Chapter 7

Agriculture: More Water and Better Farming for Improved Food Security

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Current situation

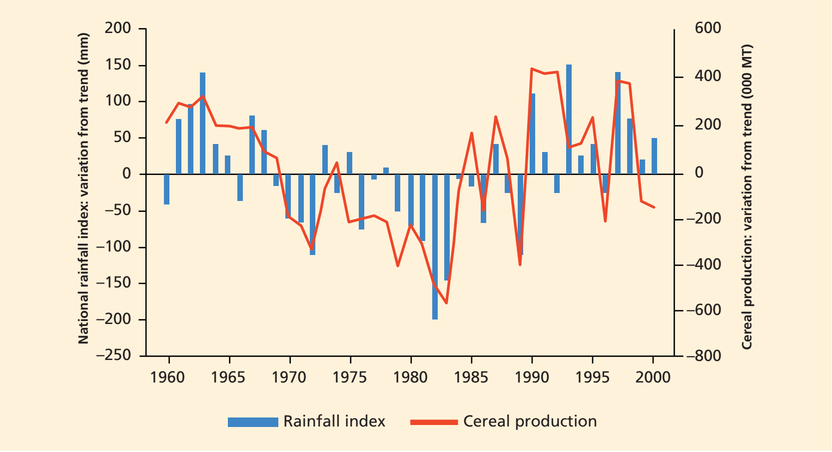
Agriculture—used here to refer to farming in general and crop cultivation in particular—is one of the two main livelihood strategies practiced in the drylands (the other being livestock-keeping). In the countries of East and West Africa in which drylands are important, agriculture is economically significant, with crop production typically contributing 10–30 percent of GDP and up to 75 percent of agricultural GDP.

Dryland agriculture is diverse, with mixed cropping predominating as a way of protecting against risk. Most dryland farming systems are dominated by one or two main staples, which are grown in association with a range of other crops having dissimilar growth cycles and different maturity dates. Generally speaking, cropping systems in drier areas are dominated by millet and sorghum, due to the superior ability of these two species to tolerate drought and heat. As rainfall levels increase and mean temperatures decline, millet and sorghum give way to maize, which is the dominant crop throughout the wet parts of the semi-arid zone and the subhumid zone. In the wettest part of the drylands, maize is increasingly associated with roots and tubers, including cassava, yam, and sweet potato.

Drylands are generally unfavorable for agriculture. The harsh agro-climatic conditions restrict the potential of many crops, and fields are chronically exposed to unpredictable shocks that can decimate production to the point of causing complete crop loss. The biggest challenge to dryland agriculture is posed by the uncertain availability of water, both in terms of quantity and timing. Although the effects of uncertain and highly variable rainfall can be mitigated through the use of irrigation, irrigation is relatively underdeveloped in the drylands, as it is across the region as a whole. Sub-Saharan Africa has the lowest level of irrigation development in the world. Across the entire region (drylands and non-drylands), about 7.1 million hectares have been developed for irrigation, representing just 3 percent of the total cultivated area. This compares to about 15 percent of cropland that is irrigated worldwide. Not only is irrigation much less developed in Sub-Saharan Africa than elsewhere, but the area that is developed is underused—more than one-fifth of the area equipped with irrigation infrastructure is reported to be out of use. Prospects for catching up with the rest of the world are bleak, as the rate of expansion of new irrigation is slow, averaging about 1 percent per year since 1995.

With irrigation still relatively underdeveloped, crop cultivation in the drylands takes place mainly in rainfed systems. Rainfed crop production in the drylands is highly correlated with rainfall, which is important because drought is a defining feature of the environment (figure 7.1). In most years, farmers sow their crops into dry soil at the beginning of the rainy season, in the expectation that the rains will follow. When the temporal distribution of rainfall differs from expectations, the consequences can be severe. The late arrival of early-season rains may spell crop failure, and terminal drought stress at the end of the growing season can be catastrophic as well. A second major constraint affecting dryland agriculture is extreme temperatures, particularly heat. Although many of the crops grown in drylands have the ability to tolerate wide temperature

Figure 7.1 Dryland cereal production and rainfall in Burkina Faso, 1960–2000



Source: Ward, Torquebiau, and Xie 2016.

Note: mm = millimeters; MT = metric tons.

fluctuations, most are unable to withstand even short periods of extreme heat or cold, especially when these occur at critical stages of the plant growth cycle.

Water scarcity and extreme heat are the two biggest constraints affecting dryland agriculture, but they are hardly the only ones. Low soil fertility and nutrient depletion are chronic problems, with an estimated three-quarters of dryland soils showing symptoms of one of more plant nutrient deficiencies. Eroding winds, uncontrolled burning, and attack by insects such as locusts and army worms can further impair productivity and increase risk in dryland cropping systems.

As a result of the many constraints, productivity in dryland farming systems is generally low, and production tends to fluctuate considerably from year to year. Across all of Sub-Saharan Africa, total factor productivity in agriculture increased very little during the three decades 1960–1990. Not until the mid-1980s did significant numbers of African farmers begin adopting more intensive technologies, leading to a modest acceleration in productivity growth (Fuglie and Rada 2013).

Opportunities

Despite the challenges they pose to farming, drylands feature a number of agroclimatic conditions that are favorable for plant growth, such as high levels of solar radiation and a relative absence of pests and diseases. These advantages confer possibilities for crop productivity gains. Where there are profitable markets and particularly where farmers have access to reliable water supplies, technological change can occur rapidly, bringing gains in income, reductions in poverty, and increases in resilience.

