Review of Agricultural Water Management Technologies and Practices

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Abstract

Low average rainfall that is seasonal, highly variable in time and space, and increasingly unreliable is the major impediment to farm households increasing their production of food, cash crops, and livestock products in Ethiopia. The impacts of this unreliable and inadequate water supply are compounded by many other problems both natural (for example poor soil fertility), and human- created (for example lack of support services and infrastructure). Improving the reliability of water supply for agriculture is therefore a necessary though not sufficient condition for reducing poverty and malnutrition and generating faster agricultural growth. There is reasonable though not conclusive evidence that some of the agricultural water management technologies reviewed in this study, under the right conditions, do lead to substantial improvements in households' food security and incomes, and that they do so in a cost-effective manner. But the tremendous diversity of conditions in Ethiopia must be acknowledged. Even within districts, there is such diversity in soils, micro-climate, cultures, and access to markets that what works on one farm may not be appropriate next door. This means there is no possibility of generalizing, no cook book approaches or sure-fire universal panaceas that will work everywhere. Following from the diversity of Ethiopia, it is no surprise that there are no cases of successful massive scaling up and out of specific agricultural water management technologies and practices. Adoption, adaptation, or rejection decisions are a function of many factors including lack of information or access, lack of fit between the technologies on offer and the capacities and needs of households, inefficient promotion strategies, flawed assumptions about households' needs and capacities and the real costs and benefits from their perspectives, ineffective targeting, lack of capacity to manage projects offering a large array of small-scale technologies to thousands of poor households, and lack of credit.

1. Introduction

Due to progress in agriculture, globally there is enough food supply that can satisfy the needs of the world's growing population and projections indicate no global food shortage in the forthcoming decades. Investments in water resources have effectively contributed to this success of modern agriculture. However, these successes are yet to be achieved particularly in many of the sub Saharan African countries including Ethiopia. Lack of reliable access to agricultural water undermines the food security and poverty reduction objectives of the region. Without guaranteed access to reliable water, the farmers, the main actors in the food security and poverty reduction battle, lack the motivation to adopt other productivity enhancing inputs such as fertilizers, high yielding varieties, herbicides, etc, which are the bases for the green revolution of the type that had been observed in Asia and Latin America.

The vast majority of the rural poor rely on rain-fed land for their survival, making them vulnerable to the highly variable and unpredictable rainfall. Some authorities suggest this variability may be increasing. Even in years having "normal" rainfall, a period of ten to fifteen days with no rain at a critical stage in crop growth can spell disaster for thousands, even millions, of poor farmers. Periodic drought and famine are the result in many regions of Ethiopia, which is hard hit by what seem to be increasingly frequent and devastating droughts, floods and famines. In addition to the hunger and starvation that ensues, the results are drastically reduced economic growth rates, serious impacts on the nutritional status of children, compounding of the already serious impacts of malaria, HIV/AIDS and other diseases, and reduced resilience to face the next drought period.

Investment in Agricultural Water Management (AWM) is often identified as one of the possible responses to this problem, and has had considerable success in Asia in terms of achieving national as well as local food security, reducing poverty, and stimulating agricultural growth (IWMI/ADB 2005). In Ethiopia, AWM investments never kept pace with those in Asia for many reasons, such that today, of all the major developing regions Ethiopia has one of the lowest percentages of cropped area irrigated (FAO 2002). Many analysts believe future increases in food supplies and economic prosperity for the rural poor in the Ethiopia will mainly come from improved agricultural water management Access to water will allow the intensification of agricultural production systems. In light of this, researchers, policy makers, NGOs, and farmers are increasingly experimenting with and promoting various innovative agricultural water management technologies and practices. It is believed that making widely available relatively low-cost AWM technologies can make a major contribution (e.g., Falkenmark and Rockström 2004; Polak 2005). There is evidence from Asia, for example that the introduction of treadle pumps has lifted millions of people out of poverty (Shah et al. 2000). Throughout India private firms and NGOs are promoting a large variety of highly cost effective agricultural water management technologies whose uptake and impacts are indeed impressive (e.g., Shah and Keller 2002; Namara et al. 2005).

This paper summarizes suitable innovative agricultural water management techniques and approaches that may be applicable to Ethiopia in combating the effects of dry spells and/or droughts based on experiences from other regions in Africa and Asia. First, the definition of Agricultural Water Management is provided based on the concept of rainfall partitioning at the field level. Second, the paper provides examples AWM technologies by categories and finally some conclusions and recommendations are made.

