Preparing Smallholder Farm Families to Adapt to Climate Change

POCKET GUIDE 3
MANAGING WATER RESOURCES

Gaye Burpee
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This publication was made possible by the generous support of the American people through the United States Agency for International Development (USAID) Office of Acquisition and Assistance under the terms of Leader with Associates Cooperative Agreement No. AID-OAA-L- 10-00003 with the University of Illinois at Urbana Champaign for the Modernizing Extension and Advisory Services (MEAS) Project.

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ISBN-10: 1-614921-39-3
ISBN-13: 978-1-61492-139-4

Download this publication and related material at http://www.crsprogramquality.org/publications/2015/7/7/preparing-smallholder-farm-families-to-adapt-to-climate-chan.html

Suggested citation: Burpee, G., B.S. Janet & A. Schmidt. 2015. *Preparing smallholder farm families to adapt to climate change: Pocket Guide 3; Managing water resources.* Catholic Relief Services: Baltimore, MD, USA

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CONTENTS

The concepts and practical suggestions in this guide come from many sources and are based on the field experiences and research of farmers, agricultural extension agents and scientists. To keep the body of the guide uncomplicated, these information sources and citations are listed together in the *References* section at the end of this guide. Information and links to helpful guides and manuals are also included throughout the guide in sections entitled *Resources*.

INTRODUCTION

Purpose and content

This set of pocket guides, *Preparing Smallholder Farm Families to Adapt to Climate Change*, is written for you, the field agent working in agricultural extension. The concepts, information and practices in these guides are meant to support your work with farm families and to help reduce their risks from weather changes. Many of the families who farm small, unirrigated plots in the tropics already struggle against poverty, degraded land, and rainfall that varies from year to year. This type of farming, sometimes called rainfed agriculture, is especially vulnerable to climate change. The suggestions in these guides can be used to help farm families make changes that will help their farms withstand bad weather by adapting to it.

These guides include practical methods that meet the objectives that the United Nations Food and Agriculture Organization outlined for climate-smart agriculture:

- Ways to increase agricultural productivity sustainably – practices that produce while protecting the environment.
- Farm practices for individual farm families and groups of families to improve their resilience to climate change.
- Practices that can reduce some of the causes of climate change – decrease greenhouse gases to avoid contributing to further changes in the climate.
- Information to help rural families take advantage of opportunities that climate change may present.

Preparing Smallholder Farm Families to Adapt to Climate Change is a set of complementary guides including:

- The role of agricultural extension and advisory services in adaptation
- Managing crops
- Managing water resources
- Managing soils

The adaptation pocket guides follow a general four-step approach developed by Catholic Relief Services for designing and implementing responses to climate change to help reduce the vulnerability of small-scale farming systems. These steps are:

- **Understanding** concepts: the effects of climate change on each guide's focus area.
- **Assessing** climate change risks for each theme and appraising agricultural vulnerability.
- **Recommending** practices for adaptation.
- **Mobilizing** community planning and action for adaptation.

See Ashby and Pachico (2012) for more information on this approach in the *Resources.*

The language of climate change

These guides will use climate change terms that you will want to know. They can help identify how farm livelihoods are vulnerable to climate change and how you can support farmers to be less vulnerable by improving their ability to adapt to climate change.

Climate change terms

Exposure to climate change is related in large part to geographic location. Inland communities in semi-arid regions may be exposed to drought, and coastal communities will have higher exposure to cyclones or hurricanes.

Sensitivity is the degree to which a system or community is affected by climate-related stresses. A cool-weather crop like coffee that grows at lower elevations will be more sensitive to increasing temperature than coffee grown higher up a mountain, and a shallow-rooted vegetable crop will be more sensitive to heavy rainfall and wind than a deep-rooted tree crop.

Adaptive capacity is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities or to cope with the consequences.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change. Vulnerability depends on the type, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and adaptive capacity.

Source: IPCC (Inter-governmental Panel on Climate Change). 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability; Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* (Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds.). Cambridge University Press: Cambridge, UK.

Three elements contribute to the vulnerability of farm livelihoods:

Livelihood vulnerability = (Exposure x Sensitivity) – Adaptive capacity

In other words, the **vulnerability** of a family's farming system is the result of its **exposure** to climate change multiplied by its **sensitivity** to climate change minus its **capacity to adapt** to climate change.

If a family grows common beans (*Phaseolus vulgaris*) in an area that is starting to have floods every three to four years for the first time in memory, its farm's **exposure** to climate change is increasing, and its yields in flood years are half of what they were in the past. Beans do not grow well in wet conditions, so they are **sensitive** to flooding. When you recommend that the family build ridges on the bean plot and raise the beans above the level at which the field usually floods, the family can reduce its **exposure** to flooding. Their **capacity to adapt** to more frequent floods also improves.

If you live where people eat taro root (*Colocasia esculenta*), you might also work with the family to plant taro instead of beans. Taro does well in wet soils, and with this change, the **sensitivity** of the crops grown on this family's farm is reduced. Finally, if this family wants to raise chickens and they can find good technical advice, this helps to increase the family's **adaptive capacity** by introducing the skills needed for another livelihood activity that is affected less by heavy rains.

The practices shared in these guides will provide suggestions on how to improve the **adaptive capacity** of the farm family and the farm community. The practices can help rainfed farmers reduce the negative effects of climate change and recover from them. It is important to understand, however, that they may not be able to overcome *all* of the vulnerabilities that are caused or made worse by climate change. Farm families must also learn to live with the changes that climate change brings.

From coffee to chocolate

For a decade, a farmer has worked to increase shade on his small coffee plot, but the shade is no longer enough to reduce the impact of rising temperatures on this cool-weather plant, which prefers temperatures of 16° to 24°C. Now the farmer is gradually replacing his aging coffee plants with cacao, which prefers warmer weather (18° to 32°C). The farmer could not overcome his farm's **vulnerability** to higher temperatures because of its **exposure**, caused by its position at a lower elevation, and coffee's **sensitivity** to higher temperatures. By making a transition to a different cash crop, he is **adapting** his farming system and learning to live with the effects of climate change.

Exposure to the risk of climate change refers to changes in rainfall and temperature. For example, more severe storms can waterlog crops or increase soil erosion; drought and heat can reduce crop yields or affect animal health. Changes may occur in the type and number of diseases, pests or weeds that can reduce crop yields or the quality of stored grains.

Sensitivity to the effects of climate change is the degree to which a farming system is affected. Take, for example, a 60-year-old farmer who plants maize. She has seen a drying trend in the weather over the past 25 years. Her yields have fallen even though she started planting a variety that is less sensitive to dry weather. Her neighbor invested in a pond and irrigation equipment and he can still grow maize. But she can grow only sorghum now, which is less sensitive to dry spells than maize. Unlike her neighbor, she faces **economic water scarcity** as well as agricultural water scarcity because she lacks the funds for the water storage and basic irrigation equipment that her neighbor has – so her production is lower, her **adaptive capacity** is less, and her **vulnerability** is greater. Smallholder farm families producing under rainfed conditions who are experiencing drying trends may be unable to resolve challenges of water scarcity through technical improvements alone.

Adaptive capacity depends on many factors other than technical practices, which are the focus of this guide. Adaptation also depends on whether the farm family has enough people to do the work (their labor) that is needed to adapt. Adaptation also depends on whether:

- The farm family has funds and other resources (their assets) to invest in changes. Assets include social networks, education and knowledge.
- Their community receives government services.
- Their community is willing to work together to make changes in their watershed (working together at different scales).
- They live in a country that has an agricultural policy and strategy to increase national climate change resilience.
- Agricultural research and extension services support adaptation, especially for rainfed farming (national systems and structures).
- Social and economic systems support fair access to water and land, education, information, financial services, extension services and infrastructure.

Inequality is another consideration in adaptive capacity. Inequality has different faces in different places: different social classes or castes, different ethnic groups, even different livelihoods such as pastoralists vs crop farmers. For example, although 43 percent of farm workers in developing countries are women, their average agricultural yields are 25 percent lower than men's. Their yields are lower not because they are less effective farmers but because of their restricted access to land, financial resources and productive inputs (appropriate tools, improved seeds or livestock). They also have less access to critical services of agricultural extension and credit. Women's time is also split between farming and household tasks such as water collection, fuel gathering, food preparation and childcare. Thus, women farmers may often have less adaptive capacity because of gender inequality.

Adaptive capacity with new information and old practices

Scientists can predict how climate change will affect a certain area and certain crops or farming systems. This climate modeling research is beginning to predict changes in temperature and precipitation within 15 to 25 years and their effects on some crops. When this information is available, it will help extension field agents make decisions about what to recommend to reduce exposure or sensitivity to climate change and how to increase adaptive capacity.

With or without information on the effects of climate change specifically for your local area, you as an extension agent will need to work with farm families struggling against hunger to reduce their sensitivity and exposure to the risks of rising temperatures and variable rainfall. Being able to adapt successfully depends a lot on knowledge and information. One of your tasks is to look for new information, training and experiences all the time and everywhere. That way you can continually learn from farmers, test new methods with them to discover what works locally and also train them in practices and methods that will result in resilient farms in their community. The changes that come as a result of climate change will continue with time, so it will be important to also continue learning.

One of your tasks is to look for new information, training and experiences all the time and everywhere.

Many of the practices that extension field agents already promote are contributing to climate change adaptation. By updating your learning, you will understand how these practices reduce vulnerability and where to focus efforts for the greatest benefit. Should you reduce exposure first or work to increase adaptive capacity? Or should you reduce sensitivity? What are the costs and benefits of starting with one or the other or a combination?

When field agents encourage farmers at lower, warmer elevations to transition from annual cropping to a mixed agroforestry system, farmers increase the number of trees that reduce gases that contribute to global warming. At the same time, the trees add leaf litter to the soil as mulch, soil evaporation is slowed, the soil holds more water, and nearby crops withstand dry spells longer. These all increase the adaptive capacity of the farming system. By returning to basic agronomy in extension services and learning to combine promising new practices with beneficial practices of the past, there is great potential for adaptation on millions of small-scale farms in the tropics.

Why do you need a guide to climate change adaptation for water?

It will be very difficult for farmers to adapt to climate change without improving water management, especially in rainfed systems. Crop, livestock, fish and forest production all depend on water. About 80 percent of the world's farmland is rainfed, and much of it is marginal land with low yields in water-scarce areas. Also, most of the food produced in the world is produced on small farms. These farmers are getting yields that are much lower than the yields they could get with improved practices and technologies. This is especially true in sub-Saharan Africa, Central America and Central Asia, where current yields are at 76 percent, 65 percent and 64 percent below potential, respectively. To improve yields, farmers will need to adapt through improvements in water management, rainwater harvesting, nutrient management, crop management and agroforestry.

Adaptation to climate change is urgent.

Climate change adaptation: the pivotal role of water. UN Water Policy Brief, 2010

Most of the impacts of climate change on agriculture and rural livelihoods are expected to result from changes in the water cycle.

Climate-Smart Agriculture Sourcebook, Module 3: Water Management. United Nations Food and Agriculture Organization, 2013

Farmers past and present are used to dealing with changes in weather and the years when rain comes earlier or in greater amounts than other years. But climate change brings new changes, and farming conditions will not return to the way they were in the past. To respond to these changes, many farmers will need to make big adjustments to their farming systems within the next 10 to 20 years. Your job as an extension agent is more important today than ever before.

Pocket Guide 3: Managing Water Resources provides a few basic concepts, guiding principles and practices to evaluate, test and use with farm families and rural communities to manage water resources and respond to climate change. Practices include improved rainwater harvesting, rainwater storage and more efficient use of water. They should be combined with crop management (*Pocket Guide 2*) to improve plants' ability to absorb water, and with improved soil management (*Pocket Guide 4*) to increase the soil's ability to retain water.

Who can use this guide?

This guide is written for government and nongovernmental agronomists, extension field agents and their managers working in rural development programs with farm families and communities. There may also be information that helps policymakers in setting government priorities. The authors understand that readers of this guide will have significant differences in training and field experience. Our hope is that all readers will find something of value to support their extension efforts in local adaptation to climate change.

How can this guide be used?

Field agents can use the guide with individual farmers or with communities in the process of analysis, design and planning of ways to adapt their farming systems to changing temperatures and the timing and amount of rainfall. The guide may also be used in the development of training workshops or as a guide in project planning. The guides provide a sample of practices for adaptation to climate change within a framework of basic concepts and principles. Also included are some participatory approaches, assessment tools and other activities that may help field staff in planning and prioritizing activities before taking action.

Climate change is location-specific.

The challenge for adaptation is that temperature and precipitation will continue to change and will require a continuous process of introducing, testing and modifying practices to fit local conditions. The optimal moment to make changes may be different for each farmer. For that reason much of the information provided here covers general approaches to water management, with some examples from different conditions, rather than a set of specific practices to be followed everywhere.

What is the content of the guide?

This guide has four parts:

- Understanding concepts: the effects of climate change on water for agriculture
- Assessing climate change risks for water and appraising agricultural vulnerability
- Recommending practices for water adaptation through improved water management
- Mobilizing community planning and action to adapt to climate change

While this guide (*Pocket Guide 3*) presents options for improving **water** management, other guides focus on other aspects of agriculture such as improved **crop** management (*Pocket Guide 2*) and **soil** management (*Pocket Guide 4*). *Pocket Guide 1* shares the general impacts of climate change on agriculture and proposes a role for extension services in supporting adaptation.

You will want to use the guides together at various stages in the adaptation process. In the early stages, when you are assessing livelihood vulnerabilities and selecting priorities for adaptation practices, water issues cannot be thought about alone. They must be considered along with soils or watershed management, for example. You will need to do an assessment first so you can set priorities and deal first with the most serious risk exposures and sensitivities due to climate change.

In addition, when setting priorities for improved water management, you will need to compare them with other priorities and consider any trade-offs. How do the various options for adapting to climate change affect other areas of farm management? For example, if you use crop residue to protect the surface of the soil from evaporation, the residue cannot be used as livestock feed, for cooking fuel or in compost. When you set priorities for action and choose options for implementation, it is important to think broadly about all the effects.

This guide includes familiar practices that are beneficial even when climate change impacts are uncertain. In cases where modeling studies predict specific local impacts, however, you will find it easier to select the practices with the greatest potential to reduce local vulnerabilities. These will be the most effective interventions, as long as you also consider the resources and preferences of farmers and the local community.

Some practices appear in more than one of the pocket guides. As an example, cover crops are mentioned in *Pocket Guide 2: Managing Crops*, as a way to control weeds and pests. They also appear in *Pocket Guide 4: Managing Soils*, as a way to improve soil fertility, soil moisture, soil structure and overall soil health. In addition, some practices will be fully effective only if they are combined with others. Even when the most limiting factor to good yields is scarce water, on degraded soils, supplementary irrigation can only result in modest yield increases. To get larger yield increases, soil fertility also needs to be improved.

Plants, soil and water interact closely with one another, and the adaptation guides are meant to be used together. Use them as a group and you will multiply their benefits and increase resilience to change, whatever the source.

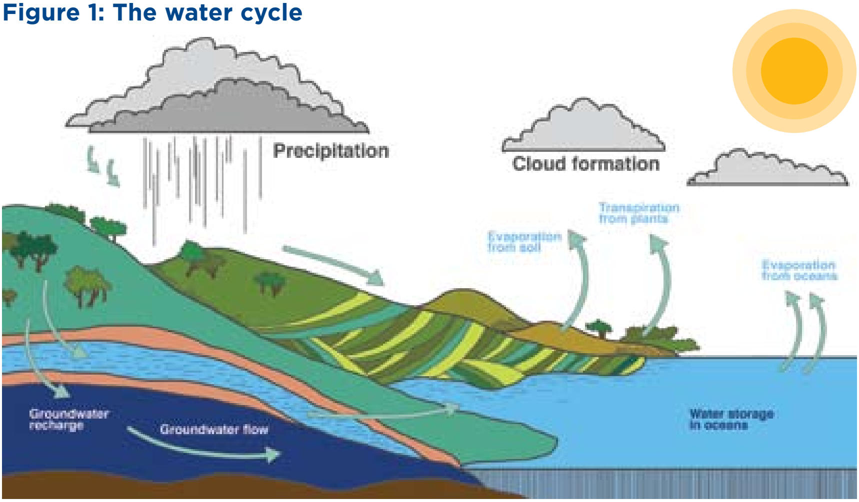
PART 1

Understanding concepts

1.1 UNDERSTANDING THE WATER CYCLE

Understanding the water cycle and how it will change with global warming will help you understand the changes and practices that will contribute to reducing the vulnerability of farmers and farming to climate change.

Figure 1: The water cycle



Adapted from: Catholic Relief Services. 2014. *Natural resource management: Basic concepts and strategies*. CRS: Baltimore, Maryland, USA.

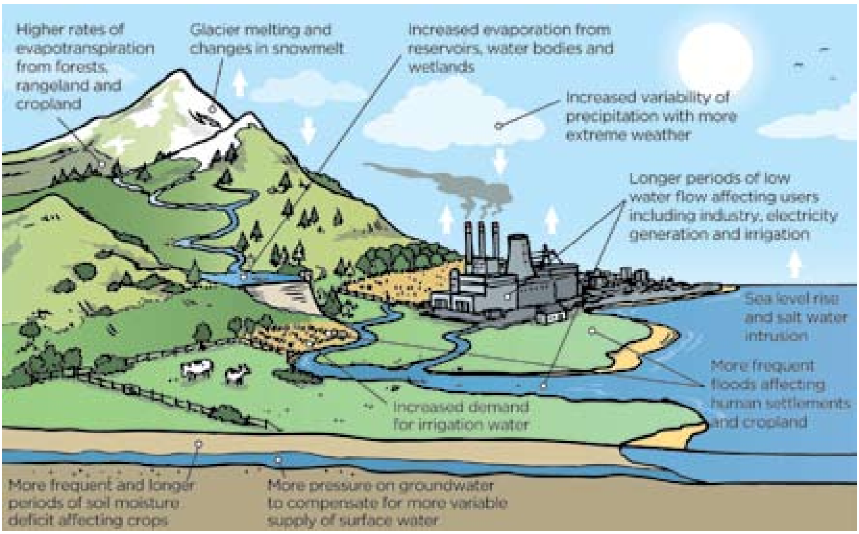
The amount of water on the earth is limited – water is neither created nor destroyed. Instead, water is like energy in that it is transformed from one state to another (liquid, vapor or solid) and moved from one place to another in a continuous cycle, circulating through many sources in different forms. The oceans contain 97 percent of all the water found on earth. The remaining 3 percent is fresh water found in rivers, lakes, glaciers, snowpack, clouds and aquifers (groundwater). Importantly for agriculture, it is also stored in the soil as soil moisture where it can be used by plants. As water flows through its many sources, the quality and properties of water also change. For example, as liquid water, it can evaporate from lakes and become vapor to form clouds if temperatures are above freezing (0° Celsius or 32° Fahrenheit). At temperatures below freezing, the lake can freeze and turn to ice, the solid form of water.

In the water cycle, the sun causes water to evaporate from the surface of oceans, lakes, reservoirs, snow, and the surface of the soil and plants (forests, cropland and pastureland). Plants also lose some water during the process of photosynthesis when the stomates in leaves open and transpire water. (Transpiration is considered to be a productive use of water before it returns to the atmosphere.) The combination of these losses of water to the atmosphere is called evapotranspiration, but evaporation and transpiration are different processes. Only pure water is evaporated – salts in the water do not evaporate. This water vapor then forms clouds within the atmosphere. As the earth rotates, clouds build up their supply of water until they become heavy, and the water falls back to the earth as freshwater precipitation. Precipitation can be in the form of rain, snow or ice. Once precipitation reaches the earth, it does one of three things:

- Runs off the land as rainfall or snowmelt into rivers, lakes and oceans.
- Enters the soil through infiltration and then evaporates from the soil surface or transpires through plant leaves before it returns to the atmosphere.
- Is absorbed by the soil and, over time, percolates into the groundwater.

1.2 THE WATER CYCLE AND CLIMATE CHANGE

Figure 2: The water cycle and predicted impacts of climate change



Graphic modeled after *Climate-smart agriculture sourcebook. Module 3: Water management* (FAO 2013)

Global warming is speeding up the water cycle. Higher temperatures increase the rate of evaporation from water bodies and wetlands, the rate of melting snow from glaciers and snow-covered areas, and the rate of transpiration from vegetation. This loss of water to the atmosphere means that the warmer air contains more moisture. Increased moisture will result in changes such as floods, landslides, droughts, or more frequent, severe storms such as cyclones and hurricanes. Water that evaporates cannot be used again until it falls as precipitation, and this process will now happen more rapidly. Because of global weather circulation patterns, generally wet areas will become wetter and dry areas drier.

"I don't remember any hurricanes when I was a boy"
In Central America, a region expected to be hit hard by climate change, temperatures are projected to increase by 1°C by the end of the 2020s and by 2°C by the 2050s. A regular dry period in the middle of the first cropping season now lasts longer during key growth stages when plants require water to produce grain. This deficit reduces yields of maize and beans, the two main staple crops. Though total rainfall is expected to drop, the number and intensity of extreme storms is expected to increase.