Agricultural productivity in many parts of the drylands is far below potential, as reflected by large and persistent gaps between yields observed in farmers' fields and yields recorded on experiment stations using optimal levels of inputs and improved management practices. The existence of these yield gaps means that technologies are available with demonstrated capacity to increase and stabilize the productivity of dryland agriculture. These technologies are not all the same, however; the benefits they deliver depend on the degree to which they address each of the three determinants of vulnerability and resilience (exposure, sensitivity, coping capacity).

Reducing exposure

Unlike the case of many livestock-keepers who can move their herds to avoid exposure to droughts and other related shocks, farmers cannot move their fields. For this reason, agriculture will always be exposed to weather shocks, especially droughts.

Reducing sensitivity

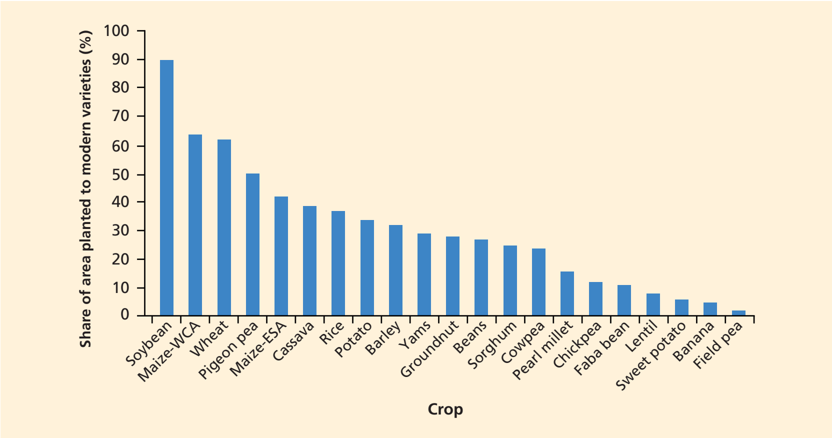
Farmers living in dryland regions are affected by droughts only to the extent that their farming activities are sensitive to the effects of those droughts. For this reason, interventions that reduce the sensitivity of dryland agriculture to droughts have the potential to reduce the vulnerability and improve the resilience of households that depend on farming as their principal livelihood source. Two broad categories of interventions are distinguished here that reduce sensitivity of crop farming to droughts: (1) improved management practices for rainfed agriculture, and (2) irrigation development.

Improved management practices for rainfed agriculture

Where there are profitable markets and particularly where farmers have access to reliable water supplies, technological change in rainfed cropping systems can occur rapidly, bringing gains in income, reductions in poverty, and increases in resilience. The modeling exercise done for this book confirmed that several opportunities for accelerating the pace of technological change offer particularly bright prospects, described as follows.

Accelerating the rate of varietal turnover. Modern varieties (MVs) of cereals, such as rice, wheat, and maize, played a major role in driving the Green Revolutions of Asia and Latin America, but they have had much less impact in Sub-Saharan Africa, where adoption of MVs has lagged (Walker et al. 2014). In 2010, across Sub-Saharan Africa as a whole, the average rate of MV adoption among 20 field crops stood at around 35 percent (figure 7.2). While this

Figure 7.2 **Adoption rate of modern varieties by crop in Sub-Saharan Africa, 2010 (%)**



Source: Constructed from Walker et al. 2014.

Note: Maize is divided into East and Southern Africa (ESA) and West and Central Africa (WCA).

adoption rate is considerably lower than the rate achieved in other developing regions, the uptake of MVs in Africa has accelerated in recent years, particularly in the case of maize and cassava, the leading dryland cereal and root crops (Walker and Alwang 2015). If current adoption rates continue, two-thirds of dryland areas will be sown to MVs by 2030.

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: higher yield potential and greater yield stability. In addition, because these advantages of hybrids are assured only when farmers purchase new seed for every cropping cycle, the demand for hybrid seed tends to be strong, 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 West Africa, which account for about 40 percent of dryland cropped area in Sub-Saharan Africa.

Improving fertility management. 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. A number of practices have demonstrated their effectiveness under diverse dryland conditions, including mulching, green manuring, composting, intercropping with legumes, and judicious use of mineral fertilizer (for a summary, see Walker and Alwang 2015). The impact of improved soil fertility management technologies is amplified when MVs are introduced at the same time because of the synergistic effects between improved germplasm and improved management practices.

Improving agricultural water management. In the drylands, which are characterized by conditions of chronic water scarcity and climatic unpredictability, soil moisture is often inadequate to achieve a decent yield, and in times of drought, farmers may face total crop failure. Many households in the drylands that rely on farming as their primary livelihood strategy are highly sensitive to soil moisture risk and to the resulting low yields or crop failure. Therefore increasing the availability of water and improving the efficiency with which available water is used can have a transformational impact in dryland rainfed agriculture.

Agricultural water management in dryland environments aims to reduce sensitivity to drought and strengthen coping capacity by bringing moisture to the plant root zone in the right quantity and quality and at the right time to achieve higher levels of productivity, essentially by one or more of three routes: (1) "just-in-time" watering to bridge drought gaps and save the crop; (2) delivering quality water at optimal intervals to the plant root zone through good water service to the field and in-field water management to promote optimal plant growth; and (3) combining water management with soil and crop management to achieve optimal crop water productivity (Ward, Torquebiau, and Xie 2016).

The most secure way to increase the availability of water to growing plants is through irrigation development, discussed in the next section (see box 7.2). Short of irrigation development, however, many tried and tested technologies are available to improve water availability and management for rainfed farming in the drylands (table 7.1). Investment programs in areas where full irrigation is not an option should focus on improved agricultural water management as part of a total livelihood package.