2. Agricultural Water Management

Figure 1 gives and indication of the partitioning of rainfall into different water flow components in rain-fed agriculture (Rockstrom 2000). Soil evaporation accounts for 30-50% of rainfall. Surface run-off is often reported to account for 10-30% of rainfall. The characteristics in dry lands of frequent, large and intensive rainfall, results in significant deep percolation amounting to some 10-30% of rainfall. The result is that productive green water flow as transpiration in general is reported to account for merely 5-10% of rainfall. The rest, between 70-90% of rainfall is lost from cropping systems as non-productive green water flow (soil evaporation) and as blue water flow (deep percolation and surface run-off).

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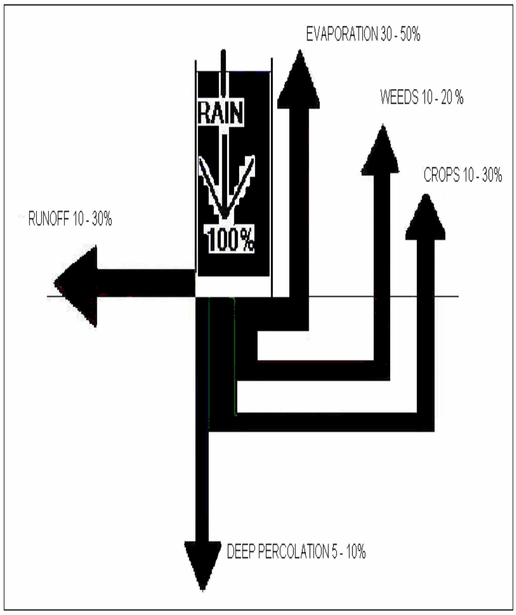

Figure1. Partitioning of rainfall at field level

The figure provides a conceptual diagram illustrating the potential for improving the productivity of rainfall: if unproductive evaporation, runoff and consumption by weeds are reduced, there will be more water available for the crop. Hence: the need for agricultural water management interventions.

The term “agricultural water management” is a broad term covering an increasingly wide range of technologies and practices available for improving water and land management. It is now a commonly accepted term to cover the range of technologies and practices whose objective is to ensure that adequate water is available in the root zone of crops when needed. It therefore includes capture and storage (in dams, in groundwater) as well as drainage of any water used for agriculture (crops, livestock, fish); lifting and transporting water from where it is captured to where it is used for agricultural production or removing excess water from where agriculture is practiced; and in-field application and management of water, including land management practices that affect water availability to crops (Merrey et al. 2006). In-field application and management of water and land is the common denominator, regardless of the source of the water, and is a critical element of all agriculture. Therefore "AWM" is critical to successful agricultural production.

3. Some examples of AWM

3.1 Technologies for Water Control and Storage

In situ soil and water conservation technologies

Soil and water conservation (SWC) refers to activities that reduce water and nutrient losses and maximize their availability in the root zone of crops: rainwater and therefore nutrients are conserved where it falls, in-situ. This distinguishes SWC from rainwater harvesting (RWH), which seeks to transfer run-off water from a "catchment" to the desired field or a storage structure (Mati 2006). RWH includes a range of micro-catchment systems, earthen bunds and other structures to capture and store run-off from elsewhere (hence, ex- situ) for use when needed. As Mati (2006) notes, the line between SWC and RWH technologies is very thin.

A recent large-scale assessment (286 interventions in 57 poor countries covering 37 million ha and 12.6 million farms) shows that "resource-conserving agriculture"— including among others rainwater harvesting, conservation agriculture, and integration of livestock and aquaculture into farming systems—has led to an average crop yield increase of 79%, and very high water productivity gains (Pretty et al. 2005). The water productivity gains ranged from 70% to 100% for rainfed cereals, legumes and roots and tubers. This work supports experimental, theoretical and practical work by Rockström (e.g., Rockström et al. 2003; Falkenmark and Rockström 2004), Hatibu and Mahoo (eds.2000), Ngigi (2003) and others that demonstrates a doubling of rainfed crop yields in the semi-arid tropical regions of SSA is possible with currently known technologies for improving water and nutrient management. Mati (2006) provides a good source on experiences with a large number of RWH and SWC technologies in eastern and southern Africa.