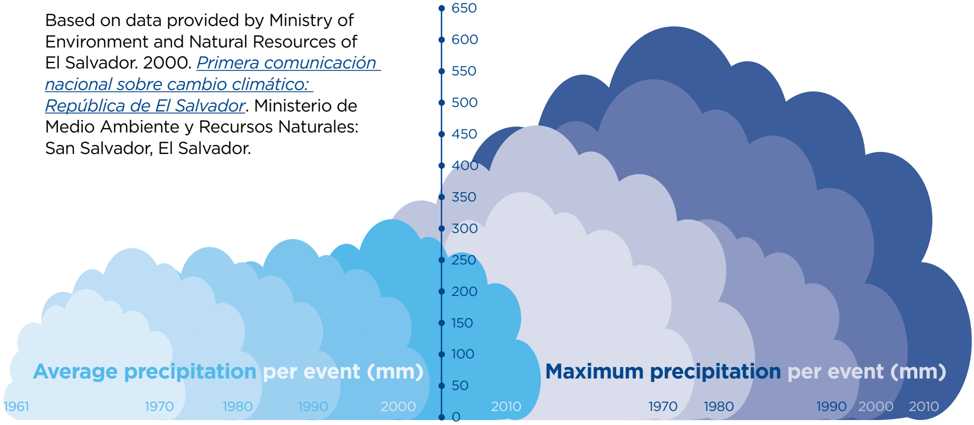
"I don't remember any hurricanes when I was a boy. The rains used to be slow and steady. We had storms, but they lasted a few hours, maybe a day. Now the rains are much harder and heavy. Before Hurricane Stan [2005], we had Hurricane Mitch [1998]. People are terrified of another hurricane coming. Before, we never saw anything like the hurricanes [that are] around here [now]. Even my grandparents don't remember storms as strong as these."

Farmer Gavino, San Marcos, Guatemala

With climate change, storms will come more often with heavier rain, and dry periods and droughts will happen more often or last longer. With increased storm events, water will move through the landscape more quickly and may become destructive, causing severe erosion, mudslides or flooding. More flooding will affect cropland and livestock, as well as downstream areas. Flooding, sea level rise and saltwater intrusion to freshwater wells and aquifers in coastal areas are already beginning to contaminate household and irrigation water sources. With more extreme events and more water lost to evaporation and runoff, deficits in soil moisture will happen more often and last longer. This causes problems for crops, grazing areas and soil health. Higher temperatures will also increase the occurrence of diseases such as malaria and dengue fever if water storage areas are not managed carefully to control mosquitoes. Crops, animals and people will be affected by heat waves.

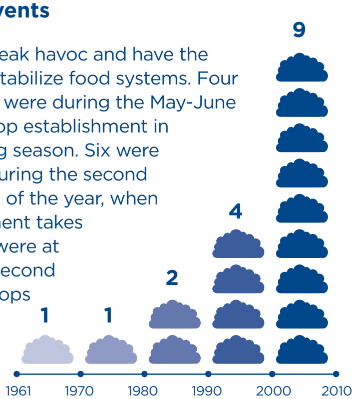
Figure 3: Extreme weather events in El Salvador by decade (1961-2010)

Based on data provided by Ministry of Environment and Natural Resources of El Salvador. 2000. *Primera comunicación nacional sobre cambio climático: República de El Salvador*. Ministerio de Medio Ambiente y Recursos Naturales: San Salvador, El Salvador.



Number of events

Such storms wreak havoc and have the potential to destabilize food systems. Four of these storms were during the May-June planting and crop establishment in the first growing season. Six were in September during the second growing season of the year, when crop establishment takes place, and five were at the end of the second season when crops mature and are harvested in October and November.



The signs are everywhere

The visible signs of global warming are everywhere, in changing temperatures and consequences such as more frequent and longer droughts, flooding, severe storms, melting glaciers, changes in rainfall patterns and the like. *Human development report 2007/2008. Fighting climate change: Human solidarity in a divided world* (UNDP 2007)

If you work in an area that is affected by larger storms or heavier rain, you are likely to see:

- More runoff water.
- More erosion carrying topsoil nutrients away from farm plots.
- More crop diseases, especially fungal diseases.
- More flooding that damages farm plots, livestock, homes and roads.
- Faster spread of livestock diseases.
- Challenges for storage of grain, seeds and livestock feed.
- Changes in well-water levels.

Near coasts, rising sea levels will mean saltwater contamination of wells and groundwater. Many farmers in the tropics already report seeing these changes in the weather:

- Warmer temperatures.
- More or longer droughts.
- Heavier rainfall.
- More severe storms and increased competition for lower quality water.

Even if you work in an area of high rainfall, you may begin to see droughts and dry spells as well as more intense flooding. In the highlands of the Himalayas, Central America, the Andes, Ethiopia and Southern Africa, rainfall is predicted to be more variable. There will be more droughts but also more floods. In these regions, many soils are degraded so they cannot hold water well, and they are increasingly sensitive to changes in rainfall.

1.3 IMPROVING WATER PRODUCTIVITY: OPPORTUNITIES IN RAINFED AGRICULTURE

Over the next 40 years, farmers will need to double production of human food and animal feed to meet the needs of growing populations and changing diets. But in many areas of the world, there is not enough new land to farm, so farmers will need to increase crop yields on the land they already farm. This will require more water because the process of photosynthesis that produces plant material (leaves, stems, roots, tubers, fruit, grain) is based on evapotranspiration, the use of water by plants and some loss of water through plant leaves. The challenge for agricultural researchers and extensionists is that this doubling of production needs to be done in spite of climate change and any changes in the timing of when the rains come or how much rain falls.

By the year 2050, the evapotranspiration that is needed to increase food production could increase by between 60 and 90 percent. But agriculture already uses over two-thirds of the water humans withdraw, much of it for irrigated production. So the increases will need to come from rainfed agriculture. Farmers will have to grow more food on about the same amount of land they now farm and often with less rainfall. In other words, they have to improve the capture and storage of rainfall and the productivity of water. This may seem impossible, especially in areas where water is scarce and farmers already struggle to grow food and raise animals. But when they combine farming practices to improve soil management, crop management and water management in the same field, the advantages of each practice increase the benefits of the others. Water is then used more efficiently. Growing food with less rainfall is not impossible, even in semi-arid West Africa, and the practices in this guide will show some of the ways of doing it.

In semi-arid and dry sub-humid regions, where farmers face long dry seasons, the main challenge for water in rainfed farming is not the total amount of water. There is actually enough total rainfall to farm. The main challenge is that rainfall varies greatly. About two of every five rural people already live in areas where water is scarce and where farmers produce under rainfed conditions. Although water is available, rainfall comes at the wrong time, and much of the water is lost. In areas with severe soil degradation, there is also massive water runoff – most water is lost rather than soaking into the soil to be used by plants for roots and tubers, grain and fruit production. A farmer who can improve water storage and manage the crop so its capacity for water uptake also improves will increase farm production.

About two of every five rural people already live in areas where water is scarce and where farmers produce under rainfed conditions.

However, the many small-scale farmers who raise crops and animals in spite of changing weather often have little information and technical expertise and limited resources to adapt. Harsh weather is especially harmful to agriculture in areas where many of these farm families live – soils are often poor, forests degraded and water scarce. The farming systems in these areas have a severely limited ability to resist and recover from change. Therefore, an important part of your role as an extension field agent is to share information and training in basic, proven practices in agronomy and water management that can increase production.

Some of these practices are:

- Soil and water conservation through minimum tillage systems (*Section 3.2*).
- On-farm rainwater harvesting (*Section 3.3*).
- Temporary irrigation, called supplementary irrigation, can protect crop growth and bridge periods of low rainfall that may now happen more often during the rainy season (*Section 3.4*).
- Modern technologies such as drip irrigation (*Section 3.4*).
- Improving soil fertility so that plants can increase absorption of water and tolerate mild stress from dry periods (*Pocket Guide 2: Crops*).

Other practices will also make the crop more stress-resistant. You might want to recommend crop varieties that were developed to be resistant to pests or disease or that have an increased tolerance to dry weather. Crop varieties that mature early are also helpful. Each local situation will be different, and your choice of practices will vary from one place to another.

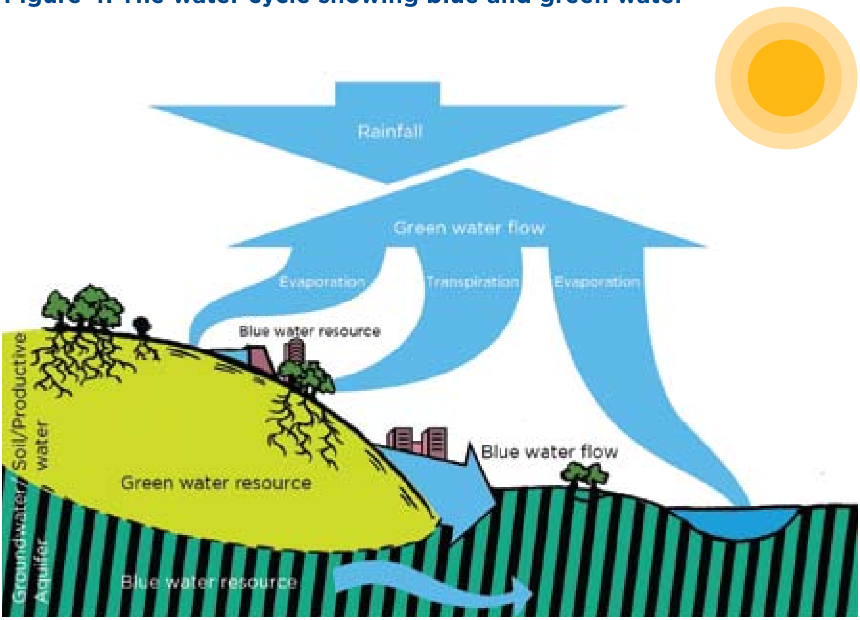
1.4 A PROMISING PERSPECTIVE ON WATER FOR AGRICULTURE

Some experts in agriculture and water are talking about two types of water. The term **blue water** is used to describe fresh water that runs off to form surface water – the lakes, rivers, reservoirs and wells – and also groundwater, or water stored in aquifers underground. Blue water is the result of where water flows once it falls as precipitation. **Green water** is rainfall and water that is stored in the soil as soil moisture. This distinction between blue and green water is helping researchers and extensionists understand and improve recommendations on climate change adaptation.

Blue water – Fresh water that runs off the land to form surface water – the lakes, rivers, reservoirs and wells – and also groundwater, or water stored in aquifers underground.

Green water – The rainfall and water that is stored in the soil as soil moisture.

Figure 4: The water cycle showing blue and green water



Source: Adapted from Falkenmark, M. & J. Rockstrom. 2006. The new blue and green water paradigm: Breaking new ground for water resource planning and management. *Journal of Water Resource Planning and Management*. 132(3), 129–132.

Most of the water used for irrigation is **blue water**, but groundwater in many parts of the world has been overused and depleted, especially in India, Southern Africa and Mexico. More groundwater is taken out than is replaced or replenished. Groundwater levels increase (recharge) only when rainfall soaks or percolates down to the aquifer. Wells must be dug deeper and deeper to find the remaining water. At the same time, irrigation from blue water on the surface – from rivers, lakes and reservoirs – is very expensive and is also facing problems of overuse.

Overall, however, **green water** resources are largely untapped for agriculture. The vulnerability of rainfed farming to climate change can be reduced with wise management of green water through collecting and storing more rainwater and managing soils to retain more moisture. The most desirable place to store water is in the soil, where most of it is protected from evaporation and where it can be redirected to plants for production. Most of the practices in this guide will help increase soil water storage.

As noted earlier, most of the farmland globally (80 percent) is farmed as rainfed land. It is vulnerable to climate change as rainfall comes in amounts that are too much, too little or too late and these farms generally have low yields. It is not necessarily the lack of water but how water, crops and soils have been managed that keeps yields low. Even in semi-arid drylands, in most cases there is enough green water for agriculture. It is possible to increase yields and improve the adaptive capacity of rainfed farms by changing practices.

Even in semi-arid drylands, in most cases there is enough green water for agriculture.

The bad news is that there is not enough blue water to produce the food the world needs in the future and to provide for water's other uses. The good news is that on rainfed farms in the tropics, farmers can double or triple today's average grain yields of about 1 ton per hectare. With support from researchers, extension field agents and governments, farmers can increase yields by managing green water better.

These practices will help:

- Collect and store rainwater above ground.
- Manage soils to capture and store more water.
- Manage crops and pastures to make better use of water.
- Manage plants to increase organic matter in the soil, which allows soils to capture and store more water.
- Manage farms and watersheds to recharge groundwater.

These practices contribute to producing more plant material (roots, leaves, stems, fruit, tubers and grain). After harvest, some of this plant material remains in the soil as roots and, some may be left on the surface by the farmer as leaves or stalks. Over time, the plant material breaks down and decomposes into organic matter containing nutrients that act as a natural soil fertilizer. Organic matter also acts as a sponge to retain water and nutrients and make it more available to plants. It also improves drainage when the soil is saturated.

Organic matter also acts as a sponge to retain water and make it more available to plants.

This organic matter:

- Makes the soil more fertile for plants.
- Helps the soil to capture, absorb and store more water, so less is lost to runoff.
- Increases the pores or holes in the soil for aeration, root growth and drainage to groundwater.
- Helps clay soils to drain.
- Helps sandy soils to retain water and nutrients.

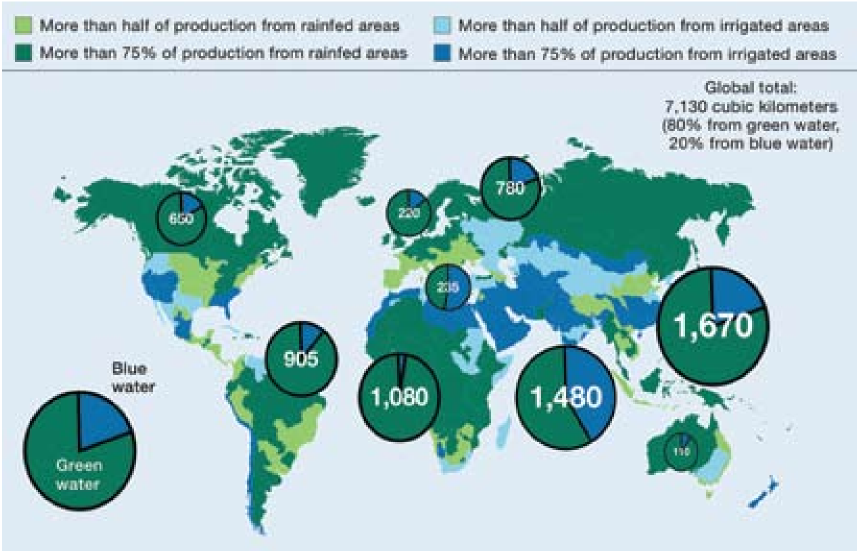
With more organic matter, better soil fertility and access to soil water, plants produce more and return more organic matter to the soil. In this way they increase benefits from year to year, as long as the farmer can leave some or most of the plant matter on the field after harvest.

This positive cycle starts with better water management and increases production just by making better use of the rain that falls on the field.

Better management of green water (rainfall and soil moisture) is fundamental to adaptation to climate change. Improved water productivity – measured as more crop per volume of rainfall – depends on crop and soil management for better plant water absorption from both sources of water, blue water and green water. Combined with collection and storage of rainwater during heavy rainfall, these strategies will reduce vulnerability to semi-arid conditions and dry spells.

Better management of green water (rainfall and soil moisture) is fundamental to adaptation to climate change.

Figure 5: Dependence on green and blue water for total agricultural production (2000)



Note: Production refers to gross value of production. The pie charts show total crop water evapotranspiration in cubic kilometers by region.
Source: International Water Management Institute (IWMI). 2007. In Molden, D., ed. *Water for food, water for life: A comprehensive assessment of water management in agriculture*. Earthscan: London, England, UK and International Water Management Institute: Colombo, Sri Lanka.

Resources

For those who have access to the Internet, web-based information sources can be helpful. The resources listed in this section will have suggestions of guides with more information on practices or basic concepts.

Ashby, J. & D. Pachico. 2012. *Climate change: From concepts to action; A guide for development practitioners.* Catholic Relief Services: Baltimore, Maryland, USA.

PART 2

Assessing climate change risks for water and appraising agricultural vulnerability

2.1 MOVING FROM CONCEPTS TO ACTION

As a field agent, knowing what challenges to expect from climate change and how they will affect water resources and local agriculture will help in decisions about what practices to recommend to farmers. The effects of climate change will vary greatly from one location to another and will change over time. Even within the same country or watershed, practices need to match the unique characteristics of each location and each farm. This section moves from concepts to action through three steps to assess vulnerability to climate change:

- Assess exposure of water resources to climate change.
- Appraise resulting agricultural livelihood vulnerability.
- Assess local adaptive capacity.

You will use the information from these assessments to identify practical on-farm options for helping farmers adapt to climate change (*Part 3*) before mobilizing community planning and action (*Part 4*).

2.2 ASSESSING THE EXPOSURE TO CLIMATE CHANGE

Exposure to climate change can be assessed through three broad approaches:

- By examining local weather records for trends.
- By undertaking climate modeling or accessing results of existing models.
- By tapping local knowledge about climate risks and indigenous water management strategies.

Strategies that farmers are already using to adapt to normal variations in weather can provide insights into potential adaptive practices under climate change. Farm families are accustomed to adapting to change, but because of the intensity, number and speed of changes that come with global warming, changes are likely to come faster than farm families can adapt to on their own.

2.3 APPRAISING VULNERABILITY OF AGRICULTURAL LIVELIHOODS

It is important to develop questions like the ones below to serve as a guide when reviewing weather records and climate models. They also help when interviewing key informants in government ministries, research agencies, local governments, development programs and rural communities:

- Is there evidence of changes in total rainfall?
- Has the start or length of the rainy season or the dry season changed noticeably?
- Are there changes in rainfall patterns? For example, is heavy rainfall occurring more often, or are there longer gaps between rains during the rainy season?
- Has drinking water and water for livestock become more or less available?
- Has the labor or time for getting drinking water increased?
- Has the flow of surface water changed; are water courses running dry?
- Has flooding become more severe or frequent?
- If groundwater is being exploited for irrigation, is the water level changing?

Information to answer some of these questions may be available from historic weather data or locally adapted climate models. For those who have access to the Internet, refer also to the previous *Resources* section. For other questions, though, the best answers may be found by working with key informants in the community, either through individual or group interviews. In cases where past work has already shown that water is a critical issue in this area, your interviews will focus specifically on water resources. More frequently, though, questions about water resources will be shared as part of a similar set of questions on soils or crop management (*Pocket Guide 2* and *Pocket Guide 3*).

It is also important to ask questions of farmers to assess the vulnerability of current farming practices:

- Have you noticed changes in the weather over the past 20 to 30 years?
- Are crop failures happening more or less often today than in the past?
- Are crop failures due to lack of water, too much water or something else?
- Are there crops that do worse now than 30 years ago?
- Are there crops that do better now than 30 years ago?
- Do livestock have enough water?

- Have there been any changes in the amount, timing or quality of water sources?
- Have there been any changes in irrigation systems or their performance?
- How have farmers here responded to changes in weather?
- Are farmers growing more drought-tolerant crop varieties or raising animals that require less water?
- Are farmers growing more water tolerant crops or crops that are tolerant of salty water?
- Are farmers switching to crops or tree crops that require less water?

As you discuss weather risks and changes in water resources with people in the community, it is natural that people will mention how severe the impact has been on various water issues. Remember to interact with people from a variety of groups in the community to hear all perspectives. For example, when it is women's and girls' responsibility to collect family drinking water, interviewing only men, who are not responsible for drinking water, may not provide an accurate view of the importance of the problem. In the same way, farmers with lowland fields in the floodplain will be more sensitive to the risk of flooding than farmers who have upland plots. Local knowledge is essential to your ability to understand livelihood problems caused by climate change and to evaluate options to adapt. Local knowledge is affected by the particular perspectives of various community members, making it important to understand and tap into diversity in the community. You may want to organize separate discussions with certain groups within a community – men, women, elderly people, youth, farmers, pastoralists – depending on the issue and the local social context.

Interact with people from a variety of groups in the community to hear all perspectives.

2.4 ASSESSING LOCAL CAPACITY TO ADAPT

Finally, questions about local capacity to adapt can help identify gaps and opportunities:

- What natural disasters affect farmers here?
- How do people manage when there is a natural disaster (bad weather)?
- Have people taken any actions (water storage, water collection systems, wells, water drainage systems, ponds for livestock use, etc.) to deal with a drought or flood?
- Do they store food grain or livestock feed for bad years, or can they obtain what they need?

- Do people have any plans to reduce the impact of bad weather (for example, to move livestock to water in times of drought or upland during floods, to reduce planting area or change crops)?
- When crops fail, what do people do to cope (forage; hunt; sell livestock or jewelry, tools or land; migrate for work; borrow money)?
- During a drought, do families have back-up sources of water that they can use for a garden or to save the most important animals?
- When there is flooding, how do people earn a living?
- What activities do men do that require water?
- What activities do women do that require water?

2.5 SELECTING PROMISING PRACTICES FOR ADAPTATION

Once you collect the basic information and analyze the exposure to risk, sensitivities and options for adaptation with local actors, you are ready to prioritize the steps to take and the practices to implement with the community. Going through this process with the community will help to identify the practices that local people find most attractive. This will speed adaptation, increase coverage of adaptation practices in the area and contribute to the spread and usage by farm families. Some methods can be used as described in the guide and some will need to be modified for local conditions or farmers. There will also be some practices that will not be appropriate locally. Additional questions can help select practices:

- On the basis of this information, are there farming practices that should be continued?
- Are there any that need to be changed?
- How can this information help communities and families to develop an action plan for adaptation?
- Once a strategy is developed, which practices seem best suited to local circumstances and should be included in an action plan?
- Which practices will result in the greatest benefit over time?
- Which practices will be best for female-headed households or female-managed plots in male-headed households?

