I. Introduction

In 1996, at the World Food Summit, Heads of State reaffirmed the right of everyone to have access to food security, expressed as a secure access at all times to safe and nutritious food. They also committed themselves to halving the present number of 800,000 of undernourished people by 2015. The achievement of this goal is central to the Strategic Framework of the Food and Agriculture Organization of the United Nations.

In many semi-arid regions of the world, irrigated agriculture alone will not be able to satisfy the future demand for food. Rainfed agriculture still supplies about 60% of the world's food and will continue to play a major role in cereal production, which is by far the most important source of food, both for direct human consumption and livestock production. In sub-Saharan Africa, rainfed cereal production accounts for about 90% of total cereal production (IFPRI, 2002).

Since the mid-1960’s, the world has managed to raise cereal production by a billion tonnes. Over the next 30 years, the challenge remains the same. As new land to put under agriculture is increasingly limited, improvement of yield will continue to be the largest source of increase in crop production. In sub-Saharan Africa, improvement of yield and area expansion account for 65% and 35% of increased food production respectively. While external support for agriculture has considerably decreased over the last 20 years and resource-poor farmers have limited access to credit and other inputs, a number of scenarios have shown that more rapid growth in rainfed yield and production could compensate for reduced investment in irrigation (IFPRI, 2002). Hence, affordable technologies to increase crop yield in rainfed agriculture would make a significant contribution to food security.

Low and irregular rainfall is a permanent threat to agriculture in many (semi-) arid areas. However, as reported by Rockstrom (2001), even rainfed agriculture is characterized by low yields, generally oscillating around 1 T ha⁻¹, there are no agro-hydrological limitations to doubling or even quadrupling on-farm staple food yields even in drought-prone environments, by producing more ‘crop per drop’ of rain. Innovative rainfed management strategies are currently being identified to improve water productivity within present farming systems. At present, one of the main issues lies with the creation of an enabling environment for a wide dissemination of the available options.
II. Strategies for improving rainfed production growth in sub-Saharan Africa.

Challenge

Low productivity in agriculture is related to inadequate rainwater management strategies. As reported by Rockstrom (2001), in many places, only some 15 to 30% of the natural occurring rainfall is productively been used by the crops. Most of the water evaporates from bare soil (30 – 50%) or is lost through runoff (10 – 25%) or deep percolation (10 – 30%). The losses are even higher, when less than 10% is used in productive food making by the crops where surface runoff is high and soil nutrient depletion is severe.

However, in many arid and semi-arid areas of sub-Saharan Africa, yields can be improved within the water balance in rainfed farming systems. Interdisciplinary approaches are required to: (1) increase the amount of water made available to the crops to satisfy their crop water requirements over time, (2) maximize water infiltration and water holding capacity of the soils and (3) improve plant water uptake capacity.
One strategy to meet the challenge is to combine 'water harvesting' systems with improved soil fertility practices, improved soil moisture conservation practices and/or improved cropping practices, for suitable farming systems. Often, it will be an iterative process to identify the combinations most likely relevant. It has to be noted that the effects of one intervention may take longer to be felt than another one and farmers are more likely to adopt measures with immediate benefits. It may then be necessary to identify with farmers the sequence in which a set of favorable changes should be introduced. This participatory design of the technology package would preferably be made simultaneously with rural appraisal of socioeconomic conditions and cost-benefit analysis to ensure its long-term sustainability.

**Water harvesting potential in sub-Saharan Africa**

a. Definition

In its broad sense, 'Water harvesting' can be defined as the 'collection of runoff for its productive use' (Siegert, 1994). More precisely, it is the 'process of collecting and concentrating runoff water from a catchment area into a run-on area, where the collected water is either directly applied to the cropping area and stored in the soil profile for immediate use by the crops (runoff farming) or stored in an on-farm storage system for future productive uses (domestic use, livestock watering, aquaculture, supplementary irrigation)'.

In this Paper, the term of 'runoff farming' systems is used where the collected water is directly applied to the cropping area and stored in the soil profile for immediate uptake by the crops.

These 'runoff farming' systems can be categorized into three groups, namely ‘on-farm micro-catchment water harvesting systems’, ‘macro-catchment water harvesting systems’ and ‘floodwater harvesting systems’, according to the type of surface runoff (e.g.: sheet flow, rill flow, etc.), the size of the catchment area and the ratio 'catchment area: cultivated area'.
b. Potential areas

- Hydro-climatic factors

In general, water harvesting has its largest potential in semi-arid to dry sub-humid regions where crop water requirement is higher than supply due to low annual rainfall, high evapotranspiration, uneven seasonal distribution and/or rainfall variability.

<table>
<thead>
<tr>
<th>Rainfall/ETP</th>
<th>Zone</th>
<th>Annual rainfall</th>
<th>Length Growing Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 – 0.5</td>
<td>Semi-arid</td>
<td>200 &lt; x &lt; 400 mm</td>
<td>60 – 119 days</td>
</tr>
<tr>
<td>0.5</td>
<td>Dry sub-humid</td>
<td>400 &lt; x &lt; 800 mm</td>
<td>120 – 179 days</td>
</tr>
</tbody>
</table>


In these regions, the result of rainfall scarcity and/or high spatial and temporal variability is a high risk for annual droughts and inter-seasonal dry spells. In sub-Sahara Africa, it has been estimated that 44% of the land surface is subject to high risk of meteorological droughts.

