Making better use of Green Water in Sub-Saharan Africa

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Context and objectives

The trend of food production in Sub-Saharan Africa (SSA) over the past two decades shows insufficient total production and a decreasing output *per caput* (FAO 1996a and b). The present food insecurity and the projected population growth in the region demand change from low yielding farming systems towards greater production and sustainability. From the biophysical point of view, low crop yields are caused by three main soil- related constraints: low rainwater use efficiency, low fertilizer usage, and inadequate soil and water conservation (Kauffman *et al.* 2000). In addition, adaptation of farming systems will be needed to respond to predicted climatic change.

Globally, dryland or rainfed agriculture produces 80 per cent of the total farm production and irrigated agriculture 20 per cent but, in SSA, dryland agriculture makes up more than 95 per cent of farm output. There is no easy answer to the question whether the focus of agricultural development in SSA should focus on irrigated or dryland agriculture: the focus has to be on both. The history of irrigation in most countries within SSA in the last 30 years has not been good and most existing schemes have performed well below their biophysical potential (Gowing 2003). Others argue that supplementary irrigation is required for rainfed agriculture, especially in the semi arid tropics (Rockström 1997, Savenije 1998). However, the starting point for this paper is that dryland agriculture will have to feed most people in SSA for the foreseeable future and that there is much scope in the improvement of rainwater use.

The term *Green Water* is being used to distinguish the portion of rainwater that infiltrates into the soil and that is effectively used for crop growth (Falkenmark, 1995), in contrast to blue (surface) water allocated to irrigated agriculture and domestic supply, which has received a great deal more attention. Rockström (2001) estimates that, in SSA, the green water fraction is only some 15 to 30 per cent of the total rainfall. This low proportion is a result of high losses through surface run-off, especially during the pre-planting and early crop stages, low infiltration into the soil during high-intensity rains, poor crop rooting conditions, and past and present soil erosion.

There are various soil and water conservation techniques that may increase the amount of green water. However, these techniques are presently inadequately practised. This situation is caused by, amongst other things, lack of investment capacity amongst small farmers and by lack of information about appropriate, effective techniques.

This paper addresses three questions: (i) Why are soils important in water supply and scarcity? (ii) What is the scope for increasing green water in SSA? (iii) How could a *Green Water Initiative* meet farmers' needs for information? It is based on a literature and data search and an e-mail questionnaire on green water issues in Southern Africa countries held in late 2002 (Ringersma 2003). It also introduces a Green Water Initiative initiated by ISRIC-FAO.

Why are soils important?

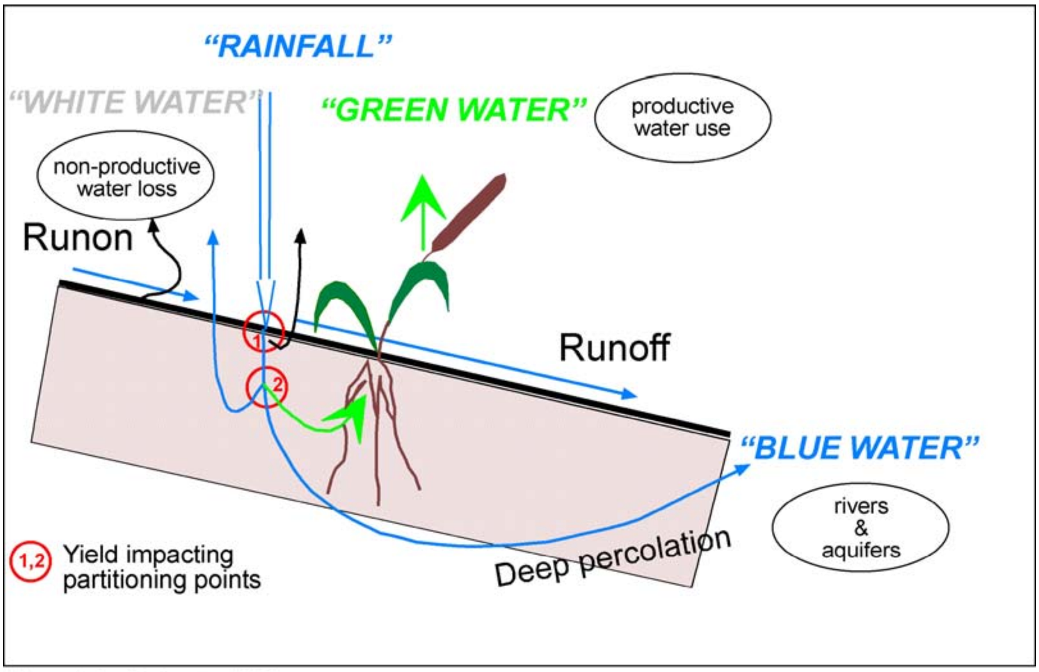
The Green Water concept

From the perspective of crop production, rainwater may be split in green, blue and white components (Figures 1 and 2):