Water and soil nutrient management are critical to successful agriculture. Soil nutrients are being mined in Ethiopia, leading to declining yields; but with the high cost and sometimes non-availability of fertilizers, Ethiopia has one of the lowest per ha use of fertilizer in the world. Yet there are a large number of both indigenous and introduced technologies and practices that can help maintain and enhance soil nutrients. SWC therefore includes techniques like terracing, ditches, stone and vegetative bunds, mulching, conservation tillage and more broadly "conservation agriculture." What specific techniques or combination of techniques is appropriate depends on local climate, soil, social and economic and other factors. Below, we provide a more detailed discussion of techniques that come under the heading of "conservation agriculture."

Conservation Agriculture

FAO suggest a definition for conservation agriculture as:

> Involving a process to maximize ground cover by retention of crop residues and to reduce tillage to the absolute minimum while exploiting the use of proper crop rotations and rational application of inputs (fertilizers and pesticides) to achieve a sustainable and

profitable production strategy for a defined production system.

In practical terms, examples of conservation agriculture techniques include the following:

- Ripping only the planting line using a tractor or animal-drawn 'rippertine', rather than normal plowing;
- Tied ridges, for holding water and facilitating infiltration in low rainfall areas (there are a variety of types of ridges;
- Mulching using both crop residue and material from non-cultivated areas, for holding water, returning nutrients to the soil, and in some cases reducing the temperature of the soils;
- Assuming hand-hoe farming: a variety of techniques referred to as pot holing, pitting, trenching (ridges and furrows);
- Where erosion control is important, various techniques such as contour ridges, storm drains, grass strips, etc. and
- Agroforestry and green manure or cover crops, many of which contribute to nitrogen fixation.

Conservation agriculture has not developed in Ethiopia and Africa in general as rapidly as its proponents wish. There are many reasons: low soil fertility combined with unreliable rainfall make agriculture risky and limited access to markets make it unprofitable; and traditional communal land tenure systems which limit land use rights to the growing season discourage investment in for example green manure or cover crops. Further, the very diversity of agricultural environments and economic conditions make selection of appropriate mixes of cost effective and appropriate technologies rather difficult. The situation is compounded by the lack of clear policy and institutional support. Although in the long run conservation agriculture is expected to save labor, during the transitional stage, i.e., the first 1-5 years, labor costs are often higher. Conservation agriculture is a long-term investment in improved soil fertility and water holding capacity, but initially the returns compared to the costs may discourage many small farmers. In some agroecological areas, soils are predominantly clay having very low infiltration rates. In such cases the depth of water infiltration is very small and water may remain (ponding) at the soil surface or in the upper layer of the soil profile if ridges are tied or pits are made.

Minimum or no tillage technologies, which are forms of conservation agriculture, are seen as ultimately labor saving while improving household food security and incomes. Daka (2006) says that in Zambia micro-basins prepared by hand hoes to capture and store rainfall lead to a doubling of maize yields to 3 tons/ha. This performance has led to accelerated adoption such that small farmers cultivating an estimated 200,000 ha of rainfed land have adopted such conservation technologies. They have the additional advantage of allowing precision planting and fertilizer applications. It makes use of tools and implements such as the jab planter and the animal drawn ripper or no-tillage planter, in combination with agronomic practices that have the potential to suppress weeds through soil cover and introduction of cover crops form a set of possibilities (SWMG 2005). Minimum tillage reduces labor requirements especially in peak seasons for land preparation and weeding, and potentially contributes to household food security by making more efficient use of rainwater and increasing soil fertility through the introduction of nitrogen fixing cover crops. Minimum tillage reduces expenditure on hiring farm power services and purchase of fertilizers, whilst generating additional revenue through the production of fodder and cash cover crops, and reduces production costs by reduced use of expensive fuel.

In Namibia, the Agronomic Board promotes conservation tillage, especially in the form of planting pits dug with a hoe (de Lange 2006); the main cost to the farmer is her own labor in the first year, but the Board claims this work can be spread over a long time period in small steps, and the work load diminishes in subsequent years through fewer weeds and higher yields. In East Africa such systems are usually used for special crops like banana and fruit trees; their use for maize as in Zambia and Namibia is considered novel.

There is a rather large menu of technologies and practices, and these can be packaged to create synergies among them and to adapt them to specific contexts. For example, combining various types of reduced tillage systems or pits with mulch, combining contour ridges or basins with mulch seems to provide very positive results. Several researchers emphasize the critical importance of combining water and soil nutrient management (Twomlow and O'Neill 2003; Stroosnijder 2003) indeed water conservation without combining with nutrient management often leads to no positive impact. This also suggests the importance of paying attention to agronomy and soils as well as water technology and markets.