Technologies to improve crop productivity in dryland environments. A technology assessment carried out for this book identified five technologies with demonstrated capacity to improve crop productivity in dryland environments: (1) drought-tolerant improved varieties, (2) heat-tolerant improved varieties, (3) fertilizer, (4) water harvesting, and (5) farmer-managed natural regeneration (FMNR) of indigenous trees. The ability of these five technologies to reduce vulnerability and increase resilience of agriculture-dependent

Table 7.1 Water management strategies for rainfed agriculture

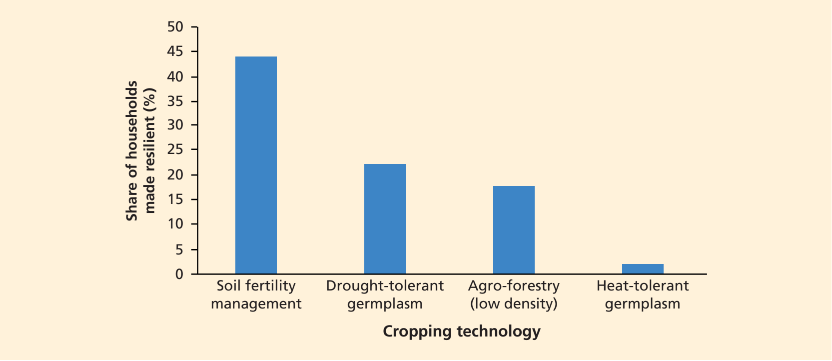
Aim	Strategy	Purpose	Techniques and structural measures
Improve water use efficiency by increasing water available to the plant roots	Soil and water conservation	Concentrate rainfall around crop roots	Bunds, ridges, broad-beds and furrows, micro basins, runoff strips Planting pits
		Maximize rainwater infiltration	Terracing, contour cultivation, conservation agriculture, dead furrows, staggered trenches
	Evaporation management	Reduce non-productive evaporation	Dry planting, mulching, conservation agriculture, inter-cropping, windbreaks, agroforestry, early plant vigor, vegetative bunds
	Water harvesting	Mitigate dry spells with supplementary irrigation, protect springs, recharge groundwater, enable off-season irrigation, and 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 evapotranspiration 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, and organic matter management

households was assessed through a multi-step modeling exercise using the "Africa RiskView" (ARV) model developed by the African Risk Capacity (a specialized agency of the African Union) and the Decision Support System for Agrotechnology Transfer (DSSAT) crop simulation model. The ARV model uses drought vulnerability profiles of the population against which drought impacts are calculated to estimate drought-affected populations under different drought scenarios. The DSSAT model allows estimation of the impacts on yields of indicator crops—in this case millet, sorghum, and maize—of the five technologies under different drought scenarios.

By combining the results of the two models and including screening criteria to restrict adoption of each technology to zones in which adoption would likely be profitable for the farmer, it was possible to estimate the number of households living in drylands in 2030 that would be made resilient by adopting one of the technologies. (A more detailed description of the modeling approach appears in the Appendix.) Because simultaneous adoption of two or more technologies results in interactive effects that are difficult to capture in the DSSAT model, the impacts of the best-bet technologies were modeled separately, and only the most effective technology was assumed to be adopted in each location. Thus the results of the modeling exercise are conservative, because they do not allow for simultaneous adoption of multiple technologies, which is likely to occur in many situations.

The results of the simulation exercise are summarized in figure 7.3. Overall, improving soil fertility through application of fertilizer was found to have the greatest potential for increasing resilience in the drylands. After soil fertility management, the technologies with the next greatest potential for increasing resilience were found to be drought-tolerant germplasm and FMNR of indigenous tree species. The effectiveness of the latter technology increases with tree

Figure 7.3 Contribution of improved cropping technologies to reducing vulnerability (%)



Source: Calculation based on the approach discussed in the Appendix.

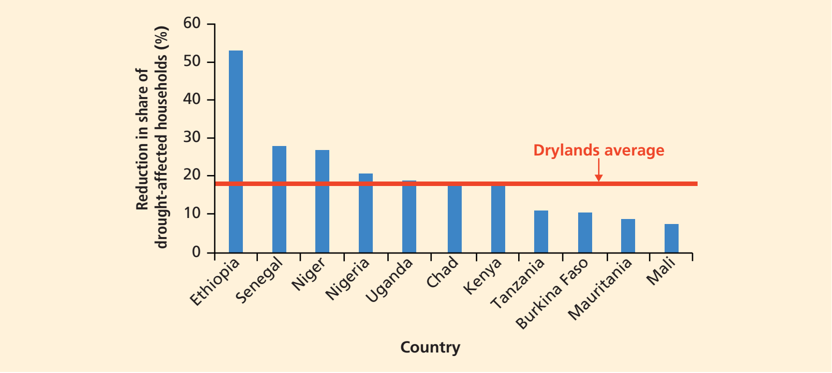
density: establishing and maintaining 10 trees per hectare (ha) on average was found to be significantly more beneficial than establishing and maintaining 5 trees per hectare on average. Heat-tolerant germplasm in and of itself was found to have limited potential. Water harvesting practices were found to have limited potential, due to the relatively high cost compared to the limited expected returns from higher yields.

In summary, adoption of improved cropping technologies could make an important contribution to reducing vulnerability and increasing resilience in the drylands, particularly in countries in which a large proportion of vulnerable households depend on agriculture as a major livelihood source. Figure 7.4 shows the reduction in 2030 in the share of drought-affected households relative to the business as usual (BAU) scenario that would occur if the most effective technology were adopted in every location in which adoption would be profitable. Across the drylands as a whole, just under 20 percent of all households could be made resilient by adopting one or more of the improved cropping technologies. In some countries the share would be much higher. For example, in Ethiopia one-half of the drought-affected households could be made resilient in the face of drought by adopting improved cropping technology. In Senegal and Niger more than one-quarter of the drought-affected households could be made resilient.