- *Green Water* is the water infiltrating into the soil, taken up by roots, used in photosynthesis and transpired by the crop;
- *White Water* is intercepted and directly evaporated by the crop canopy and the ground surface;
- *Blue Water* is made up from run-off to rivers and deep percolation to aquifers that finds its way to rivers indirectly.

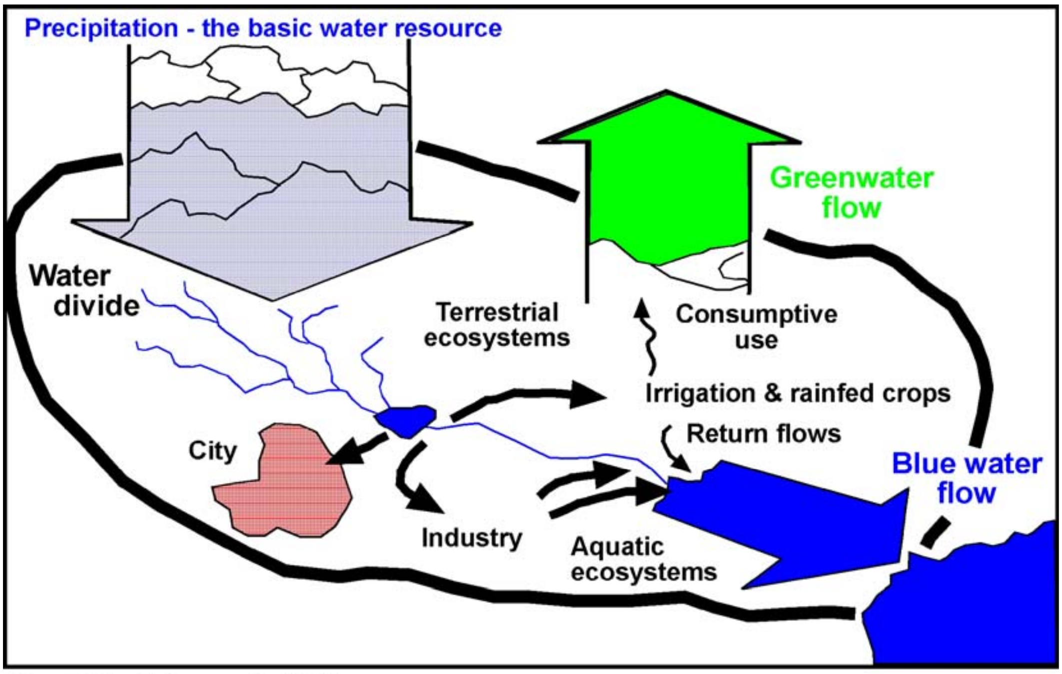
From the perspective of dry land cropping, green water is the productive component.

Figure 1 – The three components of rainwater at field level



(Adapted after Rockström, 1997)

Figure 2 – The three main components of rainwater at basin level



After Malin Falkenmark, 2003

In addition to direct input from rain, the amount of green water may be increased by irrigation and run-on (Figure 1). The infiltration and storage of run-on water can be improved by in-field water harvesting techniques, which brings up the question of definition: where does green water start, and when does it become blue water? For sake of simplicity and clarity, Ringersma (2003) includes run-off that is harvested by in-field techniques as green water, and excludes water from the larger off-farm water collecting works such as reservoirs. In other words, green water applies to dry land farming and blue water to irrigated farming.

