Green–blue water system innovations for upgrading of smallholder farming systems – a policy framework for development

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Abstract Rainfed agriculture and other depletion of water by green flows have as yet an untapped potential for improving livelihoods in semi-arid areas through income and food security. A vivid evidence of this is seen in the fact that, although working full time on food production, majority of smallholder farmers are frequently affected by shortage of food or famines. At the same time enough examples exist to show that productivity of labor, water and land under rainfed farming can be doubled or even trebled through proper land management and improved agronomic inputs supported by modest investments to reduce impacts of dry spells. However, these shining examples remain small ‘islands of success’ across the entire semi-arid areas. Farmers have not adopted these systems due to poor ratio of benefit to costs brought about by inadequate development or complete lack of food trade among the rural areas. This paper argues that there is a need for policy, strategic and programmatic frameworks which facilitate integrated management of land, water and markets. For this kind of strategy to work, a local market for food should be ensured to absorb at competitive prices the surplus produced by farmers in years of good rains. This will promote wealth creation and asset building among the poor in semi-arid areas. A food-exchange “futures” mechanism based on the principle of virtual water trade is proposed as a basis for achieving this objective.

Keywords Agriculture; green water; markets; rainfed agriculture; virtual water trading

Introduction
The Millennium Development Goal of halving by 2015 the number of people that are food insecure is a formidable challenge, which will largely depend on what happens in rainfed farming systems. The main reason is that a large majority of the 900 million people currently suffering from poor security in food and nutrition depends on smallholder rainfed farming for their livelihoods. The challenge comes from the fact that in sub-Saharan Africa, for example, the majority of people are farmers producing mainly crops and livestock for food. Yet, the region spends about USD 18 billion to import food annually, receives nearly 3 million tons in food aid even in “normal” years, and still leaves 200 million of its people chronically hungry. The opportunity for dealing with this challenge can partly be found in the realization that the 200 million that are chronically hungry are not the same people each year but there is a spatial and temporal shift of the epicenter each year due to climate variability phenomena, something that requires innovative combination of agricultural water management and trade arrangements to tackle. This paper will introduce and highlight ideas on how this can be achieved.

It is true that there is often shortage of water in the soil for plant growth in rainfed systems, but this is not caused by low rainfall as normally perceived but rather by a lack of capacity for sustainable management and use of the available rainwater. The most critical management challenge is how to deal with the poor distribution of rainfalls characterized by short periods of too much water and flooding and long periods of too little, as well as devastating dryspells that occur within the wet season. The question is,
can better management of the water depleted through evapo-transpiration in a given farm or watershed help to reduce the negative impact of dryspells and droughts? The paper starts by discussing why rainfed systems are important to sustainable livelihood options including food security. Then we evaluate the available options for enhancing the availability of soil-moisture for plant growth in rainfed systems. After that, the paper evaluates the role that trade can play in preventing recurring hunger and famines. The large picture hypothesis of this paper is that: *the real food challenge in the world today is to feed all the people with the food already being produced!*

The main conclusion of the paper is that rainfed agriculture possesses a yet untapped potential for ensuring income and food security in the semi-arid areas, but there is a need for improvements in the integrated management of land, water and food trade. On the basis of this conclusion it is suggested that there is an urgent need for policy and institutional frameworks for applying the concept of virtual water transfer in both spatial and temporal terms as a means for effective mitigation of the effects of climate variability while commercializing agriculture in the semi-arid areas.

**The missed opportunities in green water**

*Figure 1* shows an approximation of the partitioning of rainwater that falls on a single field or a watershed with several fields. It can be seen that between 50 and 100% of precipitation can be depleted from within the watershed where it falls. This occurs either by direct evaporation from water surface or bare soil or by transpiration by the vegetation (some useful crops and some weeds). This flow is what has been defined as green water flow and the proportion depends on the size of different land uses in the watershed. On the basis of this definition several authors have estimated that human and ecosystems wellbeing depends by a very high proportion on green water flows (see for example Shiklomanov, 2000; Rockstrom et al., 1999; and Savenije, 1998). With respect to food, rainfed systems produce by far the highest proportion (>60%) of food crops in the world. When animal grazing is counted the contribution of rainfed agriculture to food and commodity production is very high indeed. In sub-Saharan Africa where harvesting of food products from forests is significant, over 99% of food could easily be coming from rainfed or green water flow systems. Yet, water resources planning largely neglects green water flows and rainfed agriculture.