In addition to discussions, useful information on water resources can be gathered with community members by drawing maps of water sources and discussing their use. You can walk the area together to develop seasonal calendars of activities related to water and weather. Remember to list women’s activities and men’s activities separately. Every family and community will need to develop an adaptation plan that responds to the unique situation of each.

A final note on managing climate change risks: The purpose of this guide is to share practices that reduce risk through the use of improved water management practices. Adaptation also involves managing risks that are not covered here, for example market and financial risks. Many agricultural projects include microfinance through formation of community savings and lending groups to build basic financial skills for agricultural investments, to cover basic needs in the dry season and to serve as a foundation for formal borrowing. Projects also support collective action and farmer organizations for bargaining power and negotiation of seed and fertilizer prices or sales contracts for farm products. In addition, there is emphasis on support to specific value chains that involve public and private sector alliances to reduce market risks.

Resources

Ashby, J. & D. Pachico. 2012. *Climate change: From concepts to action: A guide for development practitioners*. Catholic Relief Services: Baltimore, Maryland, USA.

Dorward, P., D. Shepherd & M. Galpin. 2007. *Participatory farm management methods for analysis, decision making and communication*. Food and Agriculture Organization (FAO): Rome, Italy. Available at http://www.fao.org/fileadmin/user_upload/ags/publications/participatory_FM.pdf

Dummett, C., C. Hagens & D. Morel. 2013. *Guidance on participatory assessments*. Catholic Relief Services: Baltimore, Maryland, USA.

Feldstein, H.S. & J. Jiggins. 1994. *Tools for the field: Methodologies handbook for gender analysis in agriculture*. Kumarian Press: West Hartford, Connecticut, USA.

Food and Agriculture Organization. 2011. *Social analysis for agriculture and rural investment projects*. FAO: Rome, Italy.

Food and Agriculture Organization. 2012. *Participatory rural appraisal (PRA) tool box*. FAO: Rome, Italy.

PART 3

Recommending practices for water adaptation through improved management

3.1 INTRODUCTION

This section shares practices for improving water productivity and water management in rainfed farming systems.

3.1.1 A note to field agents working in agricultural extension

As a field agent working in agricultural extension, you already know how much farming varies from village to village and plot to plot. There are differences in rain, wind and temperature from one place to another; different soils, weeds, pests and diseases; different mixes of crops, trees and livestock; different preferences and prices for food in local markets; and different ways of doing the many tasks on a farm. So when there is talk of how to reduce vulnerability and how to adapt farming practices to take advantage of any opportunities that climate change brings, you probably also know this: there are no universal solutions to help farmers adapt to climate change.

Each farm family will need to develop an adaptation plan that fits the situation on their farm. This guide focuses on how to improve water management and increase water productivity for adaptation to climate change. It will be important to work with farm families to modify and test the practices discussed here to identify the solutions that work best in a particular area. The most appropriate practices may also vary over time. The practices discussed here to help farmers adapt to changes in the weather combine practices that improve water management with practices that improve soil and plant management. Together the practices can unleash a farm's full potential to adapt to either too much or too little rain. Even then, the work that field agents do with farmers on their plots will be influenced by many other factors: prices in the market, whether the family owns the land they work, family members' access to savings or credit, how many family members can work the land, and whether they have water for irrigation or equipment to irrigate if they need it.

The focus is on ways that small-scale farmers – who are often more vulnerable to climate change than farmers with more resources – can adapt farming systems that depend entirely or mostly on rain for their water. These rainfed farming systems can adjust to shortages of water with practices to collect or capture, store or retain, manage and use both rainfall and water stored in the soil (green water). The practices include more efficient management of irrigation water from sources such as rivers, reservoirs and wells (blue water). But the emphasis will be on systems that capture rainfall and on management of soils to manage water for use by crops, trees and forages. How farmers manage their crops and soils influences how much crop can be grown with the water they have – the productivity of water. A crop's ability to adapt to climate change, its resilience to poor weather and its ability to take up water improve when soil quality improves.

A crop's ability to adapt to climate change, its resilience to poor weather and its ability to take up water improve when soil quality improves.

3.1.2 Guiding principles for adaptation through water management

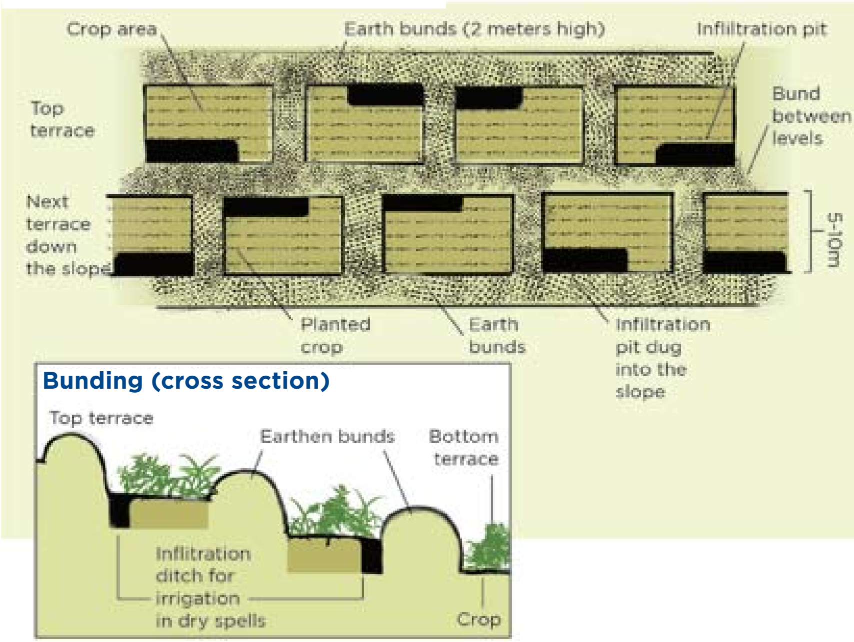
Each guide in this series will present a few simple guiding principles that, unlike practices, can be widely followed. You can keep these guiding principles in mind when you need to modify a practice to fit the situation in a particular location for a specific farming system.

More crop per drop: When rainfall is unpredictable, when rising temperatures increase evaporation and when more people are sharing less water, farmers will need to make more efficient use of water within their watersheds and on farm plots. Even in areas with excess rain, there can be dry periods or competing uses for water that make efficient use an important objective. The practices in these adaptation guides cover the role of healthy soils in conserving water, as well as water-conserving use by crops, trees and animals. Applied wisely, these farming practices can increase agricultural resilience to both water shortages and surpluses when weather varies.

Catch it where it falls: Rainfall may come in the right amount, or be too little or too much. The farmers who can capture rainfall on their plots can improve production while preventing problems of flooding, landslides and sedimentation in areas below them. They are also reducing their own use of blue water sources – rivers and groundwater – or protecting blue water sources to benefit neighbors or users in lower areas of the watershed.

Figure 6: Bunding showing infiltration pits as used in India

Bunding (bird's eye view)



Farmers in the semi-arid Sahel area of North Africa build stone bunds (raised ridges or banks of stones), often on nearly flat lands, to slow surface flow and trap rainfall. In Asia on sloped land, farmers commonly build terraces or cut into a slope to flatten a plot-size area and then surround it with soil bunds (permanent ridges made of soils with 20 percent or higher clay content) to trap rain within the plot. Farmers often dig infiltration ditches within each bunded plot for supplementary irrigation. When these ditches are scattered among many plots, excess water percolates down through the profile and can recharge groundwater evenly throughout the landscape.

You may hear other phrases for this principle, such as **slow it**, **spread it**, **sink it** and **walk water down the slope.** The steeper the slope, the closer the spacing that is needed between contour barriers, and in areas with extreme storms, the barriers need to be strong and/or high. These barriers run across the slope to slow runoff and increase infiltration.

Figure 7: Contour ditch or infiltration ditch

Manage soils to manage water: Healthy soils with high organic matter, diverse soil organisms, good structure and a robust topsoil layer will readily absorb rainwater and store it in the root zone for plant uptake during dry periods. During heavy rain, such soils also drain excess water and recharge groundwater through percolation of soil moisture through the profile. This may seem paradoxical, but a high organic matter content serves as a reservoir of water in sandy soils and improves drainage in clay soils. Organic matter improves soil structure in a clay soil by flocculating or clumping the clay particles together to form soil aggregates. This aggregation provides pathways for root growth, drainage and aeration when the soil is wet. Organic matter also feeds soil organisms and macrofauna such as earthworms and termites for increased biological activity, which further improves soil structure, creating channels and pores in the soil for water and air. In addition, soil amendments such as lime (calcium carbonate) or gypsum (calcium sulfate) can be used in acid soils to flocculate clay, improve drainage and prevent waterlogging.

Although it takes time to rebuild degraded soils with low organic matter to levels that will improve fertility and structure, farmers can increase soil moisture very quickly by changing tillage practices, making sure the soil is kept covered with vegetation or mulch, and implementing practices to increase water infiltration. A significant, untapped resource to improve adaptation in rainfed farming is a set of practices to improve soil moisture retention. (See practices in this guide, *Pocket Guide 3*, and in *Pocket Guide 4: Soil Management*.)

Analyze the economics of water productivity – Where water is scarce, farmers may select crops based on the economic value per unit of water rather than the crop yield per unit of water. For instance, farmers can grow fava beans with a return of US$0.09 per cubic meter of water used or onions at US$0.30 per cubic meter of water. This difference in crop value per unit of water can be a stronger incentive for change than the physical productivity of water. The economic productivity of water can provide a powerful motivation to encourage farmers to make changes in the crops they grow, reallocate water use and practice water conservation.

3.1.3 Improving water productivity: Growing more food with less rainfall or heavy rainfall

The practices here and in the other guides are ways to increase water productivity in rainfed and irrigated farming. They include:

1. Small-scale water collection, storage, delivery and application, especially through:
   - Increasing infiltration of rainfall into the soil and retaining water for crops by reducing water losses from runoff.
   - Decreasing water loss from the soil surface through evaporation.
2. Soil fertility management to strengthen plants and improve water uptake.
3. Practices such as minimum tillage and use of drip irrigation to conserve water.
4. Practices to reduce biomass losses, such as use of crop management practices and crop varieties that are drought-tolerant and/or resistant to pests, diseases and lodging from wind or wet soils.
5. Systems to capture, divert and store excess water for use later when climate change brings periods of too much rain too quickly. You will also need practices to soften the impact of storms and protect crops from their full force and from flooding. Practices include:
   - Capture and transfer of on-site water:
     - Rooftop collection systems.
     - Contour barriers across slopes to slow runoff.
     - Contour bunds (a raised ridge or bank) of soil planted with perennial vegetation and constructed with spillways (a slightly lowered portion of the bund where extra water can flow out) to prevent damage to the bund and divert excess water to other fields, infiltration ditches, and ponds or other water storage.
   - Improvement of soil infiltration to slow runoff through use of vegetative cover, contour barriers or mixed tree-crop systems.

- Changing planting dates or selecting varieties or crops such as flood-tolerant rice, bamboo and sugar cane (see also *Pocket Guide 2: Managing Crops*)
- Using the leaves and pods of the gum arabic (*Acacia nilotica*) tree – which tolerates seasonal flooding, fire and regular grazing – as cattle fodder. Note: it is considered invasive in some areas.
- Using Napier grass or elephant grass (*Pennisetum purpureum*), a fodder crop, which tolerates flooding, low amounts of water and infertile soils, withstands heavy grazing, and serves as a windbreak and firebreak. It is also used to stabilize bunds or earthen dikes that can trap floodwaters.
- Changing planting structure (architecture) with mounds, ridges, deep furrows or raised planting beds.
- In vulnerable, degraded areas of the watershed, working with communities to either permit or actively support natural regeneration of vegetation by controlling grazing, by fencing or the use of imprinting (*Section 3.3.7*).

3.1.4 Ground rules for water management

There are two practices that many farmers will have to change to succeed in adapting to climate change. These changes may mean adopting or developing new ways of managing the land:

No burning – Small-scale farmers often practice burning to clear fields, control insects and disease, or improve the quality of grazing land. These are important reasons. But burning every year will undo many of the gains described in this guide that can help farmers adapt to climate change. Burning speeds the loss of soil moisture because it destroys the protective layer of plant residue above the soil surface. Also, it kills important soil microorganisms that decompose crop residue into soil nutrients such as nitrogen and phosphorus, and it decreases the amount of organic matter that returns to the soil. Over time, burning is very harmful to the soil and decreases its ability to retain both water and nutrients. Continuing to burn the land increases farmers' vulnerability to climate change and contributes to the loss of good land for farming.

Burning every year will undo many of the gains described in this guide that can help farmers adapt to climate change.

Make sure that you understand why farmers burn their fields – that will help you identify alternative practices. If farmers are burning to improve pastures, explore whether the use of the keyline (*Section 3.4.3*) or contour ditches (*Section 3.3.1*) or another practice will improve productivity so that burning is not necessary.

Drastic measures

In the early 2000s, a Jesuit priest, Father Crispino, working in a degraded rural area of Maharashtra, India, refused to support agriculture with a community unless members first agreed to two rules – no burning and no free grazing. The first training he did was on how to map the village so people could make wise decisions together on land use – where to grow crops, where to leave forests and where to keep animals. In the second training, he showed how to improve pastures for rotational grazing and how to produce livestock forage so farmers could cut and carry animal feed from a farm plot to tied or penned animals. Only then did his team of extension agents train the community in contour farming (*Section 3.2.4*) with new trees and bushes planted on the bunds (*Sections 3.3.1* and *3.3.2*). With controlled grazing and a ban on burning, these new plantings survived. The sloped land of the village now grows abundant crops between rings of infiltration ditches and live barriers around the slopes, while healthy livestock graze in land set aside for them.

Source: Lobo, C. Date unknown. *Songaon decides to change*. Watershed Organisation Trust: Ahmednagar, Maharashtra, India.

Protect crop residue: In almost all areas of the tropics, but especially in areas where there is not enough water for crops, where soils are poor or where there is little clay in the soil, farmers who leave some or all of the previous crop's residue on the surface of the soil can reduce losses of soil moisture and slow the drying of soil by wind and sun. The added soil moisture reduces the temperature of the soil surface and improves seed germination. It also improves the plants' uptake of nutrients and water. During rain, crop residues will reduce erosion from the splash of raindrops, reduce soil crusting and improve the soil properties that increase infiltration of water into the soil. Crop residue is one of the most effective and least expensive methods available to farmers for protecting their soils.

But there is a challenge: crop residue can also be used for animal feed in the dry season, fuel for cooking or heating, and thatch or construction material. Extension agents need to work with farm families to find alternatives to the many uses of crop residue so it can be protected for soil cover. This is essential to improving water management and adapting to weather changes.

Resources

Catholic Relief Services. 2014. *Introduction to the five skills for rural development: guide to the multiple skills approach*. Catholic Relief Services: Baltimore, Maryland, USA.

3.2 AGRONOMIC PRACTICES FOR IMPROVED WATER MANAGEMENT

3.2.1 Minimum tillage or no-till

Minimum tillage or no-till is the practice of growing crops from year to year with little or no disturbance to the soil through plowing or tilling. This practice is used most often in mechanized, high production areas, but it is also useful on sloped plots because it decreases the need for terraces or other barriers. Along with a cover crop or a mulch of the residue cover, no-till protects soil from erosion, evaporation of water and breakdown of soil structure. It improves soil fertility by helping to retain organic matter and nutrients. In this way, it also reduces the vulnerability of crops to dry weather and overly wet weather.

Challenges for no-till: In areas with very little moisture, farmers must increase the spacing of plants to avoid competition between plants. It may be hard to grow enough vegetation to provide soil cover, especially when crop residue is used as animal feed. No-till planting may be difficult with ox-drawn planters and require a hand-jab planter instead. In the first years of no-till, farmers face an increase in weeds until enough crop residue covers the soil surface to suppress them. Until then, farmers may need to use an herbicide to control weeds.

3.2.2 Planting density

Where rainfall is low or where degraded or sandy soils have little water-holding capacity, farmers can space seeds farther apart to improve water productivity and avoid competition for scarce water. In places with enough soil water, however, planting seeds closer together (increased plant density) will increase the amount of biomass that is produced, the yield and the amount of crop per unit of water. Close spacing means the crop canopy is denser, evaporation from the soil decreases and some of the water saved is used in transpiration for plant growth.

Adjusting planting density is an easy way to maximize water productivity, but the best density will differ with the location, soil and crop. Ask farmers about the spacing they use between plants. They may already use different planting densities on different soils or with different crops. You can also determine the best density by experimenting in farmers' fields. Plant the same crop at various seeding rates and compare yield results, taking the amount of rainfall during crop growth into account. These experiments or trials may need to be repeated over a few years to see the results of different densities in wetter or dryer years. Also check with a local university or research agency for information that may be helpful.

The best planting density will differ with the location, soil and crop.

You may also want to test a traditional planting practice. Some farmers overseed their fields and then thin out the plants later to a plant population that matches rainfall amounts. This is a flexible way to adapt to uncertain weather and still maximize water productivity. Some farmers in India who live in areas where rain varies between scarcity and overabundance follow a traditional practice of broadcasting a mix of seeds from five crops, some grains and some legumes. A few grow well in wet conditions, a few in dry. The weather selects the crops that grow each year.

Challenges of planting density: There is a cost to planting extra seed that fails to grow. Also remember that when you adjust planting density, other practices are needed to make certain there is enough soil water or irrigation water available for critical stages of crop growth. Each crop has its own critical stages, and this information should be available from the Ministry of Agriculture, a university or the Internet. Closer planting distance also puts greater demands on soil fertility to meet plant nutrition needs and may require increased fertilizer applications.

3.2.3 Organic fertilizers

Organic fertilizers increase water productivity on rainfed farms. They stimulate crop growth and production of roots (organic matter in the soil). This increases soil water-holding capacity, reduces temporary moisture stress in plants, improves soil structure and prevents the erosion of rich topsoil. Organic fertilizers are made of animal or vegetable matter such as compost, leaves, decomposing crop residue, nitrogen-rich green manure (legumes), animal manure and worm compost. Organic fertilizers also include liquid fertilizers made and fermented on the farm. See also *Pocket Guide 2: Crop Management*.

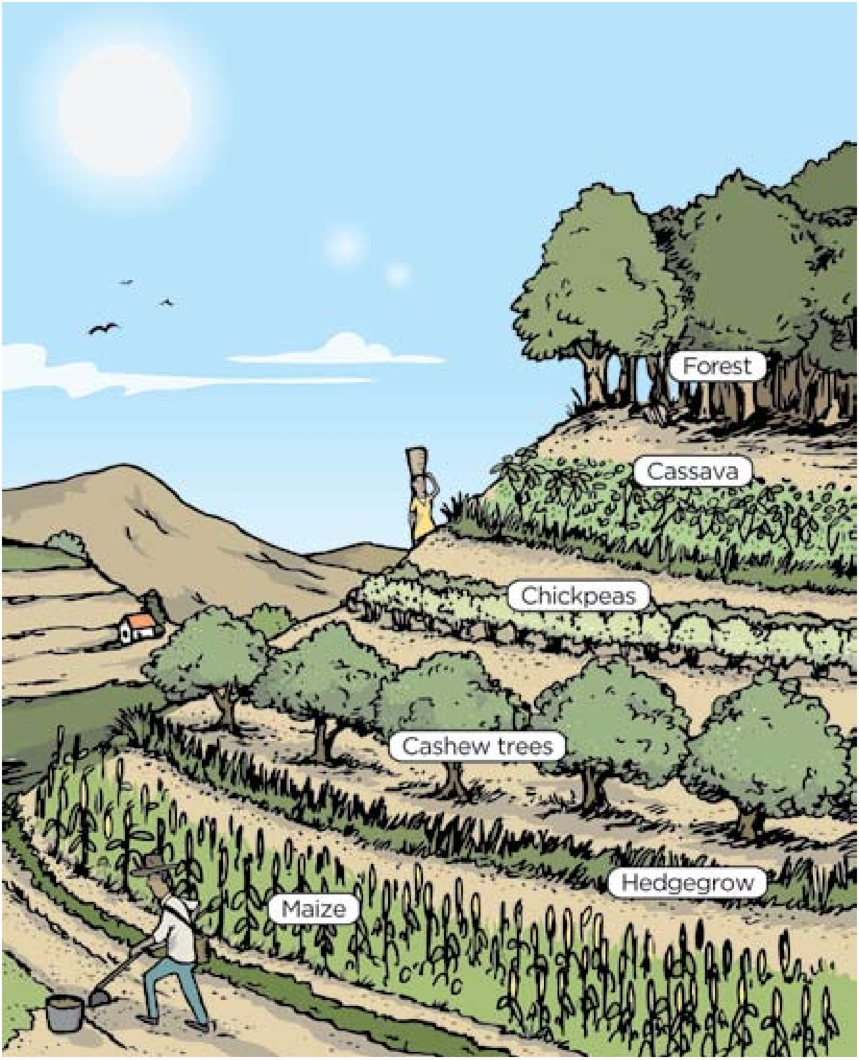
Organic fertilizers mobilize existing soil nutrients for good crop growth and release nutrients at a slower, more consistent rate than inorganic commercial fertilizers. They help to avoid the “boom-and-bust” pattern that happens when farmers apply commercial inorganic fertilizers. A combination of organic fertilizer supplemented with inorganic fertilizer gives good results in cost, soil improvement, yields and water productivity.