Irrigation development

The most reliable way to reduce the sensitivity of cropping systems in the drylands to drought shocks and to ensure adequate water supplies at critical periods during the cropping season is through irrigation. Despite their prevailing aridity, many dryland areas have considerable water resources that can be used

Figure 7.4 Reduction in the share of drought-affected households from adoption of improved cropping technologies relative to BAU scenario, 2030 (%)



Source: Calculation based on the approach discussed in the Appendix.

for irrigation, both surface water and groundwater. Yet much of this potential remains unexploited: dryland countries have developed less than one-third of their technical irrigation potential, and more than one-fifth of the area developed for irrigation is currently not in use (Xie et al. 2015).

Small-scale irrigation

Because of its relative affordability and manageability, small-scale irrigation arguably offers the most important opportunities to improve agricultural water management in drylands. Modeling work carried out for this book suggests that using conservative assumptions about costs and returns to investment capital allows considerable scope for further development of small-scale irrigation in dryland regions of Africa—up to 3 million hectares or even more (Xie et al. 2015).

Individual smallholder irrigation using low-cost pumps is spreading fast in many dryland regions, drawing water from both groundwater and surface sources. Because of the recurrent cash outlays needed to pay for fuel, operation and maintenance, and production inputs such as seed and fertilizer, small-scale irrigation works best when cash crops are being produced and when farmers have ready access to nearby markets where they can sell their production (Ward, Torquebiau, and Xie 2016).

In addition to individual smallholder irrigation, community-based small-scale irrigation offers considerable scope for expansion in drylands. Small-scale community-based irrigation has expanded in recent decades in response to new market opportunities, often with support from development programs. Because it is essentially farmer-managed, community-based small-scale irrigation tends to be well adapted to local biophysical conditions and socioeconomic circumstances (Ward, Torquebiau, and Xie 2016).

Large-scale irrigation

Large-scale irrigation offers additional opportunities for increasing and stabilizing agricultural production in dryland areas. It is difficult to predict to what extent these opportunities will be exploited, however. Because the benefits generated by agriculture alone rarely justify the cost of constructing large dams, future growth in large-scale irrigation will likely depend on decisions to invest in dams whose primary function is to generate hydro-power.

Some opportunities are more accessible than others. For example, there is scope to double production in the drylands of existing large-scale irrigation schemes that currently are underutilized. Technical and institutional modernization on the 5 million hectares currently being irrigated in the drylands could greatly increase yields—even double them in some cases—at an average cost about US$2,700 per hectare, less than half the cost of developing new irrigation. In addition, there is scope for bringing back into production some of the more than one million hectares in the drylands that are equipped for irrigation but not currently being irrigated.

With respect to developing new large-scale irrigation in the drylands, much will depend on future investments in the energy sector. It is beyond question that the technical potential to expand large-scale irrigation is significant, if technical potential is defined in terms of the availability of water and arable land. Taking into account the 120 large dams currently in existence or included in national development plans in dryland countries, and assuming conservatively that 30 percent of the water stored in these dams will be available for irrigation, up to 1.5 million hectares could be developed for large-scale irrigation. Approximately two-thirds of these dams are already operational, meaning only conveyance and distribution systems and pumping equipment are needed to bring water to the fields.

Irrigation development potential in drylands through 2030

What might be the potential impact by 2030 on productivity and production if the potential for small-scale and large-scale irrigation in the drylands was fully developed? This question was explored using a modeling approach described in Xie et al. (2015). As a baseline, it was estimated that in 2000 approximately 6.43 million hectares in all of Sub-Saharan Africa were equipped for irrigation. Of this area, approximately 4.56 million hectares (71 percent) were located in dryland regions. Table 7.2 shows the additional area that could potentially be developed for large-scale and small-scale irrigation by 2030, assuming moderate capital investment costs and two minimum acceptable internal rates of return (IRR). Restricting the analysis to the drylands as they are defined in this book (Aridity Zones 3–6), depending on the assumptions, by 2030 as little as 3.9

Table 7.2 Irrigation development potential by 2030, by aridity zone (hectares)

	Total cropland	Large-scale irrigation		Small-scale irrigation	
		5% IRR	12% IRR	5% IRR	12% IRR
Hyper-arid (Zone 1)	1,248,862	60,170	47,624	0	389
Arid (Zone 2)	567,069	0	0	2,910	5,732
Dry Semi-arid (Zone 3)	16,308,307	91,926	96,428	307,768	142,116
Wet Semi-arid (Zone 4)	25,127,335	141,132	95,102	1,238,674	897,492
Dry Subhumid (Zone 5)	29,546,353	240,395	182,831	1,716,223	1,242,597
Wet Subhumid (Zone 6)	35,610,403	450,073	373,914	1,891,591	1,620,670
Humid (Zone 7)	76,139,002	713,412	499,563	3,121,388	2,931,384
Grand Total	184,547,331	1,697,108	1,295,462	8,278,554	6,840,381

Source: You, Wood, and Wood-Sichra 2009; Xie et al. 2015.
Note: IRR = internal rate of return.

million hectares or as much as 5.2 million hectares could be developed for small-scale irrigation. For large-scale irrigation development, which will depend on the rehabilitation and construction of dams, the area is much more limited, ranging from a low of 0.75 million hectares to a high of 0.92 million hectares.

In dryland regions of West Africa and East Africa, prospects for irrigation development by 2030 vary considerably by country (table 7.3). It is interesting to note, however, that even if the potential for irrigation were fully exploited, in most cases the irrigated area would comprise only 3–20 percent of total cropland.