A good example of the low attention paid to green water flows can be found in the current debate among the ten countries that share the Nile Basin. While the annual inflow as rainwater into the upper catchments is about 2,000 billion m$^3$ the river flow at Aswan...
is less than 100 billion m$^3$. This means that depletion of water in the upper catchments, most of it in the form of green water flows and some as blue water into underground water systems, accounts for over 95% of the water in the basin. The critical question is how much livelihood and environmental benefits accrue from the depletion of 1,900 billion m$^3$ and what can be done to get more out of it without affecting or even while increasing the blue flows. It is surprising that a lot of political capital has been invested in the smaller of the two components of water flow in the basin. Opportunities are being missed in the potential that exists within the forests, wetlands and pasture and grazing lands where most of the water is being depleted. There is a need to focus more on how to make these ecosystems yield more environmental, social and economic services and benefits rather than the single minded focus on irrigation based on the little blue water flows, as schematically illustrated in Figure 2.

The main reason rainfed systems are given low attention despite their overall gross contribution to agricultural production is the low and highly variable yields as compared to irrigated systems. For example, yields in rainfed farming systems for cereals are on average extremely low – oscillating around 1 ton/ha compared to optimum potentials of more than 10 ton/ha. This is both a problem as well as an opportunity, since just doubling the yields from rainfed systems will increase its contribution to food supplies from the current 60% to 120%, theoretically eliminating the need for irrigation! Most of this can be achieved by applying to green water, simplified and cheaper versions of the water control approaches used in irrigation. The means for doing this include the well known soil and water conservation (SWC) techniques as well as supplementary irrigation based on rainwater harvesting, as discussed in the next section.

**Closing the yield gap: start by improving soil-moisture and transpiration**

There is increasing evidence that shortage of soil-moisture for plant growth is not the only limiting factor for upgrading rainfed farming systems. Soil fertility depletion often poses an equally large or even larger constraint to crop production (Breman et al., 2001). However, smallholder farmers are generally and rationally keen to start by reducing risk of crop failure due to dry spells and drought before they consider investments in soil fer-
tility, improved crop varieties, and other yield enhancing inputs (Hilhorst and Muchena, 2000). Therefore, shortage and/or variability of soil-moisture limit the variety, quantity and quality of products that a smallholder can produce, leading to a very narrow range of options for commercialization. This, together with the fluctuations in yields, makes it hard for the poor men and women in semi-arid areas to respond effectively to opportunities made possible by emerging markets, trade and globalization. It is perhaps for this reason that the proportion of poor men and women in rural semi-arid areas is estimated to be 48% as compared to about 36% in similar but humid areas, or 17% in urban areas (Leach and Mearns, 1997). There is therefore a need to increase the capacity of the poor to manage and sustainably use the available rainwater, including effective means to deal with climatic variability. Rainwater harvesting has proven to provide a large potential for doing this in ways that enhance food and income security in the semi-arid areas (Hatibu, 2002; Agarwal and Narain, 1997). This section discusses farmer-initiated and managed RWH systems, divided into three main categories:

† in-situ systems (maximize infiltration of rainwater and water holding capacity at the root zone);
† runoff farming systems (add runoff from external catchments for instantaneous infiltration);
† storage systems (harvest, store and use runoff for supplemental or full irrigation).

**Rain capture (in-situ) systems**

These are those systems conventionally viewed as soil and water conservation (SWC). Capturing rainwater where it falls and storing it in the root zone is perhaps the most cost-effective means of increasing water availability for plants. This fact is well known, but many SWC interventions in the semi-arid areas often focused on the soil and very little on water. Normally and according to farmers’ practices the emphasis should be reversed since conserving soil-water often leads to better conservation of soils while also enhancing the effective utilization of soil-nutrients by plants. The in-situ systems of RWH focus on getting the beneficial plants to effectively use through transpiration the rainwater available on the farm. They are all based on four basic principles:

(i) optimization of infiltration – the main purpose being to reduce non-productive depletion of the rainwater through evaporation and run-off, while reducing erosion and increasing re-charge of ground water;
(ii) increasing the water-holding capacity of soil within the root zone – to make most of the captured water available to plants;
(iii) ensuring an efficient water uptake (i.e. high ratio of transpiration/evapo-transpiration) by beneficial plants – achieved through appropriate agronomic and husbandry practices; and
(iv) optimizing the productivity of water used by plants, in terms of value of products – through the choice of crops with sufficient demand in accessible markets.