Challenge of organic fertilizers: The production and application of organic fertilizer, though it can be less costly than commercial fertilizer, requires more on-farm labor, and organic fertilizer can be harder to transport. The composition of organic fertilizers tends to be more complex and variable than a standard inorganic N-P-K (nitrogen-phosphorus-potassium) product, making fertility management less precise. Farmers may not have access to the materials needed to produce organic fertilizers, and many prefer the ease and precision of commercial fertilizers.

3.2.4 Contour farming

Contour farming can be used on sloped land to plant and manage crops along the contour. It can prevent or control erosion and runoff, and stores water in place for use by crops, pastures and trees.

Figure 8: Contour planting



When you plant on the contour, you plant along the same elevation across the slope at right angles to the flow of runoff (perpendicular to the slope line). This saves rainwater and reduces erosion, especially when combined with digging contour infiltration ditches and maintaining crop residue cover or planting cover crops (see also *Contour ditches* below). In this type of farming, you will see that crop rows, contours and infiltration ditches all act as small reservoirs to catch and hold rainfall. These improve infiltration and promote even distribution of water over the field.

Resources

Ashby, J.A., A.R. Braun, T. Gracia, M.P. Guerrero, L.A. Hernandez, C.A. Quiros & J.I. Roa. 2001. *Investing in farmers as researchers: Experience with local agricultural research Committees in Latin America*. CIAT Publication No. 318. CIAT: Cali, Colombia.

3.3 MANAGING SURFACE WATER AND SOIL WATER RESOURCES

In addition to the agronomic practices in the previous section, physical structures and vegetative practices in the field and landscape can also harvest water to improve water management. Millions of farm families have less water than they need – a water deficit – for part of the year. Capturing and storing as much rainfall as possible near where it falls will help them to withstand dry periods. One way to do this is to build physical structures on the farm that make the farm less dependent on groundwater and increase water storage in the soil. Physical structures include banks or bunds, contour trenches or infiltration ditches, contour stone barriers, terraces and waterways for drainage. These practices change the slope profile and divide one longer slope into several short slopes. This reduces the amount and speed of surface runoff and the amount of damage it can cause in times of heavy rainfall.

Challenge of physical structures: They are labor-intensive to install, and they collect sediment with time and so need regular maintenance during the dry season. But they can be an important part of water and soil conservation practices, especially in areas that have torrential rainfall and prolonged dry spells, areas such as the Asian highlands, West Africa and Central America.

3.3.1 Contour ditches (contour trenches, infiltration ditches)

Contour ditches are trenches that stretch along the contour of the land to capture rainfall. They help farmers adapt to weather that can change radically from little or no rain to intense rain that erodes soil. The ditches slow the speed of water moving across the land or down a slope, allowing it to infiltrate down and to the sides, feeding plants during dry periods and recharging groundwater. Some of the water may percolate into the groundwater that supplies wells. Contour ditches trap topsoil on the farm plot and can be used within a level field to capture heavy but infrequent rainfall. When small ditches are dug near houses, they provide moisture for trees and vegetable gardens.

These ditches can be dug on land that is sloped and steep or land that is nearly level. If the soil has a high proportion of sand, infiltration levels are already high, however, and ditches are unnecessary. In this case, live barriers on the contour are more appropriate (see *Live barriers*, Page 54).

The perfect practices?

On hillside plots in western Guatemala, a group of agricultural extensionists taught farmers to dig ditches along the contour to trap and store rainwater for plants directly upslope and downslope of the ditches. These well-meaning field agents were so convinced of the value of this practice for hillside farming that they promoted it with all farmers on all soils. Farmers whose soils were high in sand saw that their infiltration ditches failed to retain water. Instead they drained quickly and collapsed after a few rains. Farmers kept redigging their ditches to receive packets of food that were given to those who maintained the ditches. A confident, middle-aged local farmer heard complaints from her neighbors and showed the field agents how she had been taught not to dig ditches but instead to plant a row of sugarcane along the contour of sandy soils. She also used a grass hedge, and her live barriers stopped erosion, captured water for plant roots and added organic matter to the soil. Over time, her sandy soils had become more fertile and better able to hold water. This illustrates the importance of getting feedback from local farmers on the performance of new practices before moving to widespread promotion.

Source: Burpee, G. & K. Wilson. 2004. *The resilient family farm: Supporting agricultural development and rural economic growth*. ITDG Publishing: Warwickshire, UK.

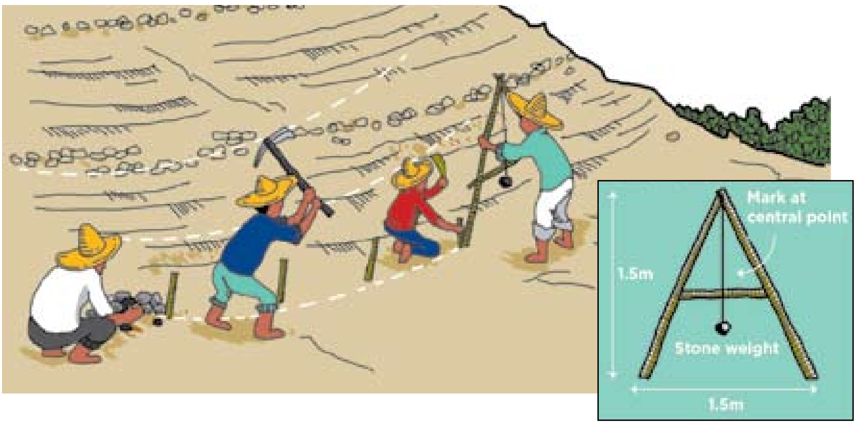
How to build contour ditches: There are no fixed rules about where and how to install a contour ditch. A good place to start is by observing the landscape from the top down. Go out with farm families during a rainstorm and study the natural flows of water – where does it gather, how fast does it move, in what direction does it flow? When you know where water flows, you will see where contour ditches are needed to slow or redirect the flow.

Work with farm families and community members to design a map of a landscape that shows where contour ditches will be built. Support farmers to be creative. The community has the power to design a productive and beautiful landscape that will be passed on to future generations. Contour ditches will often be more effective when planned at a landscape level rather than for an individual field or plot. Where plots are small and where farmers have fields at higher or lower points in the slope, collective decisions and actions, rather than individual actions, will bring greater benefits to all (see *Part 4* of this guide for more information).

To build a contour ditch, use a surveying tool such as an A-frame. You will need sticks for ground markers and a shovel, pick or digging tool. An A-frame can be made from three pieces of wood nailed together in the shape of an A, with a plumb-bob line (a weight such as a small stone attached to a rope) hanging from the top point down the middle.[1]

Observe the area where the ditch will be dug and clear the site of any plants. Starting at one end, use the A-frame to locate the 0-degree contour line (when the string and stone hang down the middle of the A-frame) and mark the two spots where the legs of the A-frame touch the ground. Keeping one leg of the A-frame on the ground to mark the current position, swing the A-frame around to find the next position on the contour (where the plumb-bob line, or the string and stone hang down the middle of the A-frame) and mark the new spot on the ground. Continue locating and marking contour points until you have reached the point where the ditch will end.

Figure 9: An A-frame device is used to mark the contour



Next, dig the earth directly below the marked contour line. On steeper slopes, dig ditches close together (1 to 2 meters); on moderate or slight slopes, space them farther apart (3 to 10 meters). In general, contour ditches are usually 50 cm wide on steep slopes and 1 meter wide on gentle slopes. The width of the ditch depends on three things: slope, the amount of rainfall and the crop – dig narrow ditches for vegetables and wider ones for trees. Start by digging ditches about 30 cm deep

1. For an instructional video on how to construct and use an A-frame, *Build and Calibrate an A-frame*,

on steep slopes and 50 cm deep on gentle slopes and adjust as needed based on local conditions.

Contour ditches on steep and very steep slopes (greater than 26% slopes) must be dug so closely together that there is little room for a crop. The most appropriate land use on steep slopes is forest, tree crops or agroforestry. Crops are not recommended. The guidelines in this table are general estimates only, to be used as initial suggestions and modified to fit local conditions. The size of the ditches will vary based on factors such as:

- Topography (flat or hilly)
- Slope (level to steep)
- Soil texture (the combination of sand, silt and clay affects drainage from the ditch and the shape of a ditch; soils with more sand are less stable for holding the shape of the ditch)
- Rainfall (duration of storms, amount and speed of water)
- Location of the water table (distance below soil surface)
- Soil moisture at the beginning of rainfall
- Whether there is a bank (or a bund, berm or dike) next to and downslope of the ditch and whether the bank is vegetated

Table 1: General suggestions for distance between contour ditches (surface distance between ditches and maximum length of ditch)

	Annual crop		**Perennial crop or pasture**	
Slope (%)	**Distance (m)**	**Maximum length (m)**	**Distance (m)**	**Maximum length (m)**
2	42.0	90		
4	25.0	120		
6	19.3	160		
8	16.6	200		
10	14.9	260	40.2	140
12-14	13.4	290	33.5-28.9	140
16	11.4	340	25.3	160
18	10.2	380	25.0	180
20	9.2	420	24.0	200
22	8.4	470	23.2	200
24-26	7.4	500	20.6	215
28-30	6.5	500	19.2	220
32-34	Not recommended		18.6	225
36-38	Not recommended		17.3	230
40	Not recommended		16.2	230

Adapted from: Crozier, C. 1986. *Soil conservation techniques of hillside farms*. Peace Corps: Washington, DC, USA and Suarez de Castro, F. 1980. *Conservación de Suelos. Serie Libros y Materiales Educativos No. 37*. IICA (Instituto Interamericano de Ciencias Agrícolas): San Jose, Costa Rica.

Size of contour ditches

- For strong slopes (13% or more), dig ditches closer together about 30 cm deep and 50-100 cm wide. Adjust for local conditions. Start with bunds below the ditch at 15 cm high and 60 cm wide.
- On gentle to moderate slopes (0-12%) start by digging the soil 40-50 cm deep and 1-3 meters wide. Start with a bund below the ditch at about 50 cm high and 1-2 meters wide. Adjust as needed.

Water will always find the path of least resistance.

Use the soil that is excavated to form a berm (narrow shelf) or bund on the downhill edge of the ditch. The berm can be planted with permanent vegetation (native grasses, bushes, trees) to stabilize the soil, and the roots and foliage will trap any sediment that overflows from the ditch in heavy rain. Over time this will form slightly sloped terraces.

Contour ditches can slow water to a standstill when they are designed to be level all across the base. In this way, they prevent erosion and allow infiltration of the soil nearby with water. Making them flat at the base and level across the entire length can be a challenge. You can measure the depth of the ditch, adding soil to any deep spots to make it a constant, even depth. Another method is to wait until the first rainfall, observe

Tips for contour ditches

1. Make sure you measure and mark the contour line before you start digging.
2. In areas where rainfall is intense, the higher the berm, the better. You can start with a layer of rocks, crop stems or woody branches at the base of the berm to increase height as well as water retention, soil aeration and rooting space in the berm.
3. Growing cover crops on the berm will help maintain soil structure, prevent erosion and add nutrients. Some examples are velvet bean (*Mucuna deeringiana*), lablab bean (*Lablab purpureus*), tepary bean (*Phaseolus acutifolius*) and jack bean (*Canavalia ensiformis*). The last three tolerate dry weather.
4. In the rainy season, water-loving plants grown near the bottom of the berm, such as lemon grass, taro or eddoe, will do well. Above the berm, vegetables with high market value are an option.
5. In the dry season, use the base of the contour ditch to plant the same vegetables. Use the top of the berm to plant crops that grow with less water, such as cassava.
6. When ditches stretch across plots that belong to different families, it’s a good idea to work together with the neighbors to plan and construct them.

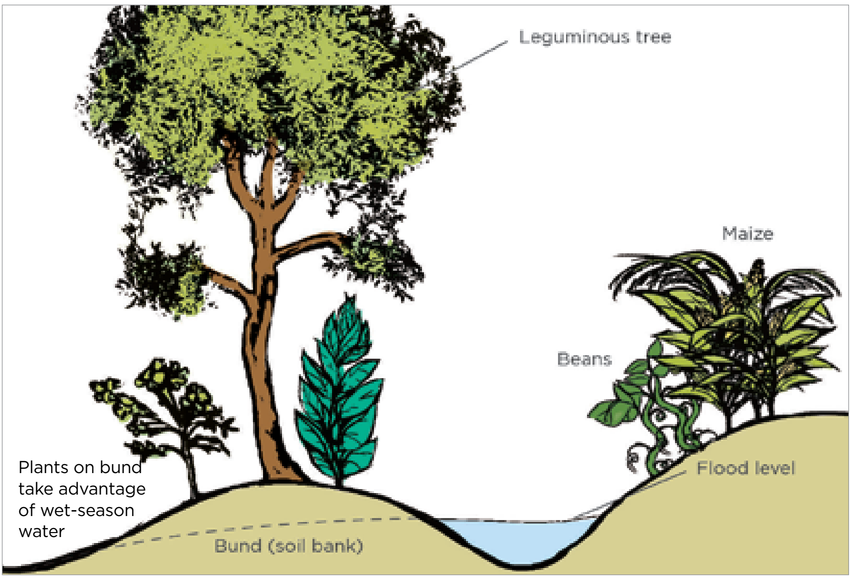
where the water flows and adjust the depth of the ditch by adding soil to deeper areas. Once that's done, you can fill the ditch with anything that allows water to percolate through: leaves, stalks, woody material or compost. Or the ditch can be left empty for ease of maintenance (redigging) or for planting during the dry season.

In heavy rainfall, contour ditches will fill with water and need a "relief valve" to drain excess water and prevent the berm from eroding. The relief valve, or spillway, is a series of slightly lowered portions of the berm, dips in the berm spaced every 3 to 10 meters apart, depending on how evenly the berm and ditch were constructed. The spillways can lead to ponds, basins, other contour ditches or another field. If farmers have access to a draft animal or plow, contour ditches can also be plowed in pastures to keep them green after the end of the rainy season.

3.3.2 Contour ditches with live barriers

By planting trees, grasses or crops on the berms above contour ditches, you can take advantage of the extra soil moisture. The roots of the plants will also help strengthen soil structure and keep the berm from eroding or washing away. Plants add organic matter that will create a layer of topsoil with time.

Figure 10: Infiltration ditch and live barrier



Adapted from *Introduction to Permaculture* (Mollison & Slay 1991)

Where hillsides are badly eroded, contour ditches with live barriers can heal the land while growing trees and plants that provide food or animal feed. After digging several contour ditches, plant fast-growing, drought-resistant plants and legumes such as beans to quickly build soil fertility and maintain moisture. If you prune and drop excess foliage, it will add extra organic material to the soil as mulch (see *Mulch,* Page 58). When soil fertility increases after a couple of years (termites or worms are a good sign of soil fertility), you can plant trees, perennial plants (bushes) and annual crops (vegetables, beans, grains) on the contour berms.

Tips for live barriers

- Use live barriers on the contour in areas at high risk of water or wind erosion.
- Use live barriers on sandy soils to reduce erosion and stabilize a slope.
- Use live barriers along contour ditches.
- Plant live barriers with species that have more than one use.

Resources

Burnett, G. 2000. *Permaculture: A beginner's guide*. Land and Liberty Press: Essex, UK.

3.3.3 Stone barriers (dead barriers, stone bunds)

When soils are too dry, compacted or degraded, a contour ditch may be impossible to dig. Instead, farmers can construct a stone barrier on the contour without a ditch.

How to build a stone barrier: Mark the contour line as described above (see *Countour ditches*, Page 34). Build a low rock wall of stones about 0.5 to 1-meter high along the contour line of a cropping area or hillside. Farmers can encourage plant growth by letting any native seeds stored in the soil above or below the barrier germinate and grow without weeding. They can also allow organic debris to build up next to the barrier during rainstorms. The new growth can provide a habitat for small wildlife and support regrowth of native grasses and trees.

Stone barriers along the contour line will slow water flow and reduce soil blown by high winds. If stones are present in a field, removing them from the soil to build barriers makes it easier for crops to grow.

Another advantage is that the work can be completed during the dry season, so the barriers are in place and working at the start of the rainy season. If enough stones are present, the barriers can be constructed as rock walls. When they are built on sloped land and are high enough, bench terraces will form as the soil fills in behind each wall. When there are not enough rocks to completely fill the barrier, the gaps can be filled by planting live barriers. Over time, stone barriers not only help reduce water and soil losses but also reduce the steepness of slopes to make crop management easier.

In dry climates where it is hard to establish new growth, even if stone barriers are not combined with a contour ditch to trap water, they can still capture small amounts of precipitation to:

1. Stabilize the slope with vegetation.
2. Slow the flow of rainwater when it does fall.
3. Provide shade for plants growing between the barriers.
4. Release heat during cold nights.

The challenge of stone barriers: When a dead barrier is used to plug a gully and stones are so tightly packed that they completely block water flow, water pressure can build up behind the stone barrier. During storms, two new gullies can form, one on each side of the dead barrier.

3.3.4 Stone barriers in semi-arid zones

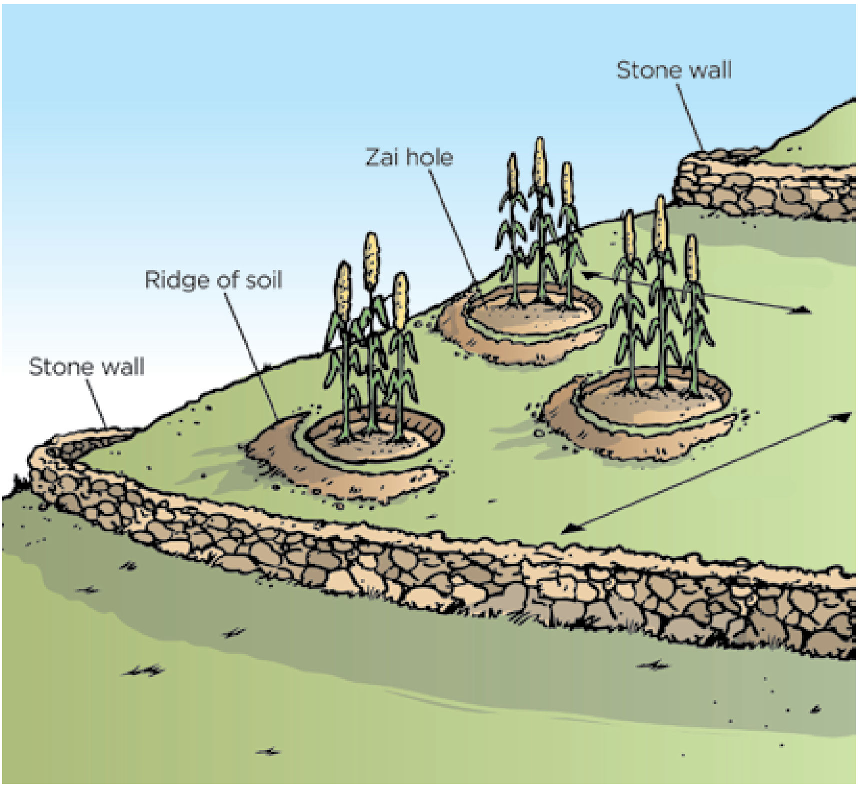
In semi-arid West Africa, conditions for agriculture are harsh. Soils are infertile, acid and crust-prone; weather is unpredictable, with droughts and intense monsoon rains. Soils undergo long periods of water stress because of runoff from crusted soils during intense rains, soil evaporation with high temperatures, and levels of organic matter too low to help retain soil moisture. Combinations of practices are the most effective for adaptation to climate change. A team of researchers led by R. Zougmore gathered evidence on one system that works well on nearly level land or slight slopes and involves stone barriers on the contour combined with traditional zai holes or semi-circular half-moon basins planted between the barriers.

Zai holes are small pits that are dug during the dry season. When the rains begin, farmers fill them with compost, manure, straw or plant leaves, such as legumes or neem, to concentrate rainwater and nutrients where the plants will grow. Half-moons are larger depressions in the soil that follow the same principle as zai holes. The combination of stone barriers with zai holes and half-moons is used to increase soil moisture and improve degraded soils. It is best suited to slopes of 3 percent to

5 percent in alternating wet and dry conditions with annual rainfall of 300 to 800 mm. For slopes that are somewhat steeper, zai holes are combined with bunds just below the zai holes.

How to design stone barriers and planting holes: Draw contour lines during the dry season and remove the top 10 to 15 cm of soil along the contour line, if possible, to seat the base layer of stones in the excavated depression. The soil that has been removed can be used as a small bund upslope from the stone barrier. Build stone barriers to a height of 20 to 30 cm above the ground. In areas where slopes are 5 percent or less, the contour barriers are spaced 20 to 50 meters apart. Within the borders of the stone barriers, break the soil crust and dig half-moons or zai holes. Zai holes are 10 to 20 cm deep and 20 to 40 cm in diameter, and they are spaced 60 to 100 cm apart between holes in the row and between rows.