Factors determining green water

The amount of green water is determined by soil, terrain and climate, and by management (Table 1):

Table 1(after Ringersma 2003)

BIOPHYSICAL FACTORS		
Soil	Water	Atmosphere
Surface conditions		
Crusting		Rainfall
Infiltration	Run-off	Intensity
	Run-on	Quantity
		Duration
Topography		
Slope		
Landform		

MANAGEMENT	
Soil management	Plant management
	Crop- factors
	transpiration coefficient
Mulching	
Tilling practices	
Early soil prep.	
Slope length	Plant density
Stone rows	
Hedgerows	

Soil depth			Water Harvesting	Early planting Weeding
Soil wetness	Soil evaporation	Atmospheric demand (PET)		
Rootable depth				
Storage capacity			Manuring* Fertilization*	
Nutrients*				
Deep soil	Percolation			
Hydraulic conductivity				

*) As far as it determines the amount of green water

- The *partitioning of rainfall* between infiltration and run-off is determined, in part, by soil surface attributes: some soils have a stable, porous surface structure, others crust and seal, especially when rains fall on a bare surface;

- The *rate of vertical and horizontal percolation* of water is determined by the soil's hydraulic conductivity;

- *Available water capacity*, the amount of green water that may be held in the soil, depends on the volume of soil accessible to roots, its texture, structure, organic matter content and the kind of clay minerals: the proportion of available water may vary by a factor ten;

- *Deep percolation* to the groundwater may be hindered by compact layers;

- Lateral *movement of infiltrated water to rivers* is determined by the composition and architecture of unlithified materials down to the bedrock, and the shape of the soil-bedrock interface, as well as the characteristics of deeper aquifers.

Therefore, knowledge of about soil qualities and their spatial distribution is needed to understand the hydrological regime of both farmers' fields and river basins.

Soil and terrain data

The pattern of soil cover is mapped at various scales. For specific purposes, the details assessed range from only few attributes to a complete determination of all standard attributes with profile description and soil classification. This comprehensive information is mostly collected in systematic surveys at catchment or regional levels. National soil institutes are custodians of national soil maps and supporting data and this soil information has been available only in paper format.
Increasingly, the information is becoming available in digital format making use of geographical information systems and relational soil databases.

At the continental level, we have the *FAO-Unesco Soil Map of the World* at a scale of 1:5.000.000 (FAO-Unesco 1974-1981). Although widely used, this map is increasingly outdated and is gradually being superseded by continental or regional soil and terrain (SOTER) digital databases. In Africa, SOTER compilation started for Kenya in 1995 at a scale of 1:1M in a joint project of the Kenyan Soil Survey and ISRIC, followed by Tanzania (FAO 1998) at scale 1:2M. SOTER databases are now completed for Angola, Botswana, Kenya, Mozambique, Namibia, Tanzania, South Africa, Swaziland, and Zimbabwe.

These national databases are being combined into a uniform database for Southern Africa – SOTERSAF (FAO-ISRIC-UNEP in prep.), at the scales 1:1M and 1:2M. SOTER databases, in combination with other information, are being used for scenario studies to support policy development at national and international level. An example in the field of green water is the assessment of the impact of soil erosion on the future productivity of maize in Kenya (Mantel and Van Engelen, 1999).

SOTER map units are defined by landform, lithology of the parent material, and the dominant soils, so that each SOTER map unit represents a unique combination. Once the SOTER unit is established, there is room in the database to describe various terrain components, each with their dominant and associated soils that cannot be mapped at the chosen scale. Each soil component is characterized by one or more geo-referenced, representative, soil profile descriptions with comprehensive field, soil chemical, and physical data (Engelen and Wen 1995). The SOTER database contains data on soil morphology, texture, stoniness, pH, available water capacity, bulk density, cation exchange capacity and exchangeable cations, carbonates, organic carbon and total nitrogen. Various thematic maps may be generated from the SOTER databases in ARCVIEW/ARC Explorer, for instance landforms, lithology, dominant soils, individual soil attributes like texture of topsoil, or derived attributes like green water.

Soil & water management

There are many soil and water management techniques that aim to reduce run-off and increase rainwater infiltration. However, most publications on these techniques offer inadequate quantitative field test and soil data. This makes it difficult to transfer effective techniques to other places. Ringersma (2003), over viewing publications that do provide adequate information on region, soil type and quantitative data on soil and water conservation, found that for SSA:

- Mulching reduces runoff by 72% (9 published field tests) and increases rain water use efficiency by 20% (4 studies);
- Appropriate tillage reduces runoff by 60% (7 published field tests) and increases rain water use efficiency by 58% (2 studies);
- Water harvesting and water conservation techniques reduce runoff by 66% (7 published field tests). One study reported a three-fold increase in crop production.