The potential for irrigation development in dryland regions of Sub-Saharan Africa is summarized in map 7.1. Two clear messages emerge from the

Table 7.3 Irrigation development potential by 2030, East and West Africa (moderate cost and 5% IRR)

	Cropland in 2000 (ha)	Irrigated area potential (ha)	Irrigated area potential (% of cropland)
Nigeria	24,523,253	1,617,654	7
Ghana	1,759,898	312,275	18
Senegal	2,266,221	255,901	11
Burkina Faso	5,176,476	174,513	3
Mali	4,696,988	141,362	3
Chad	3,539,511	94,080	3
Niger	12,232,511	118,795	1
Benin	2,030,091	135,989	7
Mozambique	2,601,577	76,433	3
Côte d'Ivoire	968,534	74,316	8
Mauritania	284,483	100,340	35
Togo	790,188	61,798	8
Cameroon	1,145,331	56,664	5
Guinea	214,349	22,927	11
Gambia, The	277,146	17,682	6
Kenya	2,629,859	335,705	13
Ethiopia	4,801,840	245,629	5
Somalia	935,603	230,028	25
Eritrea	669,799	27,865	4
Swaziland	95,822	13,488	14
Sudan	10,449,867	11,775	0.1
Djibouti	5,051	3,648	72

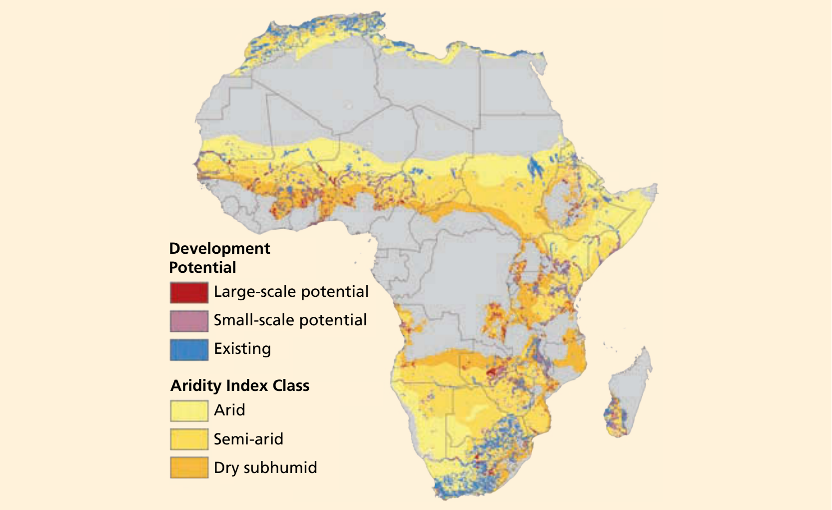
Source: Xie et al. 2015.

modeling work. First, the potential for irrigation development in the drylands is substantial, but the likely impact on crop production pales in comparison to the impact on crop production that could be achieved by fully exploiting the available opportunities to develop rainfed agriculture. Rainfed agriculture is far more important than irrigated agriculture in the drylands and will remain that way for the foreseeable future. Second, within the irrigation sector, although large-scale irrigation is generally the most reliable form of irrigation, compared to small-scale irrigation, large-scale irrigation has a limited area potential and is much smaller in size. The reason is that expansion of large-scale irrigation will depend on investments in dams that will be rehabilitated or constructed for purposes other than agriculture.

To summarize, the modeling work done for this book suggests that there is considerable scope for increasing the irrigated area in the drylands. Development of a further 6.1 million hectares (in addition to the current 4.6 million hectares) is technically feasible and economically justifiable (Xie et al. 2015). Overall, irrigation development could have a large, possibly transformational impact on farming systems and on resilience. Prospects are brightest for small-scale irrigation because of its lower costs, more decentralized management, and likely higher levels of farmer participation.

There is also considerable potential for large-scale irrigation development, concentrated along corridors located downstream from dams that will have been constructed for other (non-agricultural) purposes. Investment costs for

Map 7.1 Potential for development of small- and large-scale irrigation in Sub-Saharan Africa



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large-scale irrigation are roughly three times higher than for small-scale irrigation, but the value of the incremental production and the amount of employment created are three times as great. Large-scale irrigation poses technical, economic, and institutional challenges and risks, however, so investment in large-scale irrigation schemes is likely to proceed slowly, to provide time for models to be worked out that ensure that such schemes can be operated profitably and sustainably. In some dryland countries, improving existing large-scale irrigation schemes may pay higher returns than building new schemes.

Small- and large-scale irrigation schemes both have the potential to contribute to increased resilience, but their contributions will be somewhat different (Ward, Torquebiau, and Xie 2016). Small-scale irrigation in the drylands is used in a wide range of mixed farming systems, helping to raise and stabilize crop yields and thereby allowing large numbers of poor households to grow more home-consumed food and increase their income from cash sales. In contrast, large-scale irrigation is often associated with specialized production systems that feed into distinct and separate value chains, so it strengthens resilience by allowing households to generate cash incomes that are relatively insensitive to shocks. While the number of households that can be accommodated on large-scale schemes is usually limited, such schemes tend also to create new employment opportunities for wage laborers, thereby enhancing resilience for a broader segment of the rural population.

Improving coping capacity

Agricultural households that live in dryland regions, being unable to move out of harm's way when shocks occur and having livelihoods that are sensitive to shocks, suffer frequent income losses. For these households, the ability to survive will depend mainly on their coping capacity, that is, on their ability to draw on their own accumulated resources or resources provided by others to meet their needs during a critical period until their livelihood strategies can be reestablished.

Public policy interventions. Experience suggests that many agricultural households when hit by a shock soon exhaust their limited accumulated resources, leaving them critically dependent on public programs. Public policy thus plays an important role in supporting the recovery process, particularly for non-resilient households. In considering the instruments available to the government, it is useful to distinguish between interventions that can be implemented relatively quickly versus interventions that require time to produce results.