Figure 11: Zai holes

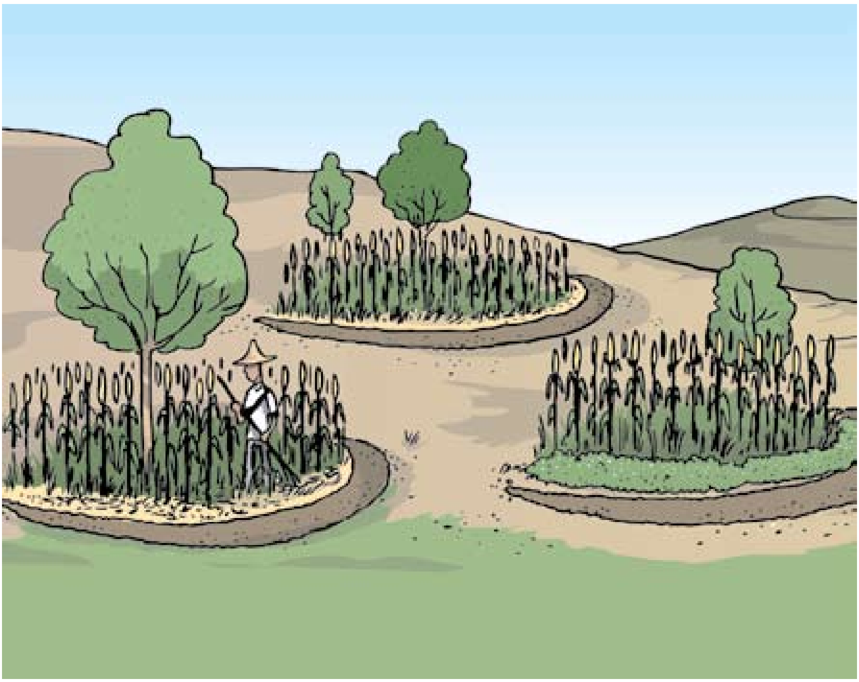


If there is a slope of more than 5 percent, use the soil from the pit to form a small half circle ridge or bund on the downslope side of the zai hole to capture additional water into the hole. At the beginning of the rainy season, add a small amount of manure or compost to each pit (200 to 600 g) mixed with about 5 cm of soil. Farmers then plant 8 to 12 seeds of sorghum or millet in each hole.

For half-moon bunds, the holes are dug in a half circle 2 to 4 meters in diameter with soil forming a half-moon bund downslope of the hole. The distance between half-moons within a row and between rows is about 2 meters. Add at least 35kg of manure or compost to each half-moon before planting.

The choice of zai holes or half-moons depends on the crop, slope and weather. Trees and mixed tree-crop plantings are more suited to half-moons; grains and legumes are planted in the smaller zai holes. Steeper slopes require larger holes to accommodate more runoff, and heavier rainfall requires larger, deeper holes with greater capacity to capture water.

Figure 12: Half-moon basins



Researchers found that no single practice alone, either stone barriers or planting holes, was enough to adapt to the harsh climate, but *combinations* of these practices resulted in significant improvements in yield and tree cover. When farmers applied compost and inorganic fertilizer to zai holes, sorghum yields were 10 times higher than yields in plots without stone barriers or zai holes, and biomass production was five times higher. With the addition of crop residue and manure, termite activity increased and improved soil structure, water infiltration, drainage and root growth in the more hospitable soil environment of planting holes.

The challenge of stone bunds, zai holes and half-moon bunds: They require access to manure or compost and large amounts of manual labor. Zai holes can require 60 to 70 days of work for one hectare in hard soils; 30 days in less-compacted soils. If the community has not already organized group labor, you might recommend this to rotate the work from plot to plot. Another role for extension is to provide training in compost production.

In clay soils and loams, planting holes may become waterlogged if annual rainfall exceeds 800mm. If this is a possibility, note that sorghum tolerates both wet and dry conditions; millet tolerates only dry weather. In sandy soils, the addition of organic matter, especially manure and compost, is essential to improve water-holding capacity.

Resources

Motis, T. & C. D'Aiuto. 2013. *Zai pit system*. ECHO Technical Note #78. Educational Concerns for Hunger Organization: North Fort Myers, Florida, USA.

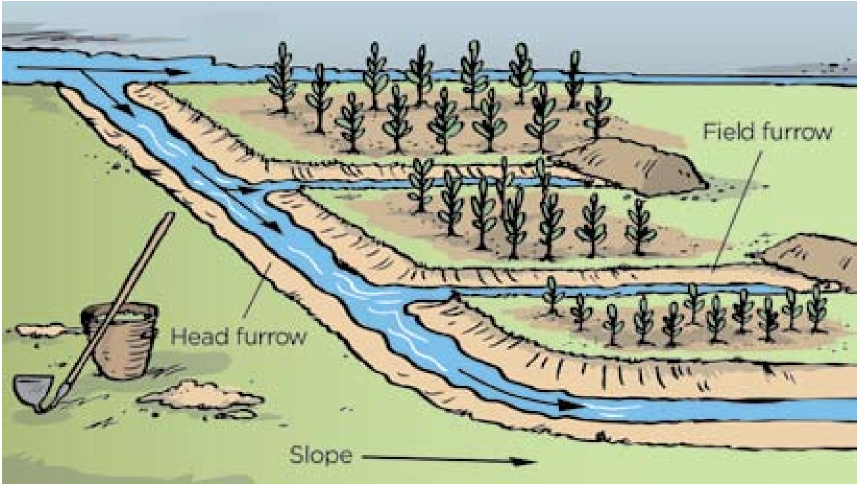
Zougmore, R., A. Jalloh & A. Tioro. 2014. Climate-smart soil water and nutrient management options in semiarid West Africa: A review of evidence and analysis of stone bunds and zai techniques. *Agriculture & Food Security* 2014, 3:16.

3.3.5 Drainage and diversion ditches

Drainage waterways lead runoff from storm water down natural drainage lines or from structures such as diversion ditches to lower lying areas. Diversion ditches are similar to contour ditches, but they are gradually sloping drainage ways that channel drainage water to contour ditches, basins, ponds or planted areas – pastures, gardens or wooded areas.

Seek to establish safe waterways by taking advantage of natural drainage lines that will not cause gullies or flooding and divert water to level terraces, depressions, pastures or the edges of wooded areas.

Figure 13: Diversion ditch



Traditional techniques of floodwater farming use natural drainage waterways: You can test this practice by constructing simple, permeable barriers of stakes or wood posts with woven brush in between the stakes to slow and spread natural floodwaters more evenly into lower, more level areas. If runoff causes contour ditches to overflow or damages bunds, farmers will need to construct diversion ditches in the same way that was used to build contour ditches to direct water to a pond, pasture or orchard. The ditch needs to be designed in a very gradual downward path.

Resources

FAO (United Nations Food and Agriculture Organization). 1988. *Watershed management field manual: Slope treatment measures and practices*. Forestry Department, United Nations Food and Agriculture Organization: Rome, Italy.

3.3.6 Water harvesting in basins and ponds

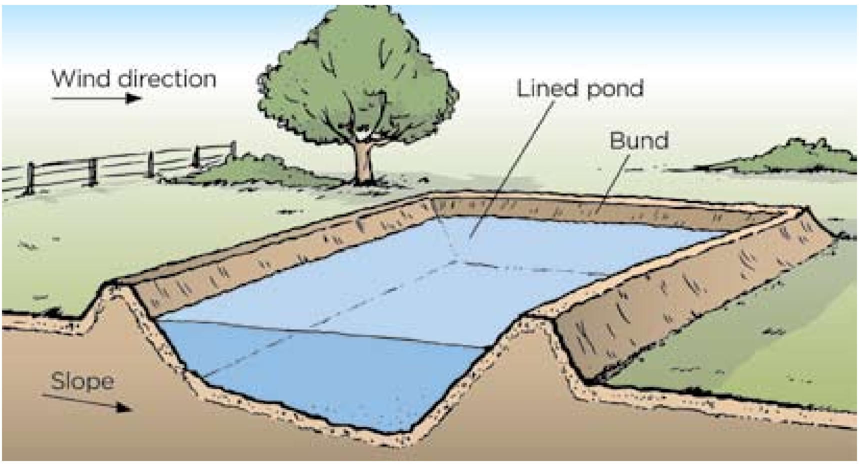
Rainwater can be collected in properly constructed **ponds** and **basins**. Although this may require arduous digging, it will allow for water collection where the farmer needs it. These structures can reduce vulnerability to weather extremes of flooding and droughts. Basins act as drainage areas that fill up only during rainstorms. Unlike ponds, which tend to store water most or all of the year, basins generally do not contain water year round. Ponds can be created anywhere that water flows through the land. They provide a destination for water to flow into and have spillways for water to overflow through. Ponds can be connected to a system of contour ditches or diversion ditches that drain water into a pond or across the land into other ponds, helping to lessen damage by heavy rainfall. Pond size will vary on the basis of location, water quantity, velocity of water flowing to the pond and farm family resources to dig it.

Shallow basins can be dug by hand and have level bottoms. They can be used as vegetable gardening areas during dry months, or these "rain gardens" can be planted with deep-rooted native plants and grasses near a runoff source such as pathways, roads or downspouts from rooftop water collection. The plants in a rain garden must be able to withstand brief periods of standing water and longer dry spells.

In areas with high amounts of seasonal rainfall, ponds act as mini reservoirs that can be used for on-site irrigation during dry periods. Ponds also support fish, plants and many diverse organisms. Fish help fertilize plants, and eat mosquitoes and pond algae. They also add a layer of food security for families by giving them direct access to fresh fish. Depending on pond size and depth, various types of fish can be introduced and grown for food consumption during times of famine. (For more information, see *Resources*.)

Another feature of ponds is their ability to absorb daytime heat and release it at night. By moderating temperature extremes, ponds create microclimates for some plant varieties to grow where normally they would not be able to grow.

Figure 14: Lined pond for irrigation



The challenge of ponds: Though ponds have many benefits, they usually require maintenance, some cash investment, and large initial time and labor commitments. If a farm family wants to build a pond, you can help by making a connection to, or consulting with, local experts to design a pond that meets the family's needs. It may also require community agreement and planning to identify pond locations, construct the pond, and manage maintenance and use.

The type of pond will vary depending on the type of landscape.

1. **Embankment ponds:** Formed by a dam constructed in a depression between two hills where the water flows down through the watershed and is collected in the basin area on the upstream side of the dam. These ponds are best suited to areas with slight to moderately rolling topography.
2. **Excavated ponds:** Usually built on relatively flat areas with rented equipment that moves earth, or shared community labor. They need an external source of water or a spring to fill and maintain water levels. This can be the most expensive type of pond.
3. **Levee ponds:** Formed in a slightly excavated basin, where the soil removed is used to build bunds around the borders of the pond, sometimes called levee edges. Water from an external source, such as a stream, may be pumped in or gravity-fed from diversion ditches.
4. **Combination watershed-levee ponds:** A levee pond built between two hills where water flows during a rainstorm. This type of pond is practical for small farmers with limited access to resources.

Tips for building ponds and basins

Small ponds can be dug by a group of people. Larger ponds are generally built using earthmoving machinery. Pond size and depth will vary with the type of pond, the space available for the pond, the amount of water to be stored, and considerations such as the presence of livestock grazing nearby and the safety of children. Some ponds will be used to store water as a reservoir for irrigation. Others may be used to grow fish and aquatic plants. Some general suggestions for pond construction follow. (See also *Resources* below.)

First, consult local professionals for advice. Then ask farmers to observe the water flow where they farm to understand the opportunities and constraints on that site. Locate potential sites for pond excavation by starting at the top of the farm where water enters. Generally, flat areas with water basins or sunken depressions in the earth make good pond sites. For most farmers, rainwater will be the most likely source of water to fill the pond. Therefore, it is important to design a contour ditch system that will feed into the pond during rainstorms, as well as a spillway or outlet for heavier water flows.

Often a pond depth of 2 meters is a good depth to start with. Ponds that are dug on the contour will help capture rainfall and minimize spillover flooding. Depending on soil type and composition, a heavy rubber liner is usually necessary to line the hole that has been dug before the pond fills with water. If the soil has lots of clay, it can be compacted to make a layer that slows percolation of water out of the pond.

Ponds should not be built on sandy soil because it does not hold water well.

For ponds that will hold fish and plants, local experts can give advice about plants, fish species and pond management. For example, the edges of the pond should be shallower for the growth of aquatic plants. Another feature for ponds with fish, if electricity and funds are available, is a small water pump to maintain oxygen levels. This prevents algae growth from building up and choking aquatic life. Local experts can help guide design and answer questions.

Basins can be formed naturally. During heavy rainstorms, large sunken areas on the land act as drainage basins to collect water and allow it to percolate slowly into the soil. Basins differ from contour ditches in that they don't have to be on the contour and can vary in size. Basins can have spillways for heavy rains. You can connect a series of basins together with small ditches or canals dug slightly below ground level. If there is a naturally occurring basin on a farmer's land, the farmer can plant water-loving plants around it to help reduce erosion and increase water infiltration.

When you help to map a farm or farming community for contour ditches and bunds, help to look for areas where the farmer might want to encourage water basin formation. Find a flat area where a shallow basin can be dug easily. Do not dig basins on steep slopes as they increase the risk of erosion, flooding or mudslides downslope. Following the flow of the land, a basin can be dug to wrap around certain features such as a tree or pathway, but make sure water will flow in the direction you want it to flow during heavy storms. Dig down about 30 to 50cm, and slope the outer edges inward to create the basin. As above, planting cover crops or other water-loving plants on the exposed soils will help to retain the shape of the basin. If you plant a tree in the middle of a basin, it is useful to make the basin diameter at least 1.5 times the diameter of the drip line of the mature tree's leaf canopy.

Avoid digging basins on steep slopes because it increases the risk of erosion from the basin down the slope.

Gravity-fed irrigation from ponds

Using ponds to supply water for irrigation by gravity has advantages in cost and simplicity (see also *Section 3.4.2*). After digging the pit for a pond in a good rainwater catchment area, attach an outlet pipe about 10cm above the base of the pond. This pipe, which runs from the base of the pond out to the slope below, will need an on/off valve so that water drains out only when needed. Connect a hose for irrigation to this valve. Sediment will settle on the bottom of the pond and should not clog the pipe, but you still need a filter or screen at the start of the outlet pipe to prevent leaves or other matter from clogging it. Compact the base of the pit by stomping on it – this will help maintain the pond's shape and structure. The final step is to line the pond with either a tough plastic sheet or homemade plaster:

1. Mix cement, straw and soil in a ratio 1:1:3 or 1:1:4 (1 part cement, 1 part straw and 3 to 4 parts soil).
2. Add water to make a thick plaster.
3. Start by plastering the sides of the pond, and finish with the pond floor.
4. Let the entire pond dry for at least three days before letting any water in.
5. Repair cracks using a mixture of cement, straw and soil in a ratio of 2:1:3.

To reduce evaporation, cover the pond with a reed mat, palm leaves or other materials. Some people float recycled, empty but recapped plastic bottles on the pond surface to increase the reflection of light off the water, and thus controlling evaporation. Light heats the water and increases the rate of evaporation. You can also grow trees around the pond to increase shade and reduce evaporation.

Resources

Chakroff, M. 1978. *Freshwater fish pond culture and management*. U.S. Peace Corps and Volunteers in Technical Assistance: Washington, DC.

FAO (United Nations Food and Agriculture Organization). United Nations Food and Agriculture Organization: Rome, Italy.
Better freshwater fish farming in Zambia. 1981.
Fish pond construction and management: A field guide and extension manual. 2005.
Handbook on small-scale freshwater fish farming. FAO Training Series No. 24. 2007.
Freshwater fish farming: The pond. 1981.

Van Eer, A., T. van Schiel & A. Hilbrands. 2004. *Small-scale freshwater fish farming*. Agromisa Foundation: Wageningen, the Netherlands.

3.3.7 Dryland restoration

When temperature extremes and harsh winds accelerate soil evaporation and plant transpiration, many of the practices already discussed will help farmers to maximize water productivity. In addition, **mulching**, **shading** and constructing **wind barriers** of stones or trees all reduce exposure to water loss and high temperatures and are basic elements to establishing any sort of agricultural production in dry climates. As you select practices and design improvements to farming systems, remember that the first step in the design process is to observe the natural elements of the landscape – including potential sources of water.

Bamboo watering stick

Hollowed-out bamboo poles with small holes punched throughout can be buried next to newly planted trees. These poles can be filled with water once a week to provide an evaporation-free, slow-release source of water directly to the roots. See also *Bamboo watering stick*, Page 61

When you start to restore land in extremely dry areas it is best to do it in phases. First look for an outside source of water to start small plants and trees. If rainfall is the only source, consider where to place earthworks to start the restoration process. For example, after a time of low rainfall, stone barriers placed on the contour will collect and trap organic debris and material for moisture retention. Farmers can begin growing drought-resistant pioneer plants to maintain soil moisture.

After a few seasons of protecting the soil with mulches and building up organic material through plant vegetation, small trees can be established to create a canopy layer and provide much-needed shade. Once a canopy layer is established, annual crops can be grown within the protective microclimate of the trees. (For a video on restoring and transforming desert landscapes into productive food forests, see *Resources* below.)

Protect. Buffer. Shade.

In dry climates, it is important to incorporate anti-evaporation strategies – protect the soil with mulch, buffer the wind with stone barriers and introduce shade by planting drought-tolerant trees, which can also be used as windbreaks.

Hardy tree species are the first to grow in severely degraded areas and can help to restore land (see *Resources*). They tend to be legumes, which can fix nitrogen (take it from the atmosphere and make it available in the soil for use by plants). They also tend to be drought-tolerant and fast-growing, and have multiple uses (forage, fuel, food, lumber). Many can be coppiced, or cut back to the stump, after which they will regrow with new branches. These species include *Acacia*, *Leucaena*, and *Sesbania*. (A more complete list of tree species suitable for land restoration is included in *Resources*.)

Resources

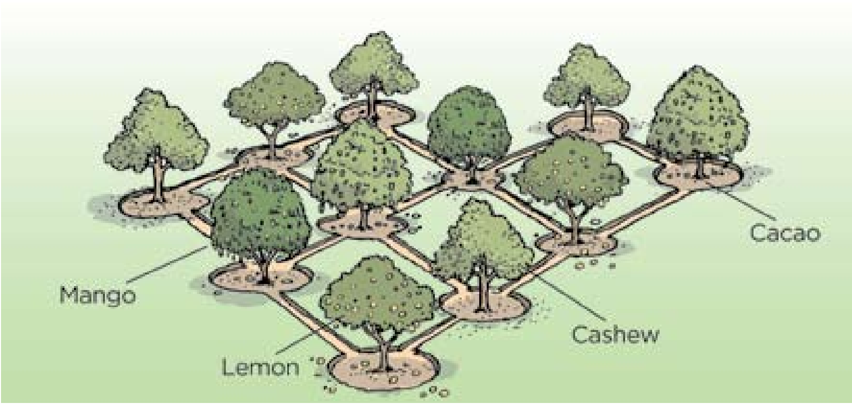
A list of pioneer plant species for desert restoration by G. Lawton

A video by G. Lawton entitled *From Desert to Oasis in 4 Years*

Net and pan system for dryland restoration

Another strategy to restore depleted or abandoned drylands is to design a net and pan network in the soil for faster establishment of pioneer tree species or small orchards. It could also be used to convert existing crop fields to an agroforestry or mixed tree-crop system or to convert degraded pastures to a higher productivity tree-forage system. Trees are planted in small basins that the farm family digs. The basins collect rainwater for percolation into the soil around the tree. The trees are connected by a network of shallow trenches that capture rainwater and sediment. By planting diverse trees and trees that have multiple uses, farm families can improve their access to food, fuel, livestock feed and wood for construction.

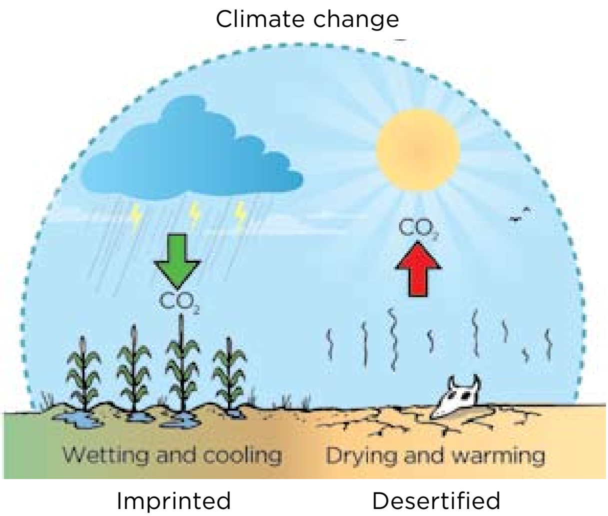
Figure 15: Net and pan system for dryland restoration



Imprinting for dryland restoration

Imprinting is a method used to restore degraded lands that have experienced overgrazing, overcultivation or deforestation. It uses small, continuous depressions in the soil placed side-by-side throughout a landscape to hold soil and rainwater in place for germinating seeds that already exist in the soil or can be added. This microtopography, a surface of many small depressions, helps seedlings establish and grow by providing this small amount of additional water capture and protection.