Ex-situ water harvesting and storage

There are a variety of technologies for harvesting rainwater from roads, foot-paths and household compounds. Many of these water run-off harvesting systems have been developed by farmers themselves, for example those capturing "sheet and rill" runoff generated by compacted surfaces like roads, paths and household compounds. Water is harvested and directed either directly onto cropped fields, or into various types of natural or man-made storage structures (see fig 2).

In this section we provide examples of small storage dams, shallow wells and boreholes, roof top water harvesting, and above- and below-ground storage tanks.

Small storage dams and tanks

A large variety of storage technologies are in use around Eastern and Southern Africa. We discuss here a few types that require minimal engineering.

Charco dam

Mati (2006) describes charco dams as small excavated pits or ponds constructed in relatively flat topography, and requiring minimal engineering. They are generally about 3 m in depth, and take advantage of areas where water collects naturally. They are used for multiple purposes including livestock water and to supply domestic water to villages and small towns. The technology can serve up to 500 households or 4,000 livestock units in semi-arid areas (SWMG 2005). Local communities are

Figure 2. Road runoff harvesting into a channel for banana production, Arabaminch, Ethiopia, 2006

responsible for the management of the dams.

The village communities participate in the planning and construction of the dams and are responsible for their operation and management. Normally the village governments form dam management committees with responsibilities of operation and maintenance of the dams. Additionally the committees are expected to come up with by-laws and measures that are acceptable and implementable by the local communities within the catchment areas of the dams.

Rooftop rainwater harvesting and above ground storage tanks

Harvesting rainwater from roofs of buildings usually combined with either storage or, with drip irrigation kits are also increasingly common in Eastern Africa (Mati 2006). Despite relatively high rainfall, the level of activity in rainwater harvesting in Ethiopia is very low and isolated until quite recently. The most common type of rainwater harvesting is the traditional one, where families catch water falling from rooftops in drums of 200-210 liters capacity for short term use. The technology is quite novel in its formal state but it has existed for a long time. A similar type of system involves the use of gutters on buildings like schools and hospitals. Though with limited application, the system referred to as 'institutional rainwater harvesting' is quite effective and uses ferrocement tanks, which collect rainwater from roof tops via gutters. The collected water is used by the concerned communal institutions.

While the collection of rainwater by a single household may not be significant in the larger scheme of things, the impact of thousands or even millions of household rainwater storage tanks can be enormous. The main components in a simple roof water collection system are the tank itself, the materials and the degree of sophistication of the whole system largely depends on the initial capital investment. Some cost effective systems involve cisterns made with ferrocement. In some cases, the harvested rainwater may be filtered. In other cases, the rainwater may be disinfected. Storage structures for roof catchments include surface tanks like ferrocement tanks and commercially available plastic tanks. Drip kits are promoted by some NGOs in combination with rooftop water harvesting, but the need for gutters and a collector tank is seen as raising the cost significantly.

Underground tanks to catch surface run-off

Underground rainwater tanks are a cheaper alternative than above-ground tanks because construction costs less; however it is then necessary to lift the water. Another problem is higher likelihood of contamination and sedimentation. The main problem, however, is lack of expertise at local level to design and construct underground tanks that are safe and functional (Mati 2006). Nevertheless, underground rainwater storage tanks (cisterns) are being aggressively promoted by several African governments, for example Ethiopia, and material on designs is available through Southern and Eastern Africa Rainwater Network (http://www.searnet.org).

In South Africa, underground tanks are currently being promoted to enable food insecure households to become more resilient against hunger. With an average rainfall of 450mm/year, the increased run-off available from the homestead yard, adjacent roads and fields as compared to rooftops, is an important potential water source. In hilly areas it is possible to channel surface run- off into above-ground tanks, but otherwise, underground tanks (cisterns) are preferred.

A wide range of building materials can be used, with the most popular currently being self-made cement-blocks and ferrocement. Rammed earth is being investigated as an affordable alternative, while geofabric with a bitumen coating has also been tried. A variety of plastic linings are being investigated for their durability and ease of installation and maintenance by households. They are said to be already in use in parts of Kenya because they are easy to construct and more affordable (Mati 2006). However, this depends greatly on the types of plastic available in any particular country. In South Africa, nine types of plastic lining are currently being investigated to identify the most suitable for specific applications.