Crop yields and returns per unit of rainfall could already be maximized with improved understanding of the rainfall regime (intensity, duration and frequency) and the prediction of expected rainfall behaviour, season by season, coupled with response management of the cropping system. The implementation of the responsive farming programme can provide localized information about expected rainfall behavior in the forthcoming season and offer guidelines or detailed recommendations to farmers about how best to proceed in the light of the rainfall forecast and actual season onset to improve soil moisture management and maximize outputs.

In addition to the hydro-climatic factors, other physical factors have to be taken into consideration to define the highest potential areas for runoff farming systems. These include the soil aspects, the topographic aspects, the agronomic aspects and the socio-economic aspects.

---

1 Responsive farming: flexible system of farming in which key decisions affecting crop water utilization and crop yield are modified each season in response to pre-season and early season predictions of season rainfall amount, duration, intensity index and other parameters as appropriate.
Farming system

One of the main challenges for developing countries is to focus investment in areas where the greatest impact on food security and resource allocation process will be achieved. This identification and resource allocation process can be facilitated by analyzing farming systems in order to develop an understanding of local factors and linkages.

A farming system is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints and for which similar development strategies and interventions would be appropriate (FAO and World Bank, 2001).

Following the classification of the farming systems for sub-Saharan Africa (FAO and World Bank, 2001), the agro-pastoral millet/sorghum farming system is a farming system with the highest potential for adoption of ‘runoff farming’ systems. Traditional crops such as sorghum and pearl millet are promising crops. They are the crops most commonly grown by poor farmers in the more water deficient areas of the drylands; they are less water intensive, require less inputs and are more nutritious than other grains such as wheat or rice. The agro-pastoral millet/sorghum farming system occupies 198 million ha (8%) of the land of the region, generally in the semi-arid zone of West Africa from Senegal to Niger and in substantial areas of East and Southern Africa from Somalia and Ethiopia to South Africa. Pressure on the limited amount of land is very high and food insecurity is caused by drought. Crop related constraints include declining soil fertility but opportunities exist with the availability of manure from livestock. When runoff farming systems are implemented in these areas, yield increases are high (up to 5 fold).

Hence, there is a high potential for the development of runoff farming systems, combined with other rainfed management strategies, in the agro-pastoral millet/sorghum farming system in sub-Sahara Africa for increased cereal production.
Traditional 'water harvesting' systems: a key entry point

Micro-catchment water harvesting systems often originate from traditional systems and case studies have often reported that improved traditional water harvesting systems have the highest adoption rate by the beneficiaries. For this reason, many traditional water harvesting systems are now being studied systematically and used as a starting point for new programmes, which identify ways to increase their efficiency.
Knowledge of the efficiency factor of ‘runoff farming’ systems is very limited. Publications indicate range between 20 to 75 %, with the highest efficiency values for micro-catchment water harvesting systems. Main factors affecting the efficiency of these systems include: (i) the catchment size relative to cropping area (ii) the collection and distribution of water within the field (iii) the main water 'losses' from the cropping field.

Hence, efficiency optimization can be achieved when the optimum catchment size relative to the cropping area is defined. As reported by ICARDA (2001), modelling tools could pay a major role for this. Efficiency can also be increased when catchment areas are treated, cultivated areas are levelled and soil moisture management practices are put in place before supplying water to the cropping area. An alternative to land levelling, which is an effective but also an expensive means of conserving runoff is the use of tied-ridging.

III. Constraints for the development of water harvesting in (semi-) arid areas of sub-Saharan Africa

International level

Globally, given the significant contribution of rainfed production to food security, insufficient investment has been made to meet the full potential of production growth in rainfed areas. Until now, development and research activities have mostly focused on the possible expansion of irrigated areas and intensification of irrigated agriculture. One of the reasons explaining the situation is that the socio-economic impacts of water harvesting are still poorly known and the investment in water harvesting schemes is limited by a severe lack of knowledge about their economic performance and their potential to contribute to food security and poverty alleviation in (semi-) arid areas.

National level

At national level, rainfed production growth is mainly hampered by the institutional, policies and capacity building aspects:

- Institutional aspects
There are often no clear strategies on water harvesting and, when water harvesting schemes are promoted, water resource engineers are too often narrowing the wide definition of water harvesting to almost exclusively represent systems, where the collected water is stored in an on-farm storage system for future productive uses (domestic use, livestock watering, aquaculture and supplementary irrigation).

For the formulation and implementation of projects, the responsibility on small-scale water harvesting is often shared amongst several government ministries/departments without proper coordination. For the monitoring and evaluation of projects, indicators are lacking and monitoring and evaluation data are not collected, even at the most basic level.