Figure 16: Imprinting for dryland restoration

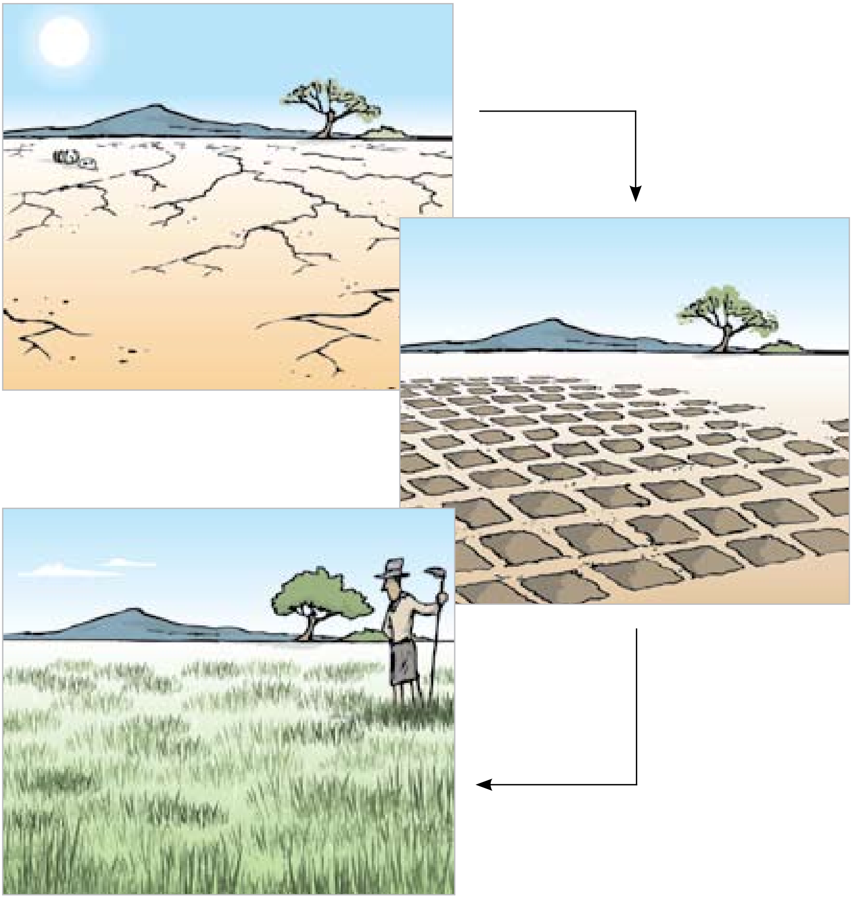


Adapted from: The Imprinting Foundation (see *Resources*)

A tractor (if available) pulling a toothed roller creates V-shaped depressions. In place of a tractor, the hooves of a draft animal, or slow-moving deep-knobbed wheels can create similar imprints. The plants growing in the rough, imprinted surface will absorb carbon dioxide (CO_2) from the air. This reduces one of the greenhouse gases that contributes to global warming, while revegetating previously bare soil.

Once land is restored, farmers who keep the soil covered throughout the year with grasses, trees, cover crops or dead plant matter will protect the land with the least effort. Many farmers also prefer this practice to the hard work of building stone barriers (*Section 3.3.3*).

Figure 17: Imprinting



Resources

IIRR. 2002. *Managing Dryland Resources: An extension manual for Eastern and Southern Africa*. International Institute of Rural Reconstruction: Nairobi, Kenya.

Information on net and pan systems

Information on imprinting

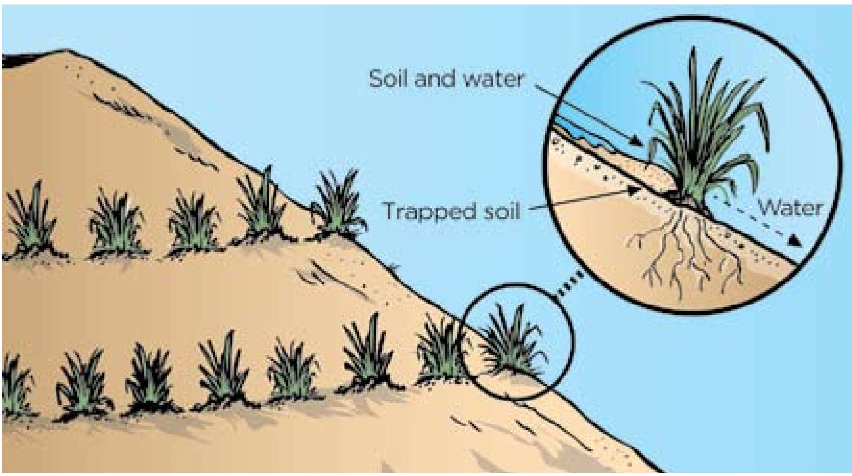
3.3.8 Water harvesting with vegetative practices – live barriers, buffer zones, cover crops and mulch

When farmers plant trees, shrubs and grasses, or maintain natural vegetation in contour strips on slopes, along contour ditches, around plot borders or along sources of water, they are also managing water. When farmers plant on the contour or at right angles to wind direction, the vegetation reduces evaporation from the soil, slows the flow of water from rainfall, improves infiltration and increases soil organic matter. The organic matter increases the soil's ability to hold water. All of these benefits help to conserve water for later use when there is no rain.

Live barriers

Live barriers are strips of vegetation that anchor the soil in place with plant roots, slow the movement of water downslope, reduce the loss of soil nutrients needed by plants and increase water productivity (the amount of biomass produced with a specific amount of water). Farmers can plant live barriers across the path of wind, around plot borders or above hillside ditches to prevent erosion and the ditches filling with soil. Plants from the grass family have dense foliage and thick root systems, so are used most often. Grasses that are also valuable as forage for animals or grasses such as sugar cane and lemon grass that are used in the household are often preferred. Many plant species have great potential as live barriers. Contour strips of leguminous trees can also add nitrogen to the soil, while producing legume fruit, firewood or livestock feed.

Figure 18: Live barriers before full coverage



If a soil is very sandy, water infiltration is not a problem. In sandy soils, infiltration ditches will only collapse with new rainfall. But permanent live barriers of bushes or trees, especially when planted with cover crops, will provide many of the benefits of live barriers above.

Buffer zones and vegetative strips

In water management, buffer zones are strips of vegetated land that are used between agricultural land and a body of water such as a river, pond, stream or spring. They protect the water source and the banks around the body of water. They help farmers adapt to climate change by reducing flooding and any water contamination from farm fertilizers and chemicals. They trap and store sediments by creating a barrier between cultivated land and bodies of water. In this way, the buffer reduces sedimentation of the water body and the maintenance needed to protect it. The root system of the vegetation and trapped sediments bind the soil on river banks by increasing the surface roughness and slowing runoff to minimize the impact of heavy rain. Buffer zones also increase aquifer recharge and raise groundwater levels. The extensive root systems of vegetation improve soil porosity – the space between soil particles – for better drainage.

How to create buffer zones: Buffer zones can form naturally if farmers leave a strip of land unplowed and ungrazed so that grasses and trees can return with time. Or they can plant the buffer zone with grasses such as king grass or vetiver, which have deep roots and will not spread to unplanted areas. The width of a buffer zone is generally 30 to 50 cm. The wider the buffer zone, the more effective it is at filtering sediment or pollutants and storing runoff.

If the aim is to protect the land above a spring, the community or landowner may be willing to fence off a large area above the spring for revegetation. Putting infiltration pits in a fenced area will improve the recharge of the spring and increase water flow from the spring. You may also need to cut back grasses near the spring during the rainy season to allow people's access to the water source. Natural grasses can be cut back to about 10 cm, vetiver can be cut back to a height of 30 to 50 cm.

Cover crops

A cover crop is planted to improve soil fertility and overall soil quality while helping to manage water, weeds, pests and disease. Cover crops reduce soil erosion and often reduce the rate and quantity of runoff. The cover crop acts as a physical barrier between rainfall and the soil surface, allowing raindrops to soak into the soil rather than running off, taking soil particles with them. The roots form pathways for water to filter into the soil and then to refill the aquifer when the amount of water exceeds the soil's holding capacity.

Figure 19: Cover crops – maize with a bean cover crop

How to use cover crops: You can plant cover crops by direct seeding or by hand broadcasting into the stubble or residue of the previous crop. When rapid soil cover is needed – for example, if you expect rains to end soon – a field can be over-seeded for dense growth early on by planting more seed per land area than is normally recommended for that cover crop. (For more information, see *Pocket Guide 2: Managing Crops*.)

Once the cover crop has grown, you can cut it back and mix the plant material into the soil or leave it as a mulch (dead plant matter left on the surface of the soil). Just before cover crops are cut, they contain a large amount of moisture that can be transferred to the soil, whether it is incorporated or left on the surface as mulch. As a mulch, cover crops conserve water by shading and cooling the soil surface while reducing evaporation of soil moisture.

As a mulch, cover crops conserve water by shading and cooling the soil surface while reducing evaporation of soil moisture.

If you work in a low rainfall area, cover crops can also reduce soil water because the cover crop itself needs some moisture to grow. In this case, help farmers to decide between the benefits of increased cover crop growth and the drawbacks of reduced soil moisture.

Table 2: Adaptation of common legume cover crops

Common name	Botanical name	Cover crop tolerates
Cowpea	*Vigna unguiculata*	Drought, shade
Jackbean	*Canavalia ensiformis,* *Canavalia brasiliensis*	Drought, low soil fertility, shade Drought, low soil fertility
Lablab bean	*Lablab purpureus*	Drought, shade
Leucaena	*Leucaena leucocephala*	Drought, shade, low soil fertility
Pigeon pea	*Cajanus cajan*	Drought, low soil fertility
Tropical kudzu	*Pueraria phaseoloides*	Flooding, shade (humid lowlands)
Velvet bean	*Mucuna pruriens*	Drought, low soil fertility Drought, low soil fertility

Adapted from *Conservation of natural resources for sustainable agriculture*

From poverty to profit: Maize-Mucuna-Mahogany farming systems

Farmers in Central America have had great success with Mucuna (velvet bean) cover crops in no-till maize production on slopes that used to be degraded. The velvet bean plants and maize residue cover and protect the soil year round, adding nitrogen and organic matter and improving soil moisture, suppressing weeds and increasing maize yields. Pigs thrive on a mix of equal parts maize and cooked Mucuna, gaining weight and going to market sooner than in the past. Every 7 to 8 meters in the maize field, farmers plant a hardwood tree of high value such as mahogany or teak. They are not concerned that the trees may take 20 to 25 years to mature, because they receive a good income from the pigs. Farmers prune the lower branches of the mahogany at the end of the dry season so shade does not interfere with maize growth. Their crop has plenty of water and natural fertility while their income increases from the sale of maize and pork.

Mulch

Mulch is dead plant matter used to cover the soil surface. It can be straw, leaves, stems, other plant residue, woody material, compost or bark.

Figure 20: Mulching

Mulch protects soil water from evaporation and the soil from wind and temperature extremes. A layer of mulch greatly reduces the need for irrigation. On crop fields, mulch also:

- Suppresses weeds that take soil nutrients and water away from crops.
- Increases soil fertility by adding organic matter.
- Reduces erosion.

Add mulch layers to contour ditches, basins, trees, gardens, and bare soil to retain soil moisture. Especially in dry areas, if you have access to it, use mulch between crop rows and around fruit trees and bushes. You can use a depth of 10 cm of mulch on well-drained soils and 5 cm on harder clay soils. Place mulch in a circle of about 1 to 3 meters in diameter around a tree.

The type of mulch you use will depend on which plants you are growing and what materials are available. You can mix legume cover crops into the soil without a problem, but it is best not to mix straw, crop residue from grains or woody material into the soil unless you also add manure or residue from legumes.[2]

2. During decomposition of grain residue, straw or woody materials, soil micro-organisms that breakdown the mulch and support decomposition need additional nitrogen from the soil. This reduces the amount of soil nitrogen that is available for plant growth. Legume cover crops, such as the ones in the table on Page 57, already have sufficient nitrogen in their residue, adding nitrogen to the soil during decomposition. Soil micro-organisms require a ratio of 24 parts carbon (C) to 1 part nitrogen (N) when they consume and breakdown plant residue. Sorghum residue has a carbon to nitrogen ratio of 63:1 and maize has a 57:1 ratio, which means that microbes must find additional nitrogen in the soil to consume these residues. This can deplete soil nitrogen for plant growth. On average legumes have a C:N ratio of 17:1, so they can be mixed directly into the soil. When grain crop residue is mixed into the soil, adding legume residue or cattle manure (C:N ratio of 17:1) or poultry manure (10:1 ratio) avoids depletion of soil nitrogen.

Tips for mulches

- Straw is a good choice for mulch when applied to the soil surface between rows of crops. It suppresses weeds, keeps vegetables or fruit off the ground and reduces plant disease. Dried palm leaves or sugar cane foliage also works well.
- Piling mulch directly against a plant or tree can hold excess moisture near the plant and encourage fungal diseases or bark decay. Keep mulch about 3 to 5 cm from the base of the plant.
- Use only mulch materials that come from disease-free plants. Plant diseases can sometimes be passed from one plant to another through the mulch.
- If mulch smells like vinegar, ammonia or sulfur, remove it and apply a different source of mulch. The smell means that the mulch has not decomposed properly.

3.4 WATER USE PRACTICES: SMALL-SCALE IRRIGATION

Farmers may report that the rainy season is delayed. Or they plant when the rains come and two weeks later the rain stops completely and they lose the entire planting. Or there is a drought that starts after crops are up and growing well. Crops wilt and die, farmers lose the crop, and it is too late to plant a new crop.

When farmers are able to store enough water in the rainy season to irrigate for even a few weeks, this can help produce or save a crop by reducing exposure to unstable weather. This type of strategic irrigation is called supplementary irrigation because it provides water for a short time during a dry spell in the rainy season.

The small-scale irrigation practices described here are used by farmers who can capture and store enough water in the rainy season for supplementary irrigation. In some cases they may be able to store enough to grow vegetables or irrigate a small orchard in the dry season. This guide presents basic information on three approaches to irrigation: drip irrigation, gravity-fed irrigation and rooftop rain collection. Because so much irrigation water comes from wells that have overused groundwater, the practices here focus on rainwater harvesting and more careful use of surface water found in nearby ponds or streams, for example. As an extension field agent, you may need to explain to farmers how to manage the use of groundwater to avoid overuse, why that is important, and how overuse of groundwater can lead to tension or conflict in the community.

How to choose an irrigation method: First, interview farmers to help them decide whether irrigation is needed, whether it is an appropriate practice for their plots and how to select the most suitable irrigation methods. Some plots near the house are more suited to hand watering, some plots are better for gravity-fed pipes or sprinklers, and some are best suited to drip irrigation. The answers to these questions will help you to plan and address any limitations or obstacles:

- What is the main source of water and where is it located?
- How much water is available and at what times of the year for which crops?
- What is the quality of water? Are there pollutants that contaminate the water and make it unsuitable for irrigation? Are there high amounts of salt that will reduce the plants' ability to absorb water?
- How steep is the land? How does rainwater flow across it? Is erosion a problem?
- What are the characteristics of the farmer's soil? Is it sandy and will it lose water quickly? How much organic matter is in the soil? (Organic matter will provide nutrients to plants to help improve water uptake. Organic matter also acts as a sponge for holding water and draining it when there is too much.)
- How deep is the topsoil, the root growing area? Is there a hard crust or a compacted layer close to the surface that prevents water from soaking into the soil? Is there a hard layer that prevents good drainage once the water infiltrates?

3.4.1 Drip irrigation

Drip irrigation conserves water and reduces soil evaporation. It uses special hoses with holes at various intervals to provide water directly to plant roots. These drip lines are placed on the surface of the soil near a row of plants, usually vegetables. Water drips slowly through the holes near the plants. Drip lines and drip equipment can be complex and costly, but the practices shared here are simple methods that most small-scale farmers can use.

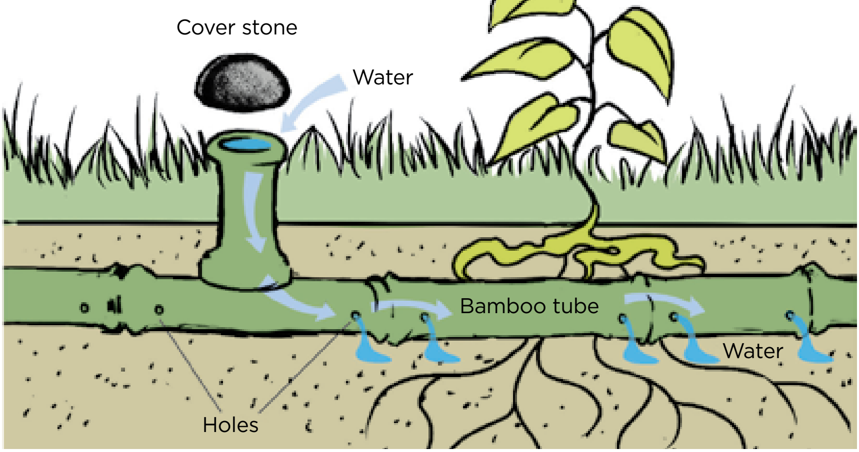
Challenges of drip irrigation: Drip irrigation is an important practice for helping farmers adapt to longer dry seasons, especially in areas where water is scarce or where farmers grow crops such as vegetables that fetch a high price in the market. With climate change, the Ministry of Agriculture or the agency in charge of agricultural extension and farmer training will probably need a training strategy to upgrade the skills of field agents in drip irrigation methods that are a good fit for farming systems in the area. Because drip irrigation relies on equipment that may be expensive, credit or savings programs may be important. Drip irrigation is typically more relevant to small or medium-sized plots of high-value crops such as vegetables than for large-scale field crops. Drip irrigation can lead to large increases in the value of crop production. Materials such as hose pipes decay, however, and have to be replaced every few years. Farmers have to manage their resources so that they can afford this essential periodic investment.

Small-scale drip irrigation

You can use the following techniques to reduce a farm's sensitivity to dry weather on almost any farm. They increase soil moisture near plant roots and decrease evaporation from the soil, so they make more water available for the plant. To provide the slow release of water for plants such as tomatoes and peppers or young tree saplings, farmers can use commercial plastic hoses, if available, or one of these alternatives:

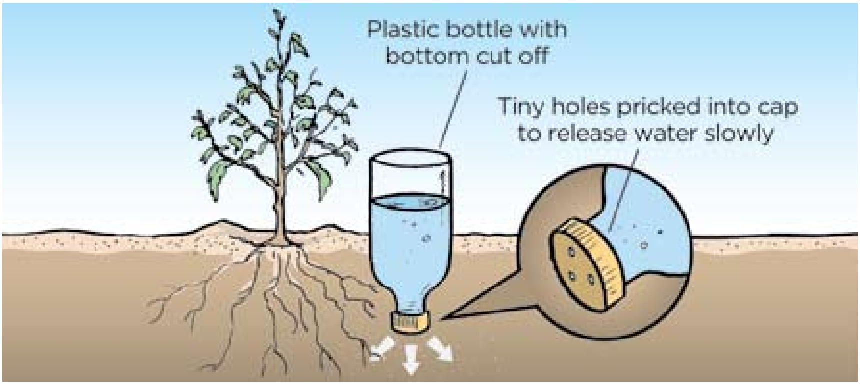
Bamboo watering sticks – Punch small holes into bamboo poles and bury them near bushes or newly planted tree saplings. Fill the bamboo poles with water as needed to irrigate plants. This practice protects water against evaporation by putting it directly into plants' root zones.

Figure 21: Bamboo watering sticks



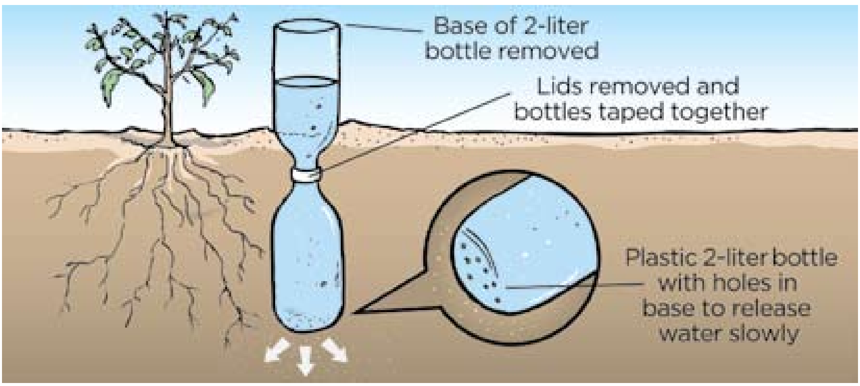
Plastic bottle irrigation method (one bottle): Poke small holes into the small round caps of 2-liter plastic soda bottles, reattach the caps to the bottles, and cut off the wide base of each plastic bottle near its bottom. Dig a small hole the size of the bottle near where plant roots will be. Place tiny stones at the base of the hole before you insert the bottle – this will prevent soil from clogging the holes and allow water to drip out. Bury most of the bottle underground, leaving the cut end, the open base, above ground. Add water to the base of the bottle every few days depending on when it empties. This method is well-suited to small plants such as vegetables.

