for example, extension to outgrowers)

Note: O&M = operation and maintenance; SSI = small-scale irrigation; PPP = public-private partnership; WUA = water users' association; WRM = water resources management.

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Dryland regions in Sub-Saharan Africa are home to one-half of the region's population and three-quarters of its poor. Poor both in natural resources and in assets and income, the inhabitants of drylands are highly vulnerable to droughts and other shocks. Despite a long history of interventions by governments, development agencies, and civil society organizations, there have been no sustained large-scale successes toward improving the resilience of drylands dwellers.

Improved Agricultural Water Management for Africa's Drylands describes the extent to which agricultural water management interventions in dryland regions of Sub-Saharan Africa can enhance the resilience and improve the well-being of the people living in those regions, proposes what can realistically be done to promote improved agricultural water management, and sets out how stakeholders can make those improvements. After reviewing the current status of irrigation and agricultural water management in the drylands, the authors discuss technical, economic, and institutional challenges to expanding irrigation. A model developed at the International Food Policy Research Institute is used to project the potential for irrigation development in the Sahel Region and the Horn of Africa. The modeling results show that irrigation development in the drylands can reduce vulnerability and improve the resilience of hundreds of thousands of farming households, but rainfed agriculture will continue to dominate for the foreseeable future. Fortunately, many soil and water conservation practices that can improve the productivity and ensure the sustainability of rainfed cropping systems are available.

The purpose of this book is to demonstrate the potentially highly beneficial role of water and water management in drylands agriculture in association with agronomic improvements, market growth, and infrastructure development, and to assess the technological and socioeconomic conditions and institutional policy frameworks that can remove barriers to adoption and allow wide-scale take-up of improved agricultural water management in the dryland regions of Sub-Saharan Africa.

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