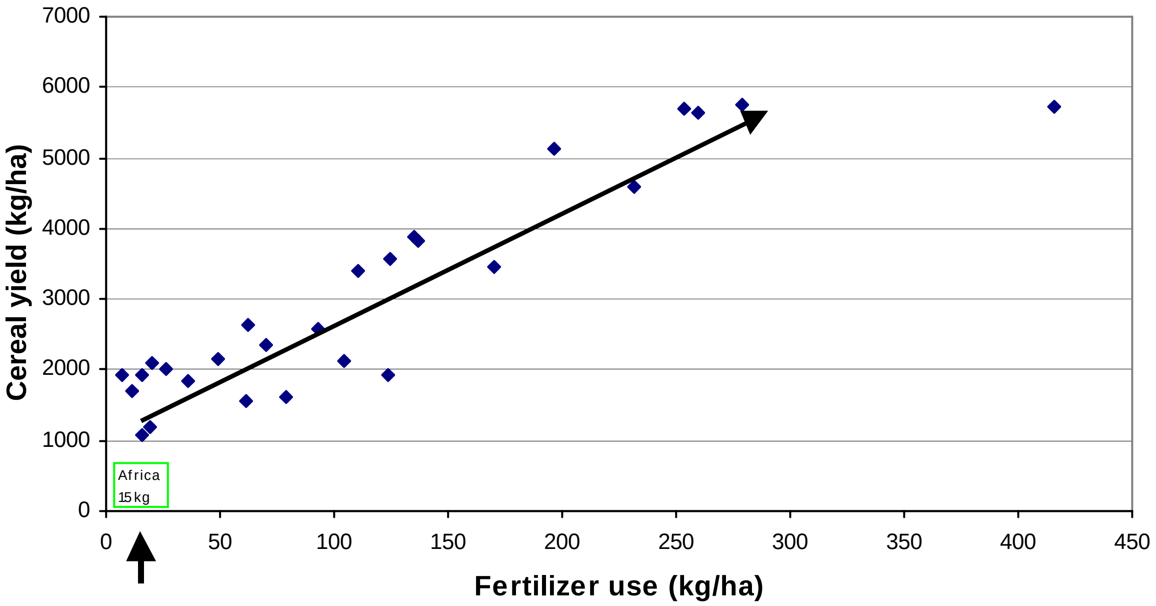
This indicates scope to substantially increase the amount of green water and, thereby, agricultural production. The publications on the rainwater use efficiency of plant management practices also show an improvement of water conservation, although the results are generally less spectacular than those achieved by soil management practices.

The World Overview of Conservation Approaches and Technologies Program - WOCAT (Liniger *et al.* 2002, van Lynden *et al.* 2002) is documenting and evaluating soil and water conservation (SWC) experiences worldwide. Local experts, in consultation with land users, collect the information using questionnaires. The information is stored in a database that facilitates data entry, editing and querying. The questionnaire on SWC technologies (QT) covers details of a technology as applied in a specific case. The second questionnaire (QA) describes the approach, *i.e.* the ways and means and conditions for successfull implementation of a technology (WOCAT 2003). The case studies may cover project-implemented changes, traditional practices, or farmers' innovations (Mutunga and Critchley 2002). After 10 years of collection of practical field information, the WOCAT database contains some 300 technologies and 120 approaches from more than 35 countries. Sub-Saharan countries account for about two-thirds of these, with more than 75 technologies related to water harvesting or soil water conservation. The system enables an evaluation of the strengths and weaknesses of any particular technology under given circumstances on the basis of a set of indicators. Such an assessment may be made of a technology in its present environment or may be used to assess its applicability in another area.

Water and soil fertility

Both water and nutrients are major soil-related constraints on crop production in Sub-Saharan Africa (Penning de Vries and Djitèye 1982). A trend analysis of cereal yield versus fertilizer use for Asia over the past 30 years is given in Figure 3. The very low current use of fertilizers in Sub-Saharan Africa suggests great scope for improvement. We are sure that the same picture applies to effective techniques to conserve and restore green water, although measurement will be more complex.