Public policy interventions that can be implemented in the short run to strengthen the coping capacity of agriculture-dependent populations include: (1) introducing crop insurance to provide compensation for production losses, and (2) establishing scalable safety nets to provide alternative sources of income until the farming enterprise can be fully restored. (Crop insurance is discussed in the next section; scalable safety nets are discussed in Chapter 9.)

Crop insurance. In theory, crop insurance addresses the problem of systemic risk from yield variability in dryland agriculture (for a general discussion, see Hazell, Pomareda, and Valdes 1986). In addition to directly protecting farmers from yield losses due to adverse weather and outbreaks of diseases or pests, crop insurance indirectly enhances resiliency in the production environment because farmers with insurance will be more willing to adopt technologies perceived to be profitable without having to worry as much about the vagaries of the weather. Increased profits attributable to the improved technologies can be reinvested to further limit sensitivity to risk and to improve coping mechanisms and strategies.

In practice, crop insurance that is voluntary and oriented to the individual producer is vulnerable to consistent and sizable losses because of moral hazard and adverse selection (Brown, Mobarak, and Zolanska 2014). Moral hazard refers to negative incentives as farmers are rewarded for exerting less effort when yields approach payout trigger points. Adverse selection becomes a problem when the more productive farmers with higher yields do not participate in crop insurance programs. Both moral hazard and adverse selection erode the actuarial basis for cost-effective crop insurance.

Interest in crop insurance has waxed and waned over the years, and a number of pilot programs have been launched to test out different design features. Several advances in design have brightened the prospects for crop insurance, including the use of a homogeneous area approach to compensation (which eliminated the moral hazard problem, because individual farmers could not manipulate yield estimates calculated over large areas) and, instead of targeting individual farmers, using rainfall instead of yields as the criterion for determining payouts (much easier to measure, because rainfall data are more readily available than yield data, especially following the advent of automatic weather stations).

Despite some isolated success stories, demand for crop insurance among smallholder farmers has remained weak, even when rainfall insurance has been partially subsidized and thoroughly explained. With sufficient targeting and structuring of design to highly contextual conditions, the widely acknowledged problem of weak demand may not be insurmountable. But at least one seasoned observer of insurance over the past 40 years believes that rainfall insurance is not a viable option for improved risk management drylands, arguing that poor farmers are often cash/credit-constrained and therefore cannot advance the money before sowing time to buy insurance that pays out only after the harvest (Binswanger-Mkhize 2012). Others are more sanguine. For example, Brown, Mobarak, and Zelanska (2014) concede that credit constraints, limited financial literacy of farmers, and basis risk limit the demand for rainfall insurance, but they are confident that as the chain of evidence becomes longer with research and as several of these obstacles are overcome, pilot applications can be scaled up to make a substantive contribution to risk management in dryland agriculture.

Challenges

Opportunities exist to increase and stabilize agricultural production in drylands, but they will not be easy to exploit. Multiple constraints will have to be overcome to enable the successful adoption of productivity-enhancing improved technologies.

The first and perhaps most obvious challenge is financial. Adoption of improved agricultural technology entails two types of cost: (1) costs incurred by the farmers who adopt the technology, especially the costs of purchased inputs such as improved seed, fertilizer, and crop chemicals; and (2) costs incurred by the public sector in promoting the improved technology (e.g., the cost of paying extension agents to provide advisory services, mount publicity campaigns, and train farmers in the use of new technologies). Depending on the technology, the first type of cost can be small (e.g., in the case of improved seed) or large (e.g., in the case of fertilizer). In the latter case, farmers may lack the resources to pay, in which case adoption is unlikely to occur without subsidies or other forms of assistance. The second type of cost is generally quite modest compared to other types of public interventions, as large numbers of farmers can often be reached through relatively low-cost promotional campaigns. Estimates made for this book suggest that five cropping technologies—drought-tolerant varieties, heat-tolerant varieties, chemical fertilizer, water harvesting, and tree-based systems—could be promoted throughout the dryland countries in East and West Africa for US$126–426 million, depending on how effectively promotional efforts are targeted (for details, see Walker et al. 2016). It is important to note, however, that just because an improved technology has been promoted does not mean it will be adopted, as farmers reached by the extension campaign will have to weigh numerous factors before deciding whether or not a promoted technology is right for them.

Aside from cost, several other types of challenges will have to be overcome to ensure successful uptake of improved agricultural production technologies.

Harsh agro-climatic conditions. Improved crop production technologies can deliver significant benefits during years of normal weather, but even the best technologies are likely to fail in the face of prolonged drought or extreme heat (see box 7.1). In dryland areas where extreme weather events are common, investing in improved technologies carries risk, which some farmers—particularly the poorest farmers—may be unwilling to take on.

Infrastructure constraints. Farmers will be willing to invest in improved technologies only when they are confident that they will be able to produce a decent crop and sell surplus production for remunerative prices. In the drylands

BOX 7.1

How will climate change affect dryland agriculture?

The effects on dryland agriculture of droughts and other extreme weather events are readily apparent. In contrast, the effects of climate change resulting from global warming are much less visible, since they occur gradually and manifest themselves differentially through space and time.

Lobell and Field (2007) carried out a comprehensive review of crop modeling exercises and climatic analyses on the impacts of global warming on crop productivity. Maize was identified as the crop most requiring attention in Sub-Saharan Africa, due to its economic and nutritional importance. Because maize germplasm is sensitive to temperature changes, Lobell and Field concluded that the relevant question is not whether climate change will have deleterious impacts on maize yields, but rather how much productivity will be lost from rising temperatures.