Clearly, there is a large range of potential small scale technologies for capturing water and directing it either onto crops or into storage facilities for later use. Many of them are quite low-cost and easily constructed by local people from local materials, with minimal technical assistance; and many of them provide water that can be used for many purposes, not just agriculture. As with other small-scale technologies, combining different ones to capture, store, and apply water is often synergistic: a small amount of water captured and stored can be used very productively and with minimal labor cost by combining with drip kits or treadle pumps. But adaptation to local conditions, with poor farmers empowered to make their own decisions rather than being passive recipients is critical to success.

Groundwater

Hand dug shallow wells

In many parts of SSA, shallow wells are constructed in valley bottoms and equipped with pumps or other manual technologies. The water is used for human use, livestock and some supplementary irrigation during dry spells. These are largely privately constructed.

Boreholes

In many SSA countries, small-bore wells (boreholes) are drilled and equipped to supply community water for domestic use and animal watering. However, in dry areas, the development of community food gardens has been based almost exclusively on borehole water. Boreholes for food production are mostly equipped with diesel or electric-powered pumps. Electric pumps are preferred, because both the operation costs and the maintenance requirements and costs are less than those for diesel motors. In Ethiopia, livestock herders and remote rural communities are highly dependent on borehole water, which is often their only water source. Some regions in Ethiopia have developed effective programs for the provision of water supply based on boreholes.

Diversion systems

Often referred to as off-take systems, diversion systems are probably the most common form of irrigation system in Ethiopia. Diversion systems often utilize natural river flow; however, regulation of river flow via a permanent structure in the river bed is also a common practice to increase the off-take. Diversion systems abstract water over a sustained period of time and are able to deliver regular irrigation throughout the cropping regime. A key characteristic of diversion systems is the adequacy of water supply during the dry seasons and the ability to irrigate a dry season crop in addition to providing supplemental irrigation during the rainy seasons.

3.2 Technologies for Water Lifting and Conveyance

Treadle pumps

Treadle pumps are a potentially high-return, high-impact AWM intervention. More specifically, they are especially appropriate where there is a water source close to the surface (less than 6 meters) and close to the field to be irrigated (less than 200 meters), and they will be especially profitable when farmers have access to markets where they can sell high-value fruits and vegetables. They can be used for supplementary irrigation during dry spells, though this is not commonly found. There is evidence that in many circumstances they can benefit very poor people and women, but this often depends on the local culture and social structure. Treadle pumps are also versatile—they can be used for many purposes where water needs to be lifted; they are not limited to irrigation (See Figure 3 for sample models of treadle pumps in different countries of Africa).

The successful programs to promote treadle pumps have paid considerable attention to the manufacture, sales, and after-sales service of treadle pumps, and to training farmers in their use. It is quite likely that the additional attention to helping farmers link effectively to output markets further enhances their positive economic impacts. Providing packages that combine treadle pumps with water-efficient application technologies such as low- cost drip systems can further enhance the returns, especially where either water is scarce, or labor shortage limits the capacity to pump.

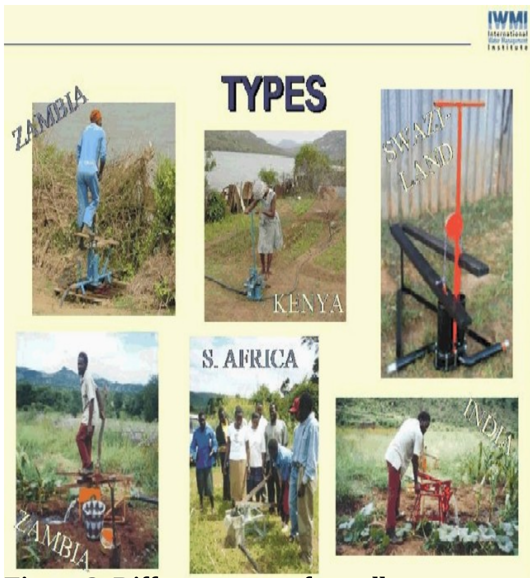

Figure 3. Different types of treadle pumps

Motorized pumps

Low-cost motorized pumps have had a big impact in Asia, but in Africa there is far less experience except in West Africa, especially Nigeria. Impediments to their rapid uptake include:

- In most countries, they are either not available or are too expensive;
- Lack of scale means that the input supply market (spare parts, maintenance expertise) is weak;
- Relatively high fuel prices and rural electrification is not wide spread; and
- Limited markets for high value produce.