Figure 3 – Yield increase and fertilizer use in Asia compared to average fertilizer use in Sub-Sahara Africa (Source: Kauffman and Hartemink 2003)



A Green Water Initiative

There is a demand for quantitative information on green water, present and potential, at regional scale from FAO, UN conventions (*e.g.* UNCCD), and initiatives for intensification of Sub-Saharan Agriculture such as NEPAD. Further interest was expressed by various NARS and universities in Southern Africa participating in an e-mail consultation at the end of 2002. Most recently, the WCT symposium at Bloemfontein, 9 April 2003, has emphasized the need to support farmers with information on appropriate technologies provided to farmer-supporting agencies and research and extension institutions.

The aim of the ISRIC-FAO Green Water Initiative is to stimulate learning about how to improve green water use and management in dryland agriculture. This may be achieved by making accessible the wealth of information on soils, climate, water and conservation technologies, in a simple and user-friendly way.

The user groups concerned are, first, institutions supporting farmers (extension services, farmers' associations and cooperatives, NGOs, regional networks). Others include universities and colleges; agricultural research institutions (NARs, CGIAR institutions, regional networks); hydrological institutions and networks like Waternet; and policy makers. To develop this initiative, the interests of user groups need to be identified and worked out together with representatives of the user groups themselves. Topics to be discussed include the kind, format and scale of the information that is required, as well as the user interfaces to be developed.

This proposal adds value to current and earlier research and extension efforts by:

- *For farmers* (through associations, cooperatives, extension services and networks), it will make available information on improved soil and water management techniques tailored to specific climate, soil and terrain, and socio-economic conditions. This will require both an inventory and manual of techniques and the development of user-targeted query facilities & interfaces;

- *For research and educational institutions,* it will link and integrate currently available data, information and knowledge bases. It will allow transnational extrapolation of promising technologies, and will support exchange and learning;

- *For river basin managers,* it will allow scenario studies about the role of various land use options to optimize water flows;

- *For policy makers,* it will be possible to make quantitative regional estimates of where inputs and policy initiatives for green water will be required, and scenario studies of the likely outcomes of different options.

Conclusion: the three legged stool

We know from experience that, if green water management techniques are to be taken up effectively, they need to be:

- Known and understood in biophysical, economic and practical terms;
- Practicable within the existing social and economic situation - that is, matching well with existing farming systems;
- Be effective in the local situation;
- Be profitable to the farmer in the short term.

We also know from experience that the outcomes of soil and water conservation programs throughout SSA have been largely disappointing. The absence of active links between the technologies introduced, local biophysical conditions and the societal context has been striking (Dalal-Clayton and Dent 2001, Dalal-Clayton *et al*. 2003). To make good these knowledge gaps, we are proposing a three-legged, regional (SSA) knowledge base comprising:

1. An inventory and manual of <u>green water management systems</u>, linked with the biophysical and social conditions under which they have been effective, or not effective. WOCAT may provide a ready foundation for this leg;

2. A <u>biophysical database</u>, which might be based on SOTERSAF, showing the location and extent of the soil-landform-climatic units that determine the success or otherwise of particular technologies, distilled into a manageable number of management units. As well as a biophysical inventory, it is essential to explain the particular green water management needs of each unit and the potential for increasing green water within it;

3. A database of <u>social and economic prerequisites</u> – the conditions that determine the practicability and success, or otherwise, of green water management systems; also spatially located. This leg must be developed *de novo* with stakeholders. We envisage a minimum, generic framework of information on social and economic conditions, for which the socio-economic

information in WOCAT may offer a first source. Local users will be able to handle the current socio-economic information for their own areas within this framework.

All this information can be exchanged easily in digital format but can also be disseminated through the traditional media. A major input of the program will be to develop interactive querying interfaces to satisfy the user-group needs. By working within a regional network, packages of green water management systems, requisite policy initiatives, and financial support may be put together on the basis of the combined information. The difference from the present situation is that they will be making use of the world knowledge base rather than *ad hoc* efforts that apply a few known technologies to areas and social situations to which they may be ill-matched. At the policy-support level, it will be possible to test a variety of scenarios in terms of biophysical, economic and social effectiveness.

Requirements for success for the project include:

- National partners will form the backbone of the project in terms of inputs, outputs and identifying and directing the project goals;
- Farmers' interests will be secured through a stakeholders' steering group;
- Existing databases and networks on water, soils, soil and water conservation technologies *etc*. will be used, and built upon where required;
- International partners will facilitate project implementation (*e.g.* transnational/regional aspects, correlation) and complement local research capacity.

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