Many countries of sub-Sahara Africa have weak organizational structures and/or mechanisms, at both national and grassroot levels, to avoid adverse impact and ensure equitable access to water resources within the watershed. However, the situation is different in South Africa where the Integrated Catchment Management Approach has been a useful mechanism for local level coordination.

- Capacity building

Government departments, research centres, universities and extension services are not sufficiently aware of available rainfed management strategies and many countries lack qualified staff for adequate feasibility studies, correct design of water harvesting systems and integration with appropriate soil and crop management practices. In terms of capacity building, some of the main needs (human resources, infrastructure, funding, etc.) concern the collection and analysis of hydrological data for careful planning and design of water harvesting systems. It should also be noted that most countries do not have the capacity to compile and analyze reliable statistics on runoff farming indicating the extent and the relative importance of each system.

Local level

2 Areas under spate irrigation (also called ‘floodwater diversion’) are the only statistics made available in Aquastat. Aquastat is the FAO’s global information system on water and agriculture. The objective is to provide users with information on the state of agricultural water management across the world.
At local level, some efforts were recently made to assess the adoption level of water harvesting techniques by the beneficiaries in arid and semi-arid areas of Western and Central Africa (FAO, 1999). The results vary considerably from one site to another. Failures are reported to be mainly due to lack of participation of the beneficiaries at all stages of the project, high manpower requirement for maintenance, unsustainable systems (e.g. not technically appropriate, not affordable, not profitable, not socially acceptable, not environmentally sound, etc.), etc.

IV. FAO programme of activities on water harvesting

1. To develop a methodology to assist countries to collect reliable statistics on runoff farming systems.

Reliable statistics will assist in assessing the current situation and estimate the contribution of these systems to food security. More complete and reliable data will also assist decision-makers in analyzing trends, make projections and formulate national strategies and projects.

Action: FAO is currently reviewing its database ‘Aquastat’ to consider the various forms of runoff farming systems. In addition, it is continuously updating its database with data reported by member countries.

2. To improve collection of basic field data: - (i) Collection of data on the main factors to take into consideration to identify suitable sites and to ensure effective planning of water harvesting systems. These data include data on climate, hydrology, soil, crops, topography, socio-economics, etc. – (ii) Long-term monitoring of basic climatic and hydrological data to ensure effective water harvesting system design. Action: Field projects.

Remark: For spate irrigation systems, there is a need for quantitative measurement on sediment loads and discharge rates. The FAO’s World River Yields Sediment Database could be used to start addressing this issue (http://www.fao.org/ag/agl/aglw/sediment/default.asp).

3. To raise awareness of countries on available technology options and to build capacities at all levels on planning, design and implementation water harvesting systems, particularly for improved rainfed agriculture.

Action: FAO has developed a two-week training course for technicians on water harvesting. The
aim is to raise awareness of member countries in (semi-) arid areas on available technology options and to build field staff capacities on the use of available data for more efficient planning and systematic design of water harvesting systems. The training includes the hydrological factors (e.g. rainfall analysis, rainfall/runoff analysis, flood analysis for the determination of the ‘Catchment area : Cultivated area’ ratio, storage capacity and spillway design), soil factors, agronomic factors and socio-economic factors. FAO has already conducted training courses in several countries (Tunisia, Ethiopia, Yemen, Myanmar, Laos, Vietnam, Mongolia, China) and is receiving an increasing number of requests from member countries for 2003/2004.

4. **To assess social, economical and environmental impacts of water harvesting systems.**
Funding agencies use evaluation data as a rational basis for funding interventions and decision-makers need them for policy formulation, further planning and mobilization of this foreign assistance.

**Action:** (i) **Social aspects:** FAO is implementing case studies in HIV/AIDS affected areas in Kenya & Uganda (focusing on farm micro- and macro-catchment water harvesting system) (i) to assess applicability and replicability aspects of water harvesting technology options by HIV/AIDS affected groups. The studies will assess labour needs, economic return to labour and gender division of labour. (ii) **Economical aspects:** FAO is also implementing case studies in 8 sub-Saharan countries to demonstrate economic viability of water harvesting systems, estimating investment costs and main benefits.

5. **To improve understanding and management of groundwater recharge in agriculture water use systems.**
Recharge in areas under cultivation is largely incidental and has too often been the result of poor management. Leakage from reservoirs and infiltration excess from irrigation systems or runoff farming systems (e.g. spate irrigation systems) all contribute to enhance aquifer recharge. In countries such as India, the aspect of incidental recharge is increasingly recognized as a valuable by-product of an integrated water resources development scheme to the extent that it is often scavenged.

**Action:** FAO is currently approaching IAEA for application of isotope techniques to assess shallow groundwater recharge in agriculture water use systems. The improvement of scientific knowledge on shallow groundwater recharge in agriculture water use systems, both in terms of quantity and quality, is intended to make this aspect better understood and managed.
V. References


FAO, 1994. Water harvesting for improved agricultural production. FAO, Rome, Italy


Rosegrant, M., Cai, X., Cline, S., and Nakagawa, N., 2002. Role of rainfed agriculture in the Future of Global Food Production. Environment and Production Technology Division

http://www.davis.com/~wharf/