For all the reasons given above, it is likely there are limited opportunities for poor farmers to make profitable use of motorized pumps, particularly if promoted on individual basis. Communal ownership and operation may be feasible and may have substantial poverty reducing impacts.

3.3 Field Application Technologies

Drip irrigation systems

Drip irrigation enables the farmer to make use of limited amounts of water and fertilizer which can be applied together with the irrigation water to grow high value crops. Drip irrigation allows precise application of small amounts of water directly to the root zone. In terms of Figure 1 on rainfall partitioning, it reduces losses from evaporation, weeds, runoff and percolation. Drip irrigation is popularly viewed as one of the most water efficient types of irrigation, but Laker (2006) warns that in large areas the soils are not suitable for drip irrigation, notably course sands and severely crusting soils.

Conventional drip irrigation systems typically cost US$ 5,000–10,000 per hectare or more, installed in East and Southern Africa. Recent advances have introduced some adaptations that make them accessible to small- scale farmers. Simple drip irrigation systems are now available which would cost a farmer US$ 15 to cover 15 m^2, or US$ 200–400 for a bigger system covering 500 m^2 (Sijali, 2001; Sijali and Okumu 2002, 2003)1.

1 The reader is referred to Sijali's excellent handbook (2001), with diagrams of layouts and functions of virtually every type of bucket and drum drip kits available in Eastern and Southern Africa.

While there are numerous individual farmers in Africa who have benefited from low-cost bucket and drum drip kits, there is no evidence of successful implementation on a larger scale. This is in contrast to South Asia, where there has been considerable success, both in terms of market-driven systems aimed at relatively better-off farmers, and in terms of targeting poor farmers. The technology is potentially very beneficial and profitable to poor small farmers but only under certain conditions. These include:

- Dry area or growing season when there is a high premium on maximizing productivity of water; they are not likely to be attractive in relatively wet areas.
- A reliable water source close to the garden to be irrigated.
- Soils are suitable for drip irrigation or are sufficiently ameliorated to ensure their suitability.
- Effective program for promotion (social marketing), training, technical support, provision of spare parts, and targeting to people who can really benefit.
- They must save labor, especially small kits for poor families whose labor supply is a constraint.
- Robust but simple technology, which is affordable and easy to maintain and operate.
- Access to output markets for higher value fruits and vegetables.

Clay pot (sub-surface irrigation), also called 'pitcher' irrigation

This is a low-cost indigenous sub-surface drip system achieved by use of unglazed fired clay pots that remain micro-porous and are molded by hand by rural women. There also exist molding machines that can mass produce clay pots with specifications of porosity and firing temperature to eliminate possibility of shrinking and swelling of clay which may lead to cracking. The clay pots are buried in the ground with their necks appearing above ground in a row at specific plant intervals. Plants are planted adjacent to the pot on either side and the pots filled with water and covered with a clay lid to avoid direct evaporation of water and rodents drinking the water (See figure 4). Using the principle of moisture potential, water oozes out of the pot from its high water potential to wet the surrounding soil outside the pot where the soil water potential is low. The water is instantaneously taken up by the crop from its root zone around the clay pot. The pots are made of locally available clay with optimum properties of strength (to resist crushing), permeability (to exude water into the soil at an approximately steady rate), and size (to hold enough water for at least one day's supply). Such use of soil-embedded porous jars is one of the oldest continuous irrigation methods that probably originated in the Far East and North Africa.

Figure 4. Clay pot/sub-surface irrigation

This is a very suitable technology for poor rural women as they make the pots for sale (income generation), and because it is less labor intensive than most alternatives, it has high labor returns and suits people disadvantaged by physical handicaps or HIV/AIDS. Water as well as fertilizer productivity is also very high. Clay pots have a lot of potential for backyard vegetable and flower production even in urban areas. In a wet period, they can also be used for drainage by emptying the pots as water infiltrates back in from saturated soil.

It has been well established that irrigation intervals between 7-14 days and water saving between 50% and 70% are achievable, resulting in yield increases between 30% and 45% over conventional flood furrow and basin irrigation systems. This indicates a high potential for labor saving while irrigating. Crops that prosper under this system include tomatoes, rape leaf vegetable, cauliflower, maize, beans and fruit trees. This was achieved at far higher water productivity than conventional irrigation.

The potential of clay-pot irrigation has not been fully exploited by farmers in the eastern and southern Africa region, even though the technology is suitable for small-scale farmers. The value of the clay pot or pitcher irrigation is confirmed by several authors from across the globe (Bainbridge 2002).