Figure 22: Plastic bottle irrigation method (one bottle)



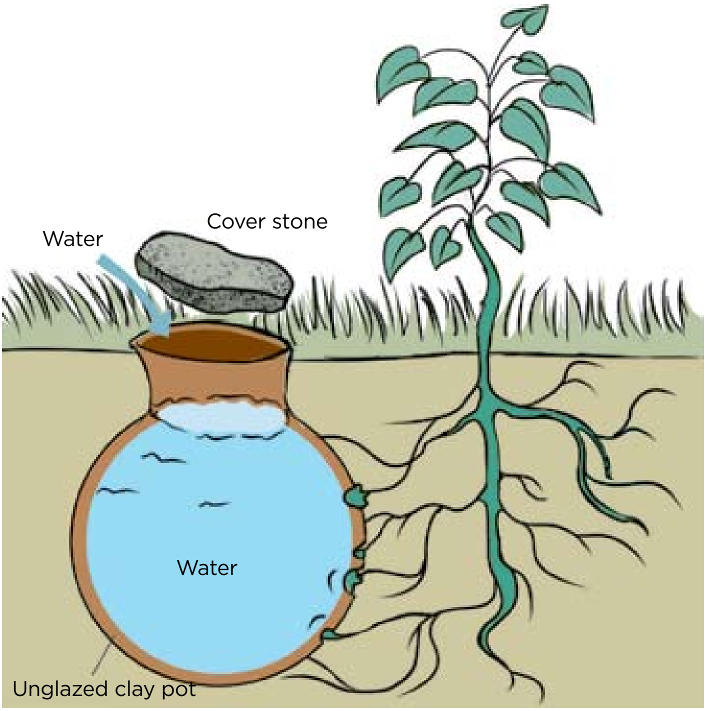
Plastic bottle irrigation method (two bottles): Poke small holes into the wide base of a 2-liter plastic bottle. Dig a small hole the size of the wide base of the bottle near where plant roots will be. Place tiny stones at the base of the hole before you insert the bottle. Bury most of the bottle underground, leaving the small mouth of the bottle near ground level. Cut off the wide base of another bottle of the same size near its base. Take off the bottle cap, turn the bottle upside down and attach the two small bottle mouths together with strong tape or wire so that water can flow from the top bottle to the bottom bottle. Fill the upper bottle with water as needed. Cover the open end of the top bottle with a rock or the cut-off base to prevent evaporation and keep mosquitoes out. This method is appropriate for plants such as young fruit trees, which need more water than vegetables, but it requires access to more recycled plastic bottles.

Figure 23: Plastic bottle irrigation method (two bottles)



Clay pots: Large, porous clay pots can be used as slow-release irrigators for nearby plants. In crop beds, pots can be buried up to their rims or necks in the soil. Water is then poured into the clay pots every 7 to 10 days. From there it slowly moistens soil and is absorbed by plant roots. Make sure the top is covered to keep insects, especially mosquitoes, out.

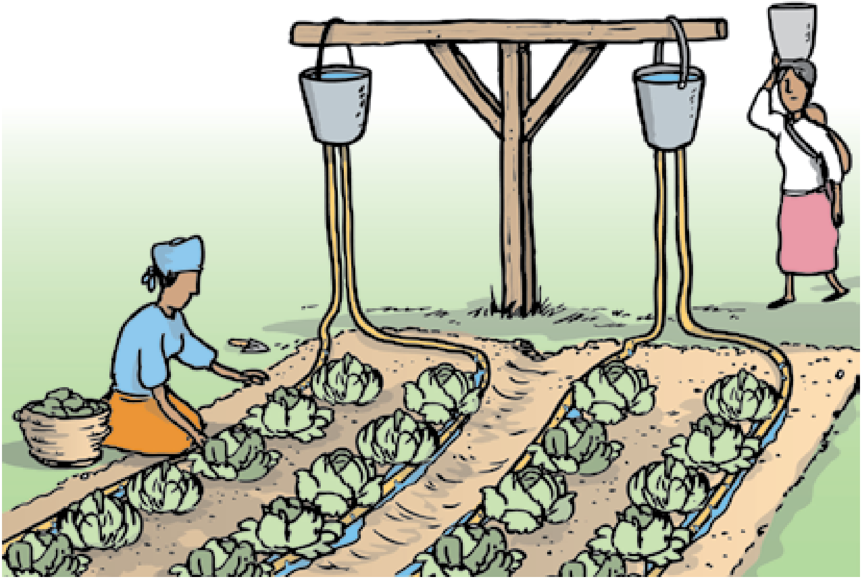
Figure 24: Clay pot buried in the soil



Drip irrigation using buckets

Buckets can also be used to irrigate 100 to 200 plants per bucket. You need one 20-liter bucket, a small filter and about 30 meters of drip hose (a hose with holes punched at regular distances along its length). The hose is connected to the base of the bucket and extends along the row of crops. The bucket must be placed at least 1 meter above the ground so that water flows by gravity down to the plants. The small filter over the hole at the base of the bucket prevents any sediment or soil from entering the hose. Additional hoses can be hooked up to the bucket (or other buckets) to extend the irrigation area. For larger crop areas, it is more cost-effective to use a single 200-liter barrel.

Figure 25: Drip irrigation using buckets



3.4.2 Gravity-fed irrigation

To complement pond irrigation (see *Section 3.3.6*, Page 45), farmers can design rainwater collection and storage methods that deliver irrigation water by gravity. When the source of water is above the area to irrigate, gravity does the work of moving water down to the crop. Gravity-fed systems are cheaper, more reliable and easier to maintain than methods of irrigation that use electric pumps. Pumps are more appropriate for larger fields and require access to larger amounts of irrigation water to be effective, an amount that may not be available to small farms.

The challenge of gravity-fed irrigation: Insufficient pressure on the water from above can cause occasional low water flow.

Tips for gravity-fed irrigation

- The water source should always be higher than the area to be irrigated.
- When ponds and large barrels supply the water, be sure to connect a pipe with a shut-off valve to the bottom of the water source so the farmer can control the timing of irrigation. In ponds, this point is the lowest acceptable water level for the pond.

Gravity-fed irrigation from rooftop water catchment

Water that falls on a roof that is sloped and made of metal or another non-permeable material can be collected and stored using gutters and rain barrels. Even small roofs can collect large amounts of water. This is an easy way to collect rainwater for irrigation if a family can afford to invest in materials such as a metal roof and gutters that lead to a downspout. A gutter system on the edges of the roof will channel rainwater into storage barrels. Farmers can install a simple gutter made from bamboo, if available, sliced in half vertically and attached with wire to the edge of the roof. The gutter is used to drain water to a tank or barrel. A series of mesh screens is used to filter out roof debris, mosquitoes and other insects.

Place barrels near the downspout and cover the rain barrels with tight lids to keep mosquitoes out. If mosquitoes are found to be breeding in the barrels, the barrels should be emptied immediately. On relatively flat land, raise barrels onto a platform to improve water flow down to a garden or crop. Most households start with a system of small barrels (100 to 200 liters). Barrels and tanks can be acquired from various places. Large plastic or metal trashcans will work, and the harder the plastic, the longer the barrel will last. Multiple barrels can be used side-by-side to create larger systems when it is too costly to build a tank. Whenever possible, remember to use gravity to move water through a system.

Figure 26: Rooftop catchment system for rainwater

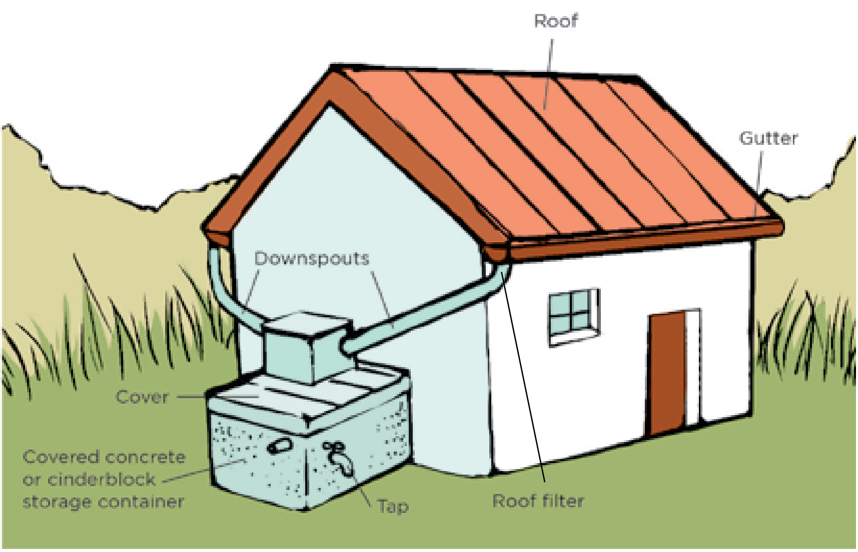
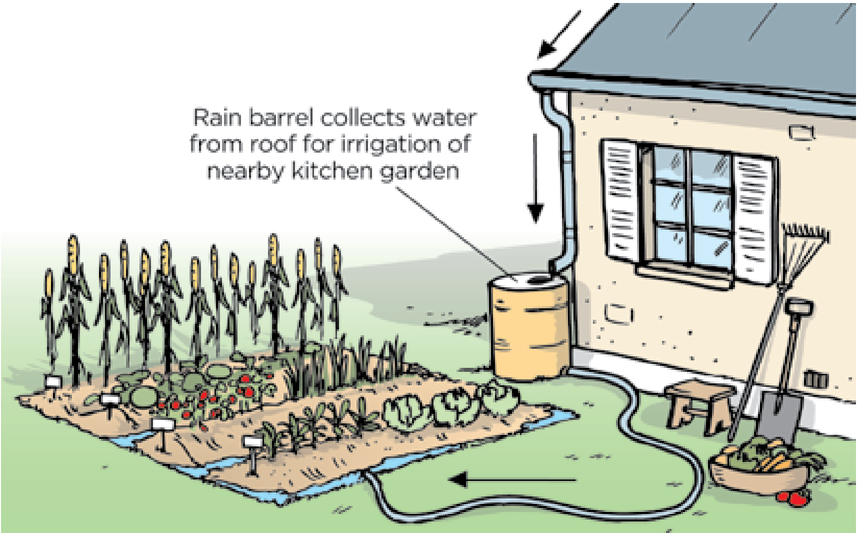


Figure 27: Rain barrel collects water from roof for irrigation of nearby kitchen garden



> **WARNING!**
>
> **Do not** use a barrel or tank that was previously used to hold automotive oil, pesticides or any other harmful materials.

There are many ways to build a roof catchment system. Technical experts such as water engineers in your area can help. If you have access to the Internet, websites listed in the *Resources* section have information on how to construct rooftop collection systems with rain barrels.

Resources

FAO. 2013. *Captación y almacenamiento de agua de lluvia: Opciones técnicas para la agricultura familiar en América Latina y el Caribe*. Oficina Regional de la FAO para América Latina y el Caribe: Santiago, Chile.

Rees, D. 1998. *Rainwater harvesting: Technical brief*. Practical Action: Rugby, Warwickshire, UK.

UNEP. Date unknown. 3.4 Rainwater harvesting for agricultural water supply. In *Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Countries of* ***Asia***. United Nations Environment Programme: Rome, Italy.

UNEP. 2008. 1.1 Rainwater harvesting from rooftop catchments. In *Sourcebook of Alternative Technologies for Freshwater Augmentation in* ***Latin America and the Caribbean***. United Nations Environment Programme: Rome, Italy.

UNEP. Date unknown. 2.1.2. Rock and roof catchments. In *Sourcebook of Alternative Technologies for Freshwater Augmentation in* ***Africa***. United Nations Environment Programme: Rome, Italy.

Worm, J. & T. van Hattum. 2006. *Rainwater harvesting for domestic use*. Agrodok 43. Agromisa Foundation and CTA: Wageningen,The Netherlands.

See *Section 3.3.6.* for information on *Gravity-fed irrigation from ponds*, Page 49

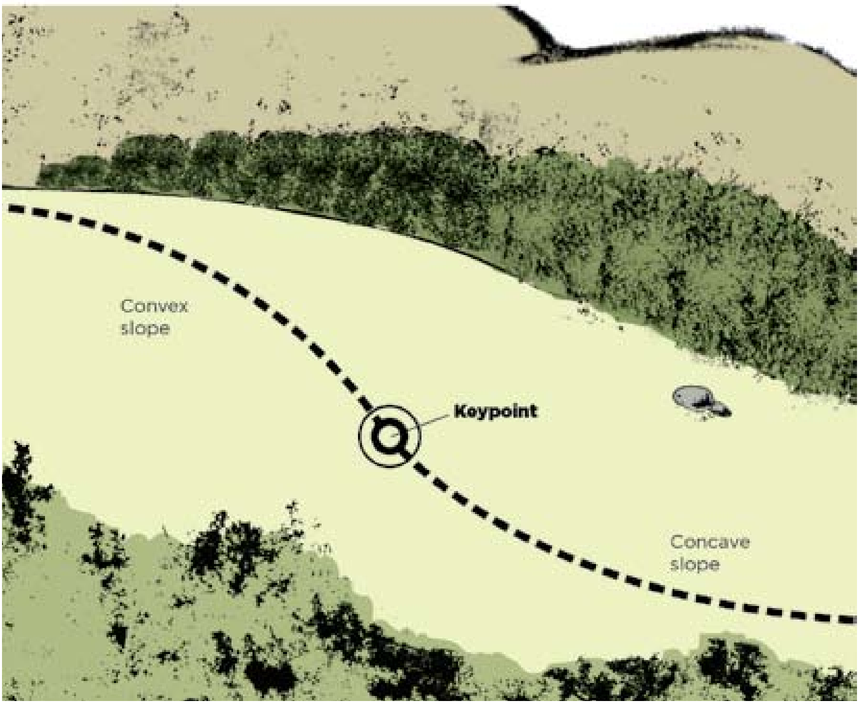
3.4.3 Landscape irrigation with keylines

Micro-watersheds and slopes often have unique shapes that allow nearby farmers to maximize rainwater harvesting, especially if they are able to work together.

When looking at a sloped landscape from top to bottom, you can often see an S-shaped curve with a convex slope (curved outward) at the top and an inflection point in the middle where the curve changes from convex to concave (curved inward) at the base. The set of inflection points (the many keypoints) running across the slope form a **keyline** when linked together. The keyline is where rainwater runoff concentrates and reaches maximum speed. This is the ideal location to collect water for irrigation on farm plots or pastures below because the keyline is the wettest part of the slope.

The keyline is the ideal location to collect water for irrigation on farm plots or pastures below because the keyline is the wettest part of the slope.

Figure 28: Finding a slope's keypoint



If a farmer or community digs contour ditches or plows deep contour rows in parallel lines from the keyline down the slope, water will penetrate more deeply down the slope to keep a pasture greener or provide water longer for a dry-season crop. Together a community can build a series of dams, ponds and contour ditches along the keyline. If you are interested in testing a keyline system, there are resources with helpful examples.

Resources

Feineigle, M. 2013. *Keyline planning and cultivation*. Permaculture Research Institute: New South Wales, Australia.

Additional keyline information

For traditional water harvesting, storage and irrigation techniques see: **Verma**, L.R. 1998. *Indigenous technology knowledge for watershed management in upper north-west Himalayas of India*. United Nations Food and Agriculture Organization: Rome, Italy.

3.5 COMBINING PRACTICES IN FARMING SYSTEMS TO MANAGE RISK

Many of the individual practices in this guide can help to manage the risk of climate change by reducing a farm's vulnerability to different amounts of rainfall. Another way to manage risk is to combine practices and diversify the activities on the farm. When one fails, another may succeed. The farmer who plants only one crop and has no trees or livestock is at risk from a long, heavy rain or dry spell. Instead, growing millet and peanuts, raising laying hens and growing mangoes or nuts near the house will reduce risk. Adjusting the planting times or changing the mix of crops also reduces risk.

Another way to manage risk is to combine practices and diversify the activities on the farm. When one fails, another may succeed.

Managing drought risk in Senegal's peanut basin

There are farmers in the heart of Senegal's peanut basin who grow both upland crops and lowland plots. In recent years they have experienced more frequent dry spells. Production in their upland rainfed fields has suffered and become less certain, so they now invest less time and effort in these fields. Farmers still plant crops there and they get some harvest most years, but they no longer take out loans for plowing or to buy fertilizer and seed. Instead they invest more of their resources in the lowlands, buying irrigation pumps that allow them to produce higher-value crops several times a year by using surface water for irrigation.

Source: B.M. Simpson, personal communication

The following three farming systems have great potential to manage the risk of uncertain rainfall and improve water productivity. Each combines practices that improve the resilience of the farming system to climate change by increasing the benefits of individual practices for yield, soil health and water productivity (the yield produced per volume of water):

- Conservation agriculture
- Agroforestry
- Mixed crop-livestock systems

The benefits of these systems are not automatic. Like the individual practices in this guide, the farming systems must be designed for the particular local conditions of climate, soil, the location of the farm in the landscape, and the limitations, needs and objectives of the farm family.

3.5.1 Agroforestry

Agroforestry is a complex land use system where farmers grow trees with agricultural crops, pastures or livestock. Agroforestry systems are diverse and the benefits can be many, from diversifying production and income to improving natural resources. Benefits can include soil conservation, less runoff and greater soil fertility, improved water capture and conservation, as well as more variety in the vegetation.

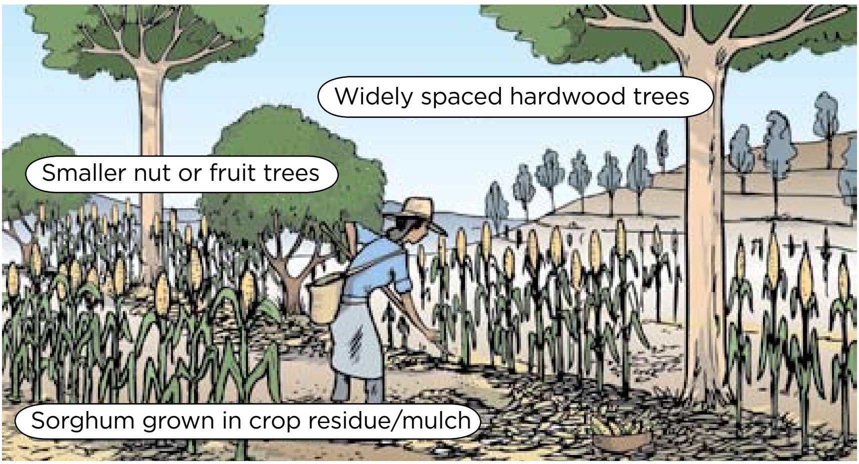
Live barriers in crop fields (see *Section 3.3.2 Contour ditches with live barriers*, and *Section 3.3.8. Live barriers*) are an agroforestry practice that can conserve water and soil. Alley cropping is another that alternates rows of crops between rows of trees (see *Pocket Guide 2: Crop Management*). Trees in semi-arid regions can be used to form live barriers in alley cropping or as windbreaks. They bring partial shade to nearby crops and can increase the humidity of the air, which decreases water loss from crops through evaporation.

Another example from the sub-humid tropics of Central America is the Quesungual slash-and-mulch system for drought-prone hillsides developed by farmers and experts from the UN's Food and Agriculture Organization, and named for the village in which it began. It is an alternative to traditional slash-and-burn practices. Farmers slash residue from maize, beans or sorghum crops and lower branches from dispersed trees growing in the crop field. They leave the residue on the field as mulch. With planting sticks they direct plant (direct seed) the crop. Food security, crop yields and water productivity increase at lower cost to the farmer. This system is a modification of conservation agriculture that includes dispersed trees in the farm plot.

How to implement a Quesungual slash-and-mulch system with dispersed trees: Although this farming system is a rotation of maize, sorghum and beans, you can use other crop rotations. In Central America it is applied to sloped land of up to 900 meters of altitude. Instead of burning to clear the field, farmers allow about 15 to 20 tall trees to remain on a 1- to 3-hectare plot. The trees provide shade, valuable hardwoods, and different tree products. Their prunings and leaves mulch and enrich the soil. Smaller trees and bushes often also remain. Farmers clear vegetation with tools, such as machetes or cutlasses, and prune smaller trees and shrubs to a height of 1.5 to 2 meters each year before the rains come.

Farmers plant maize or sorghum at the beginning of the first rainy season into the mulch layer using planting sticks. Crop residue can be cut back before planting beans at the beginning of the second rainy season immediately after harvest of the grain crop.

Figure 29: Quesungual slash-and-mulch system



3.5.2 Conservation agriculture

Conservation agriculture covers a range of farming systems modified for local conditions and follows three basic practices:

- There is little or no disturbance of the soil from cultivation or plowing, often called minimum tillage or no-till.
- Year-round soil cover protects the soil with vegetation, such as a mulch or a cover crop.
- Crops are rotated and alternate between a grain crop such as maize, sorghum or millet and a legume crop such as common bean (*Phaseolus vulgaris*) or soybean (*Glycine max*). Farmers often plant them in association – in the same field at the same time.

The benefits of conservation agriculture are best when all three practices are applied together and they bring these benefits:

- Improved interactions between the soil, crop and water for more soil pores that allow for better root growth and water movement.
- Increased availability of water for longer periods of time.
- Increased soil organic matter.
- Greater numbers of soil organisms and increased biological activity.
- Better nutrient cycling (movement between soil nutrients used by plants and the return of nutrients to the soil when plant material decomposes into organic matter).
- Improved soil fertility.