Fischer, Byerlee, and Edmeades (2014) recently addressed this issue in a survey of the burgeoning literature on the agricultural consequences of global warming. Among their conclusions:

- CO_2 is expected to increase by 26 percent to 480 parts per million (ppm) by 2050; with rising CO_2 levels, average global temperatures are forecast to increase by 2°C by 2050.
- Chronic warming, especially hot spells above 30°C, depresses yields by speeding up crop development and by reducing grain numbers and size.
- Predicted changes in precipitation attributed to global warming are not that sizable and are too uncertain to warrant rigorous impact assessment at this time.
- Estimates from regression studies and simulation modeling suggest that average yields of maize, rice, and wheat will fall by 5 percent for each 1°C increase in temperature. In the absence of adaptation, global warming of 2°C by 2050 would lead to a 10 percent decrease in cereal yields.
- These pure temperature effects will be offset by gains from increasing CO_2 concentration especially in crops that use the C3 carbon fixation metabolic pathway (wheat, rice, and soybean), where the utilization of CO_2 in photosynthesis is not as efficient as in coarse cereals. Hence, the total yield effect is negligible in rice and wheat and is equivalent to an 8 percent loss of productivity in maize.

Fischer, Byerlee, and Edmeades (2014) express optimism that plant breeding and crop agronomy can be deployed to dampen declines in yield from global warming by 2050. Many agricultural research centers have committed

(continued next page)

Box 7.1 *(continued)*

resources to screening materials for and finding sources of tolerance to heat stress. In the past, sustained breeding efforts for resistance or tolerance to heat stress have not paid dividends for maize at CIMMYT (International Maize and Wheat Improvement Center) and for potato at CIP (International Potato Center). However, several physiological aspects remain to be explored, which could provide the basis for effective heat tolerance in these and other crops. Pearl millet, a hybrid prized for its heat tolerance, is one of the leading cultivars in India in the State of Rajasthan, an environment very similar to the Southern Sahelian Zone (Asare-Marfo et al. 2013).

Fischer, Byerlee and Edmeades (2014) also highlight tactical crop management as a source of innovations designed to combat the adverse effects of climate change. The opportunities are largely location-specific and rely on knowledge about timeliness in the use of inputs. Many of the advances in this area will likely be made in the course of "normal" crop improvement, as the additionality of global warming to the other problems being addressed by agronomic researchers is difficult to envisage in highly specific terms.

producing a decent crop and selling surplus production at remunerative prices are often threatened by underdeveloped irrigation infrastructure, inadequate and unreliable power supplies, and weak transport systems.

Institutional weaknesses. The development of improved agricultural technologies and the transfer of these technologies to farmers are joint-impact, high-exclusion-cost activities, which is why they are usually considered public goods and provided through public institutions. Yet in most dryland countries, the public institutions that provide research and extension services are weak and ineffective. Provision of production inputs (e.g., seed, fertilizer, crop chemicals) and financial services are activities that lend themselves more readily to private provision, but the riskiness and low profitability of dryland agriculture has discouraged investment by private firms, so distribution networks for inputs remain underdeveloped, and financial institutions lending to the agriculture sector are few and far between.

Economic constraints and trade-offs. The low productivity of dryland agriculture is compounded by the lack of economic incentives to invest in the sector. With production dispersed across vast areas, value chains poorly articulated and inefficient, and agricultural policies fragmented and often acting at cross purposes, dryland agriculture faces a number of daunting economic constraints and trade-offs (box 7.2).

BOX 7.2

Rainfed or irrigated agriculture: A fundamental choice

In seeking to improve the productivity, stability, and sustainability of dryland agriculture, policy makers face a fundamental question: Should attention be focused on improving rainfed production systems, expanding irrigated production systems, or both?

Currently, more than 90 percent of the staples produced and consumed in Sub-Saharan Africa is produced in rainfed systems, and only 5 percent is produced under irrigation. Using realistic assumptions about future area expansion and yield growth, the UN Food and Agriculture Organization (FAO) projects that rainfed agriculture can continue to meet 90 percent of incremental demand for decades to come. Noting that investment in irrigation is economically justifiable only when irrigation facilities can be used to produce high-value cash crops, FAO projects that as soon as 2050, irrigated production is unlikely to contribute more than 10 percent of staples production.

The FAO vision, which is shared by many analysts, suggests that African policy makers and development partners should follow a strategy of promoting production of cereals and grain legumes in drylands, and rice and horticultural crops in irrigated zones. Investments should be tailored accordingly. In zones deemed unfavorable for irrigation, efforts should focus on promoting adoption of improved technologies that can improve productivity and stabilize production of rainfed agriculture, with an emphasis on reducing risk and increasing resilience among vulnerable households. In zones deemed favorable for irrigation, efforts should focus on developing irrigation and promoting production of high-value crops, with emphases on increasing revenues, improving food security, and reducing poverty.

Deciding an appropriate balance between these two complementary objectives will not be easy. From a public policy perspective, given a fixed amount of resources, there is a clear trade-off between investing in small improvements for the large number of households in the drylands that engage in rainfed production, and investing in large improvements for the relatively small number of households that could take advantage of irrigation technology. Investments that target rainfed production systems will not promote highly visible results, but because they can benefit so many households, they have the potential to improve the livelihoods and increase the resilience of the large majority of the population. The policy choice thus pits small reductions in poverty for the many against large reductions in poverty for the few. And given the vast discrepancy in the numbers of households falling into each category, as well as the high cost of irrigation development, targeting dryland agriculture is likely to be the better choice.

Key messages

More than 200 million people living in dryland regions of Sub-Saharan Africa make their living from agriculture. Most of these people are exposed to weather shocks, especially drought, that can decimate their incomes, destroy their assets, and plunge them into a poverty trap from which it is difficult to emerge. Their lack of resilience in the face of these shocks can be attributed in large part to the poor performance of agriculture on which their livelihood depends.

Opportunities exist to improve the fortunes of these households. Improved farming technologies are available that can increase and stabilize the production of millet, sorghum, maize, and other leading staples. Yet most of these technologies have not been adopted on a large scale, for reasons that include lack of farmer knowledge, non-availability of inputs, unfavorable price incentives, and high levels of production risk.