There are numerous advantages to using buried clay pot irrigation. First, pots are not as sensitive to clogging as drip emitters, although they may clog over time (after 3-4 seasons) and require renewal by reheating the pots. Second, the system does not require a pressurized water system, which is difficult to establish and maintain at remote sites. Third, animals are less likely to damage or clog buried pots than aboveground drip systems. Fourth, by selecting lids that collect rainfall, any precipitation that does fall can be conserved and used. Finally, buried pots are more robust than drip systems because they do not rely on continuous supplies of power or water to operate.

We conclude that clay pot irrigation is a cost effective and easy-to-implement alternative to bucket and drip irrigation kits. The pots can be manufactured locally and therefore create employment for poor people (often women), and can be used by poor women and men to irrigation vegetables and fruit trees cost effectively. They are appropriate wherever water is scarce, or where obtaining water is expensive, putting a premium on water conservation.

Sprinkler Systems

Sprinkler Irrigation is a method of applying irrigation water which is similar to rainfall. Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air and irrigated entire soil surface through spray heads so that it breaks up into small water drops which fall to the ground. Sprinklers provide efficient coverage for small to large areas and are suitable for use on all types of crops. It is also adaptable to nearly all irrigable soils since sprinklers are available in a wide range of discharge capacity. Micro and Mini sprinkler kits are available in sizes from 100 to 1000 m^2. Systems more than 1000 m^2 can be customized to suit specific requirements. Micro-sprinklers are spaced at 3m x 3m mini-sprinklers are spaced at 6m x 6m in order to produce uniform wetting. Micro-sprinklers require 5 m to 10 m operating pressure whereas mini-sprinkler requires 10 to 15 meters of operating pressure. Micro and Mini sprinklers can be shifted from one place to other to cover larger areas and thus are potentially useful for small scale farmers with varying land holdings.

4. Concluding Remarks

- Low average rainfall that is seasonal, highly variable in time and space, and increasingly unreliable is the major impediment to farm households increasing their production of food, cash crops, and livestock products in Ethiopia. The impacts of this unreliable and inadequate water supply are compounded by many other problems natural (for example poor soil fertility) and human- created (for example lack of support services and infrastructure). Improving the reliability of water supply for agriculture is therefore a necessary though not sufficient condition for reducing poverty and malnutrition and generating faster agricultural growth.
- AWM technologies and practices are complementary in nature. For instance, while the water lifting technologies, diversion and storage systems are means of accessing water from a source, the application technologies are means of efficiently using the accessed water. This combination has to be appreciated in any future investment planning, particularly given the scarcity of water.
- It is important also to note that some of the technologies and practices have been known to the farmers for many years or are indigenous, but the extent of their use or adoption is low. This may reflect their highly location-specific nature.
- The literature on agricultural water management is usually crop-biased while the livestock production sector constitutes a vital livelihood system of the rural people in Ethiopia and elsewhere. A lot of innovative water management systems for livestock production systems that warrant further consideration are available.
- There is reasonable though not conclusive evidence that some of the AWM technologies reviewed in this study, under the right conditions, do lead to substantial improvements in households' food security and incomes, and that they do so in a cost-effective manner. This is especially true for treadle pumps, but there is enough case study and anecdotal evidence to suggest that the statement also applies to low-cost drip kits, clay pot irrigation, conservation farming practices that integrate nutrient and water management, and a variety of in-situ and ex-situ water harvesting and storage technologies.
- There are many actors and many projects involved in studying and (especially) promoting a large number of different AWM technologies and practices in Ethiopia. However, there has been little or systematic analysis of their effectiveness, impacts and sustainability, or attempts to understand what strategies work and why, and what does not work and why. Undoubtedly the same mistakes are being repeated needlessly. While a multiplicity of effective local and international NGOs is to be encouraged, it would be useful to find out systematically what are the main strengths and weaknesses (comparative advantages) of each, and develop mechanisms for better coordination and sharing of experiences and lessons learned.
- The tremendous diversity of conditions in Ethiopia must be acknowledged. Even within districts, there is such diversity in soils, micro- climate, cultures, and access to markets that what works on one farm may not be appropriate next door. This means there is no possibility of generalizing, no cook book approaches or sure-fire universal panaceas that will work everywhere. Unfortunately, it appears that there are cases where AWM technologies not really appropriate to local conditions

and needs are promoted (and rejected). Further, there has been a failure to take an integrated approach, in several senses: recognition of the multiplicity of household water needs given the diversity of livelihoods (for example integration of livestock, crops, brick making, etc.); recognition of the potential synergies of integrating AWM technologies, for example combining treadle pumps with efficient application technologies with soil conservation practices; integrating water and nutrient management; and pursuing implementation strategies that integrate attention to support services (inputs), attention to production processes, and to outcomes on the demand side in terms of both household food security and nutrition and access to well-functioning markets.