Figure 30: Direct seeding into conservation agriculture field

These changes also increase water productivity. Water infiltration improves when the vegetative cover protects the soil from surface crusting and the soil has improved ability to hold water. Research shows that:

- Conservation agriculture and improved tillage in a summary of farming systems in Africa and Latin America showed increased crop yields of maize of 20 percent to 120 percent over a five-year period.
- Farmers with poor soils will need to apply fertilizer initially to guarantee the benefits of conservation agriculture.
- Farmers who match fertilizer applications to soil and crop needs will improve the crop's ability to make the best use of water and can increase the water use efficiency (more crop per drop of rainfall) by 15 to 25 percent.

A note of caution: Conservation agriculture may not be appropriate for soils that drain poorly because it can increase waterlogging and plants may suffer if the soil is wet for too long.

Challenges of conservation agriculture: Initially farmers may need to apply herbicides to control weeds until the residue layer thickens. Probably the greatest challenge of conservation agriculture for small farms of the tropics is the practice of leaving crop residue on the field to cover the soil during the dry season. Farmers may traditionally burn the residue, or use it for fuel or animal feed. As an extension field agent, if you know of areas where conservation agriculture has great potential to improve adaptive capacity, you will need to work with farmers to find other sources of dry season feed.

One option that you can test with farmers who own animals is to set aside part (20 to 25 percent)[3] of the land now used to grow grain and plant forages there instead. The grass and legume forages can be grazed, cut and carried to penned or tied livestock or made into hay for the dry season.

When a farmer converts some of the land that is now used for grain to produce forages, it can:

- Improve farm income from livestock.
- Improve soil quality of conservation agriculture plots by increasing vegetative cover through growing forages as legume cover crops.
- Improve soil quality by applying livestock manure that increases in amount and improves its quality with better quality of the feed from the planted forages.
- Improve grain yields on the remaining land due to the benefits above.

3. The amount of land will depend on the number of livestock the farmer is feeding and the number of people in the farm family depending on grain for food. In some cases starting with less land will be best

Another option is to introduce forages as part of the grain-legume rotation in conservation agriculture. This three-part rotation will increase the farm's diversity and reduce its vulnerability to climate change. You can support farmers by finding out what forage research has been done in your area to identify those that fit best in local farming systems. If that research does not exist, there may be information about forages in nearby areas or countries with similar farming systems. Or you may be able to influence your agency to lobby for the research that is needed. A few questions to explore are:

- Which forages (or forage production systems) fit best into local farming systems?
- Which forages are best for local livestock?
- How much land needs to be put into forage production in pastures to be able to leave crop residue from maize, sorghum, millet, dryland rice, etc. on the conservation agriculture field?

3.5.3 Mixed crop-livestock systems

Farmers who raise livestock can increase their adaptive capacity in several ways:

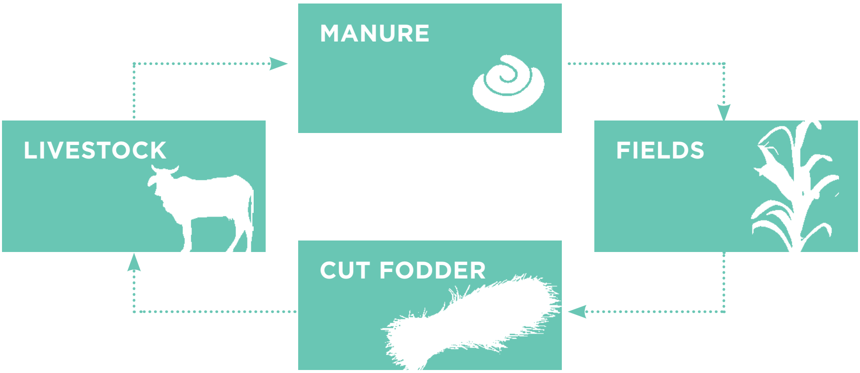
- When the crop rotation includes forages it becomes more diverse. This reduces some of the risk of exposure to variable weather and changes in market prices for grain crops.
- When livestock are part of the farming system, they recycle nutrients for soil fertility through their manure. They also supply protein in diets. On small farms, the milk and eggs can be used daily, thus the need for cold storage that requires electricity is avoided.

Livestock products provide one-third of the protein in human diets and use almost one-third of the water used for agriculture worldwide. With rising demand for animal protein and growing competition for water, the water productivity of livestock will be key to climate change adaptation. With the support of extension agents and development projects, farmers will have to produce the same benefits with fewer animals and they will need to use less water per animal. This can be done by increasing the productivity of each animal through better feed, providing enough water for livestock in the dry season and improving animal health.

Animals grow faster and produce more milk when farmers provide watering points near grazing areas or livestock paths in the dry season.

During long dry seasons, animals often have to go far for water. This uses up energy that reduces their weight gain and milk production. If farmers can provide water through setting up enough watering points and distributing them well in areas where animals graze, water productivity is increased. This also decreases soil and pasture degradation from animals trampling too few watering areas.

Figure 31: Diversify with crops and livestock to recycle nutrients



Source: Herrero et al 2010

PART 4

Mobilizing community action and planning to adapt to climate change

Some of the practices in this guide are best adopted through community action, especially those that require manual labor or that cover communal property or large areas:

- Digging contour ditches across the landscape.
- Digging ponds.
- Digging zai holes.
- Creating keyline systems for water harvesting.
- Establishing and maintaining buffer zones around sources of water.
- Developing and managing irrigation systems that serve more than one farm.

There are many possible practices and changes that farm families can make to adapt to climate change. But adaptation will not succeed unless farmers and communities take action that is important to them and their situations. As extension agents, you and your colleagues will need to support and guide this process of community mobilization.

There is no single way to guide a process for community planning and action. You will need to modify and adapt these recommendations to suit local conditions. This process has four steps:

1. Consider where and how the community is vulnerable to the risks of climate change (participatory assessments) and evaluate their capacity to adapt to the risks.
2. Support the community to develop an action plan to respond to these risks.
3. Support the community to implement their plan.
4. Assist the community to monitor, evaluate and learn from their action plan.

The objectives of community planning and action are to strengthen local capacity to:

- Understand and assess their climate change risks, their assets and capacity to adapt.
- Plan and prepare for the local effects of climate change.
- Reduce the effects of climate change on the most vulnerable community members.
- Develop an adaptation strategy to reduce vulnerability to progressive climate change effects by combining local knowledge and expert (or scientific) knowledge.
- Respond to and recover from climate related shocks (floods, droughts, extreme storms).
- Collaborate and negotiate with local government for coordinated adaptation and support.

4.1 Participatory assessments

In this step, different groups in the community assess their group's vulnerability and capacity. There may be a group of pastoralists (sheep or cattle farmers), a group of crop growers, a group of women or female-headed households, a group of youths, a group of elderly villagers. The information from these self-assessments can then be combined with the information that you and the community gathered on climate change impacts in *Part 2*.

Use good judgment when you share the information gathered from the small groups with the entire community. If done carefully, it will help to make sure that the perspectives of different groups are shared in a neutral, constructive way. In this way the community can develop an action plan that is both strategic and inclusive. One way to assess vulnerability and capacity is to use the six asset categories that are common in rural livelihood frameworks – human, social, political, financial, natural and physical. You can ask each small group to list a major vulnerability of the community and a community capacity related to each.

One way to assess vulnerability and capacity is to use the asset categories that are common in rural livelihood frameworks – human, social, political, financial, natural and physical.

Table 3: Community assessment of vulnerability and adaptive capacity using six asset categories

GROUP: Farm families who produce grain crops		
ASSETS	**Examples of VULNERABILITY**	**ADAPTIVE CAPACITY**
Natural assets	A drought used to occur every 9 to 10 years but now occurs every 3 years.	Early maturing varieties and drought-tolerant varieties of two grain crops are available for everyone.
Human assets	Female-headed households use only traditional crop varieties.	The community has knowledge of new varieties and can organize to buy improved seed bulk for everyone.
Social assets	There is tension between farmers over access to a spring for irrigation.	A non-operating water committee can re-form and develop a rotating system for fair water use and fees. The youth group can coordinate and monitor the system.
Financial assets	Savings and loan bank will not lend to rural communities for irrigation.	Community will implement community savings and lending groups with training from a local NGO.
Physical assets	Community has no silos or storage containers for grain or animal feed. Community has no water storage for livestock in dry years. The spring that supplies a reservoir always runs dry.	Second floor of school can be used for temporary storage using local materials for construction of storage containers. See below.
Political assets	Community voted for the losing political party in the last election. As a result, community requests for government support to build water systems and make road improvements have been ignored.	Upstream community will allow access to a quarry for material to make concrete watering tanks for animals and will fence a deforested area for natural regeneration of water that supplies the reservoir and better groundwater recharge. In exchange, the two communities will form work crews for semi-annual road repair between the two communities.

Adapted from Ashby, J. & D. Pachico. 2012. *Climate change: From concepts to action: A guide for development practitioners*. Catholic Relief Services: Baltimore, Maryland, USA.

4.2 Develop a community action plan

In this step the community will discuss and agree on a realistic action plan. As a field agent, you and your colleagues will facilitate discussions to reach a collective agreement on the most important climate change vulnerability and the solutions for adaptation that the community will act on. See also *Resources* for tools and techniques for participatory planning. The following questions will help the community to prioritize:

Questions to help prioritize the most important community vulnerabilities to climate change

- Will this vulnerability (this impact of climate change) happen often or not?
- Will the number of households affected be large or small?
- From the time that this first appears, does it develop very quickly (no time to prepare) or slowly (enough time to prepare)?
- Do the effects of this impact of climate change last a long time or a short time?
- Is the damage caused very costly or not very costly?
- Is this very likely or not very likely to happen?

Source: Ashby & Pachico, 2012.

The action plan is based on:

- Information from the assessments of climate change impacts and local vulnerabilities.
- Community prioritization of one vulnerability to act on (at most three).
- A vulnerability and adaptive capacity assessment for each priority vulnerability.
- Information about potential technical solutions or adaptations that combine local knowledge and expert inputs.

Some of the elements of the action plan will be:

- A local organization that coordinates action plan activities and monitors progress of the plan with procedures for monitoring and evaluation.
- A map of areas that are vulnerable to natural disaster and safe zones for people and livestock to take shelter.
- Land use plans for farms and micro-watershed.
- Technical solutions for adaptation.
- A plan for testing technical solutions locally.
- A financial plan.

- A plan for technical assistance and adaptation of non-farm livelihoods.
- A plan for local savings and lending so solutions can be adopted.
- Disaster preparedness and emergency response plans.
- A benefit-sharing agreement, for example on who gets to use pond water.
- Maintenance of community structures.

4.3 Implementation of action plans

Implementation requires resources from both the community and external sources, and training to build local capacity so it can continue adapting with progressive changes in weather and water resources. It needs a plan to prepare for a crisis and build assets to recover from climate shocks such as higher temperature, variable rainfall and high wind. This will include water collection and storage as well as storage of supplies produced with water – food, animal feed and fuel.

To support adaptive capacity, the action plan will need to consider activities for:

- Training in how to continue assessments of climate change vulnerability, exposure, sensitivity and adaptive capacity within the community.
- Testing and experimenting with water management practices for crops, trees and livestock.
- Developing experience and confidence in combining local and external knowledge about practices for adaptation. For example, extension agents may promote drip irrigation, but if the drip line is too costly, farmers will need to design or test alternative drip irrigation methods using local materials.

4.4 Monitoring, evaluation and learning

Adaptation depends on groups of people working together.

In this step you will support the community to monitor progress in their action plan. They may need to make adjustments to the plan and they will need to evaluate the vulnerabilities and adaptive capacity to see if they have changed. Participatory monitoring and evaluation (M&E) with the community will strengthen its adaptive capacity and help everyone involved in the plan to use monitoring information to make adjustments.

Participatory M&E will support community learning and help the community to see that they are responsible for continuing the process of adaptation themselves by making use of internal resources and seeking external resources for information, technical support and financial support to make sure they adapt successfully to continued change.

Resources

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GLOSSARY

Adaptation Measures taken to reduce vulnerability to expected climate change impacts, such as applying mulch to soils to capture more water and prevent water loss down a slope, or planting a crop variety that is more tolerant to drought than the current variety.

Adaptive capacity The ability of a system to adjust to climate change, moderate potential damages, take advantage of opportunities or cope with the consequences of climate change. The ability to implement adaptation measures may involve building farm assets such as cash, livestock or even community support, for example, to store grain for times when crops fail.

Agroforestry A land use system in which farmers grow trees or woody perennials (bushes, shrubs) with agricultural crops, pastures or livestock.

Aquifer An underground layer of water-bearing rock that is permeable, with openings to hold water and through which it can pass. Aquifers act as reservoirs for groundwater, the name for the water found in an aquifer. The top of the water level in an aquifer is called the water table. An aquifer fills with water from rain or melted snow that drains into the ground. In some areas, the water passes down through the soil above the aquifer; in others, it enters through joints and cracks in rocks.

Basin As used in this guide, a basin is a shallow area, hollow or depression surrounded by higher land, often dug by hand to collect water during the rainy season. Unlike ponds which contain water year-round, basins generally hold water for part of the year. (In other documents, the word basin is often used to refer to a large geographic area, a river drainage basin or an area drained by a river.)

Bench terrace A level area or a step that is cut into the side of a slope.

Berm A raised bank, ridge or mound of earth running across a slope or bordering a river, stream or canal.

Biomass The total material produced by a plant (stalk, stem, leaves, roots, grain, fruit).

Bund An embankment or ridge of soil placed across a slope or bordering a crop field, similar to a berm.

Blue water Fresh water that runs off the land to form surface water the lakes, rivers, reservoirs and wells and also groundwater, or water stored in aquifers underground.

Broadcasting (seeds) Scattering seed by hand (or using equipment) across a large area.

Buffer zone In water management, buffer zones are strips of vegetated land placed between agricultural land and a body of water such as a river, pond, stream or spring, to protect the water source and the banks around the body of water.

Canopy / crop canopy The upper layer of a forest (leaves and branches) or the aboveground portion of a crop.

Climate change A long-term change in the earth's climate, especially due to an increase in average land temperatures, which have risen 0.74°C globally over the last century.

Compost Decayed organic material used as a fertilizer which can include decomposed leaves and other crop residue, straw, livestock manure, legume leaves, and food waste.

Conservation agriculture A farming system that combines minimum tillage or plowing, year-round vegetative cover on the soil, and crop rotation of grains and legumes.

Contour farming (ditches, trenches) A method used on sloped land to plant and manage crops located across the slope or to dig ditches or trenches across the slope to capture rainfall and store water.

Cover crop A crop, often a legume, planted to prevent soil from eroding, trap rainfall, improve soil fertility and control weeds.

Dead barrier A barrier made of crop residue or stones to trap topsoil and rainfall within an area or plot. Dead barriers are often built across the contour to trap runoff water for agriculture.

Diameter A straight line that passes through the center of a circle.

Dike A long embankment or wall to hold back water.

Diversion ditch Small excavations for **diverting** the flow of water away from slopes or bunds to an area where it can be safely discharged through a stable outlet or to a sediment basin.

Erosion The removal of topsoil through rainfall, wind, overgrazing, over cultivation, clearing of forests faster than the processes that form it.

Evaporation When a liquid such as water changes into vapor.

Exposure Exposure to climate change is related in large part to geographic location. Inland communities in semi-arid regions may be exposed to drought and coastal communities will have higher exposure to cyclones or hurricanes.

Flocculation When clay particles clump together.

Forages Animal feed or food for livestock.

Global warming A gradual increase in the overall temperature of the earth's atmosphere due to the greenhouse effect caused by increases in carbon dioxide and other gases.

Greenhouse effect When the earth's atmosphere traps solar radiation because of an increase in certain gases, and increases the temperature of the atmosphere above normal.

Greenhouse gases The earth's atmosphere has a number of gases which trap the heat given off by the earth. These include **water vapor** which occurs naturally in the atmosphere; **carbon dioxide** which is produced when people and animals breathe, when fossil fuels (coal, oil, gas) are used, forests are cut; **methane gas** which is produced when cattle digest their feed and when rice is grown in paddies; **nitrous oxide** which occurs when plants decompose or rot; and **ozone** which occurs naturally.

Green water The rainfall and water that is stored in the soil as soil moisture.

Groundwater The name for the water found in an aquifer. *See also* Aquifer.

Half-moons Large semi-circular depressions or basins in the soil to concentrate rainwater and nutrients where the plants grow. They are used most frequently in semi-arid areas and where soils are crusted, compacted or infertile and often for growing tree crops.

Inorganic fertilizer A commercial plant fertilizer made of synthetic materials formed through chemical processes.

Keyline The set of inflection points between a convex and concave curve of a slope and the points running across the slope to form a keyline where rainwater runoff concentrates and reaches maximum speed. This is an ideal location to collect water for irrigation.

Legume A plant in which the seed is grown in a pod such as a pea or bean. Legumes have the ability to 'fix' nitrogen, or take nitrogen from the atmosphere and convert it into a form that plants can use with the help of a bacteria called rhizobia. (Nitrogen is essential for plant growth.)

Live barriers Barriers of vegetation, often built across the contour to slow or prevent runoff and erosion.

Macrofauna Soil organisms that are at least 1 mm in size.

Mitigation Climate change mitigation refers to efforts to reduce or prevent the emission of greenhouse gases through efficient use of energy, and reforesting to increase the tree populations that use carbon dioxide, reducing that greenhouse gas and storing (sequestering) carbon in the plant material.

Mulch A protective covering of crop residue spread or left on the soil surface to reduce evaporation, maintain even soil temperature, prevent erosion, control weeds and enrich the soil.

Nutrient cycling Soil nutrients come from the breakdown of mineral-bearing rocks and from organic matter, which comes from the decomposition of plants and animals. The nutrients that plants get from the soil are stored in all plant tissues, such as leaves, stalks and grain. When these tissues fall to the ground they start to break down and together with decomposing dead insects, animals and animal feces are eventually reincorporated into the soil by rainfall and earthworms. There, the organic matter is further broken down and slowly transformed to become nutrients that are available to growing plants (and the cycle continues).

Organic matter Decomposed plant or animal matter (anything that contained carbon compounds). Organic matter contains nutrients that act as a natural soil fertilizer, helps to retain soil water, and improves drainage when the soil is saturated.

Organic fertilizers Made of animal or vegetable matter such as compost, leaves, decomposing crop residue, nitrogen-rich green manure (legumes), animal manure and worm compost.

Photosynthesis A process used by plants and other organisms to convert light energy, normally from the sun, into chemical energy that can be released to form sugars and fuel plant growth and production.

Pioneer species Hardy plants that are the first to colonize a damaged or degraded ecosystem that has been burned or flooded, for example.

Porosity, **soil pores** Pores are spaces of many different sizes in the soil and are essential for storing air and water, microbes, nutrients and organic matter. *See also* Soil aggregates.

Rainfed farming The farming systems that rely entirely or mostly on rainfall for their water.

Runoff Precipitation that moves along the surface of the land and neither evaporates, transpires nor penetrates the surface to become groundwater.

Sapling A young tree with a slender trunk.

Stone barrier A wall of stones, often built along the contour to capture runoff and topsoil for agriculture.

Sediments Materials such as soil particles and pebbles that settle to the bottom of the water in a river or stream.

Sensitivity The degree to which a system or community is affected by climate-related stresses.

Slope A surface that is slanted or inclined and not level, with one side higher than the other. It can be represented in degrees or as a percentage. Percent slope is calculated by dividing the vertical change (the rise) by the horizontal change (the run) and multiplying by 100. (Rise ÷ Run) x 100 = Slope %.

Soil aggregates Clumps of soil particles held together by clay, organic material such as roots and organic compounds from bacteria and fungi. Some of the soil particles that make up an aggregate fit closely together and some do not. This creates spaces of many different sizes in the soil and these spaces, or **pores**, within and between soil aggregates are essential for storing air and water, microbes, nutrients and organic matter. Soils with many aggregates are more stable and less susceptible to erosion.

Soil structure The arrangement of the solid parts of the soil and the pore space located between them. Soil structure depends on how individual soil granules clump or bind together and aggregate, and therefore, the arrangement of soil pores between them. *See also* Soil aggregates.

Soil texture The proportions of soil particles of various sizes in the soil, the amounts of sand, silt and clay. Texture influences the amount of water and air that the soil holds, the rate at which water can enter and move through soil and how easy it is to work the soil.

Spillway An outlet for water to flow through. On bunds, it is a slightly lowered portion of the bund where excess water can flow out without damaging the bund.

Tillage Plowing or disturbance of the soil surface before planting.

Topography Different elevations of the land from valleys to mountains.

Transpiration The evaporation of water from plant leaves while their stomates are open for the passage of carbon dioxide and oxygen during the process of photosynthesis (plant production and growth).

Vegetative cover A cover of growing plants or dead plant material (crop residue) as a mulch on the soil surface all year round.

Vulnerability The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. Vulnerability depends on the type, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and adaptive capacity.

Waterlogging When the soil is saturated with water.

Water productivity The amount of yield or total crop biomass produced per volume or unit of water.

Watershed (also called basin) A ridge of land or high area of hills and mountains where the rain that falls and water that collects drains to the same rivers and lakes at lower elevations.

Water stress When the demand or need for water is greater than the water available.

Water table The top of the water level in an aquifer. *See also* Aquifer.

Windbreak A line of trees or bushes that provides shelter from the wind or breaks its force by being planted across its path.

Zai holes Small pits that are dug during the dry season to concentrate rainwater and nutrients where the plants will grow. They are filled with compost, manure, straw or plant leaves for improving soil fertility and structure.

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