Irrigation is technically and economically feasible in some areas and offers additional opportunities to increase and stabilize food production, especially in the case of small-scale irrigation systems, which tend to be more affordable and easier to manage. Large-scale, dam-based irrigation systems make sense in certain situations, but their potential is more difficult to exploit because of high investment costs and daunting institutional and governance challenges. While irrigation represents an excellent option in some areas, it is important to keep in mind that prospects for irrigation development are limited in the drylands, so for the foreseeable future, rainfed agriculture will continue to be far more important.

Future production growth in the drylands is expected to come mainly from raising yields and increasing the number of crop rotations on land that is already being cultivated (intensification), rather than from bringing new land into cultivation (extensification). Controlling for rainfall, average yields in rainfed cropping systems in Sub-Saharan Africa are still much lower than yields in rainfed cropping systems in other regions, suggesting that there is considerable scope to intensify production in these systems. Furthermore, unlike in other regions, production of low-value cereals under irrigation is not generally economic in Sub-Saharan Africa unless the cereals can be grown in rotation with one or more high-value cash crops. The long-run strategy for dryland agriculture therefore must be to promote production of staples in rainfed systems and production of high-value cereals (e.g., rice), horticultural cops, and industrial crops in irrigated systems.

Considerable potential exists in the drylands to improve the productivity of rainfed agriculture and to expand irrigation. Exploiting the available opportunities will require policy reforms and institutional changes backed by supporting investment. Attention must focus on:

- Strengthening innovation systems at the national and regional level, for example, by supporting the emergence of multi-actor networks that can leverage the strengths of public institutions, private firms, and civil society organizations.
- Promoting improvements in rainfed agriculture to increase and stabilize production of food staples and strengthen resilience of vulnerable households.
- Promoting investments in irrigated agriculture, both small-scale and large scale, to increase production of high-value cash crops and raise incomes and reduce poverty of commercially oriented farmers.

Improving the productivity and stability of agriculture in the drylands has the potential to make a significant contribution to reducing vulnerability and increasing resilience. At the same time, it is important to keep in mind that in an environment characterized by limited agro-climatic potential and subject to repeated shocks, farming on small land holdings may not generate sufficient income to bring people out of poverty.

References

Asare-Marfo, D., E. Birol, B. Karandikar, D. Roy, and S. Singh. 2013. "Varietal Adoption of Pearl Millet (Bajra) in Maharashtra and Rajasthan, India: A Summary Paper." HarvestPlus, International Food Policy Research Institute, Washington, DC.

Binswanger-Mkhize, H.P. 2012. "Is There Too Much Hype about Index-Based Agricultural Insurance?" *Journal of Development Studies* 48: 187–200.

Brown, J.K., M.A. Mobarak, and T.V. Zelanska. 2014. "Barriers to Adoption of Products and Technologies That Aid Risk Management in Developing Counties." Background paper to the *World Bank 2014 Development Report*. World Bank, Washington, DC.

Fischer, R.A., D. Byerlee, and G.O. Edmeades. 2014. "Crop Yields and Global Food Security: Will Yield Increase Continue to Feed the World?" ACIAR Monograph No. 158. Australian Centre for International Agricultural Research (ACIAR): Canberra. http://aciar.gov.au/publication/mn158.

Fuglie, K.O., and N.E. Rada. 2013. "Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa." ERR-145, U.S. Department of Agriculture, Economic Research Service, Washington, DC.

Hazell, P., C. Pomareda, and A. Valdes, eds. 1986. *Crop Insurance for Agricultural Development: Issues and Experience*. Baltimore, MD: Johns Hopkins University Press.

Lobell, D.B., and C.B. Field. 2007. "Global Scale Climate-Crop Yield Relationships and the Impacts of Recent Warming." *Environmental Research Letters* 2 (1).

Walker, T., with T. Hash, F. Rattunde, and E. Weltzien. 2016. *Improved Crop Productivity for Africa's Drylands.* World Bank Studies. Washington, DC: World Bank.

Walker, T., and J. Alwang, eds. 2015. *Improved Varieties in the Food Crops of Sub-Saharan Africa: Assessing Progress in the Generation, Adoption and Impact of New Technologies.* Wallingford, UK: CABI Publishing.

Walker, T., A. Alene, J. Ndjeunga, R. Labarta, Y. Yigezu, A. Diagne, R. Andrade, R. Muthoni, H. De Groote, K. Mausch, C. Yirga, F. Simtowe, E. Katungi, W. Jogo, M. Jaleta, and S. Pandey. 2014. "Measuring the Effectiveness of Crop Improvement Research in Sub-Saharan Africa from the Perspectives of Varietal Output, Adoption, and Change: 20 Crops, 30 Countries, and 1,150 Cultivars in Farmers' Fields." Standing Panel on Impact Assessment (SPIA), CGIAR (Consultative Group for International Agricultural Research Program on Policies, Institutions, and Markets) Science Council, Rome.

Ward, C., with R. Torquebiau and H. Xie. 2016. *Improved Agricultural Water Management for Africa's Drylands.* World Bank Studies. Washington, DC: World Bank.

You, L., S. Wood, and U. Wood-Sichra. 2009. "Generating Plausible Crop Distribution Maps for Sub-Saharan Africa Using a Spatially Disaggregated Data Fusion and Optimization Approach." *Agricultural System* 99(2–3): 126–40.

Xie, H., W. Anderson, N. Perez, C. Ringler, L. You, and N. Cenacchi. 2015. "Agricultural Water Management for the African Drylands South of the Sahara." Background report for the Africa Drylands Study. International Food Policy Research Institute, Washington, DC.