- Following from the diversity of Ethiopia, it is no surprise that there are no cases of successful massive scaling up and out of specific AWM technologies and practices. Adoption, adaptation, or rejection decisions are a function of many factors including lack of information or access, lack of fit between the technologies on offer and the capacities and needs of households, inefficient promotion strategies, flawed assumptions about households' needs and capacities and the real costs and benefits from their perspectives (for example the assumption of surplus labor availability), ineffective targeting, lack of capacity to manage projects offering a large array of small-scale technologies to thousands of poor households, and lack of credit.
- In many regions in southern Africa where there is a water source no more than 6 meters below the surface or 200 m away from where the water is needed, treadle pump offer a potentially high-return and high-impact intervention. The pumped water can be used for many domestic and productive purposes, not only irrigation. The evidence from Malawi, Tanzania and Zambia demonstrates the potentially very high impact on food security and incomes.
- Like low-cost drip irrigation kits, although so far clay pot irrigation has not been implemented on any scale, we believe this is also a low-cost technology that can result in a very high level of water and labor productivity.
- The term "conservation agriculture" covers a large range of in-situ water and land management technologies and practices, some of which require large initial investments to implement. But some of the practices described under this heading are relatively low-cost, with very high potential returns. The critical issue is that many interventions have failed to address the necessity of integrating water and nutrient management: adding water by itself can actually lead to more rapid depletion of nutrients, while soil nutrients cannot be efficiently used by plants without water. Because of the complexity and diversity of most Ethiopian farming systems, there is no monolithic package of conservation agriculture technologies; rather farmers need to be supported and assisted to try new ideas and combinations of practices that work under their conditions.
- As with in-situ water and land management practices, there is a wide range of low- cost and easy-to-construct ex-situ water harvesting and storage practices that under specific conditions are effective and can have large impacts on food security and livelihoods. As is the case for others, adaptation to local conditions with poor people empowered to make their own decisions rather than being passive recipients is critical to success.
- Following from the observations above regarding the diversity of conditions and situations and the fact that no single AWM technology or practice can be a panacea, we strongly recommend that supporting the creativity of the user is essential if people are going to improve their food security and escape from poverty. Therefore, participatory approaches that encourage and support creativity and innovation, for example by offering choices and menus that can be adapted and combined as needed, participatory approaches that empower users to make their own decisions, and provision of support services that reduce risk and makes available resources that are not otherwise at hand.

- While supporting the need to invest in major water (and indeed other) infrastructure at a far greater scale than seen so far in Ethiopia, we strongly recommend scaling up investments in AWM technologies and practices because it offers a relatively faster and more cost-effective way to achieve the MDGs than for example major irrigation investments. Many AWM technologies are far less expensive per household than formal irrigation, their benefits begin immediately upon acquisition, and they are not plagued by all the management problems, transaction costs and negative externalities often characterizing formal irrigation. Of course, for poor people living in areas where there is no adequate source of water, infrastructural development is necessary to bring water close to the people in need.
- AWM technologies are "divisible"; i.e., can be used by individuals or small groups directly. They also lend themselves to provision by the private sector, unlike large water infrastructure projects with large public good and common property characteristics. Therefore, we recommend that governments examine how to make their policies more conducive to encouraging private sector firms to manufacture, supply, and even experiment and innovate AWM technologies.
- We recommend that NGOs and governments currently promoting AWM technologies as part of their relief efforts move away from short term relief to long-term development. We have found cases where well-meaning provision of technologies like bucket and drip kits has had no impact, because of the lack of longer term service provision and training. This is not a good use of scarce resources. It is clear that the most successful programs are those that take a longer term integrated perspective toward creating the conditions conducive to sustainability.
- Finally, we strongly recommend more investment in monitoring, impact assessment, pilot testing of innovations, and sharing the lessons learned widely among government agencies, investors, donors, private firms and farmers. Creating "learning alliances" among interested partners to collaborate in these endeavors is one effective way to achieve this.

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