Many techniques have been developed around the world for achieving i) to iii) and shown to work very well in the research farm or projects. For example, converting from plowing to sub-soiling and ripping in parts of semi-arid Tanzania led to doubling of yields in good years, due to increased capture of rainwater (Figure 3). However, these shining results from projects remain small ‘islands of success’ across the entire spectrum of natural resources management (NRM) (El-Swaify et al., 1999).

**Runoff farming systems**

This system is technically similar to the previous but it is designed to provide more water for crop growth through the diversion of storm floods from gullies and ephemeral...
streams, into crop or pasture land. For runoff farming to be effective it must be an add-on to already elaborate in-situ systems. This is why in many parts of Tanzania, farmers construct cultivated reservoirs or paddies to facilitate concentration of high volumes of water adequate for rice production. It is designed to capture and store rainwater where it falls with provisions for supply of extra water from external catchments. The system is an improvement of the in-situ system in that it retains the focus on getting the beneficial plants to use most of the rainwater available on the farm, while providing for extra amount of water and often nutrients from outside the farm. Using this approach, many farmers in semi-arid areas of Tanzania have changed from the cultivation of sorghum and millet, to rice or maize with follow-up legume crops that exploit residue moisture in the field. This system is now widely used in nearly all the semi-arid areas of central Tanzania. The system accounts for over 70% of the area cultivated with rice and over 35% of the rice produced in Tanzania. It has enabled farmers to grow a marketable crop in dry areas, providing opportunity for poverty reduction. As a strategy for upgrading rainfed farming, this approach has been shown to work very well under different conditions in Asia as well. In India (Agarwal and Narain, 1997) and in China (Zhu and Li, 2001) provide examples showing that external water harvesting systems – which add runoff water to the cultivated area – are relatively common.

Small scale storage of harvested water

The approaches described above are designed to store water in the root zone or flooding the cultivated land. The benefits that can be achieved are high but have a limit due to limited control of the water and dependency entirely on the storage capacity of the soil. Furthermore, they do not deal adequately with the most critical problem, which is often the inter- and intra-seasonal variability and within season dry spells. Studies in Eastern Africa have shown that agricultural dry spells exceeding 15 days often affect maize grown on sandy soils during the critical flowering and grain filling stages, at a frequency of three out of four rainy seasons (Barron et al., 2003). Such dry spells often wipe off the benefits from crop (full scale) transpiration before and after the dry spell. The crop could therefore use high quantities of water for transpiration but produce very little grain and biomass at the end, leading to very low productivity of water. Small scale storage of harvested water can help to provide protective or bridging irrigation to reduce or reverse the negative effects of dry spells while increasing the productivity of green water flows (Oweis et al., 1999).

Storage makes sense because often the gross amount of rainfall does not change – what changes is its timing. Thus, poor smallholder producers of crops and livestock in the semi-arid areas face frequent food shortages and livelihood losses due to inter-seasonal variations. A case study in Tanzania has shown that historically, floods have caused
about 38% of all declared disasters, while droughts caused 33% (Hatibu and Mahoo, 2000). Often the floods and droughts occurred in the same area, and within the same season. The problem is that when it rains in the semi-arid areas, runoff response is very rapid and if not captured the water flows as a flood wave to sinks, from where it is often not economical to recover it for beneficial use.

Introducing storage systems as well as efficient water application technologies can increase the effectiveness of the rainwater harvesting systems. This involves farm ponds, charco dams and small to medium size reservoirs coupled with efficient application of the water in required quantities, when it is required and in the root zone where it is effectively used by plants. On-farm research in Tanzania is demonstrating that protective irrigation to bridge dryspells can lead to threefold increase in yields especially when integrated with improved inputs and agronomy as discussed in the next section.

What are the impacts at people’s level?
Evidence is accumulating showing that the simple rainwater harvesting systems described above are paying real dividends at farmers’ level. Here we use preliminary results from work being conducted by the Sokoine University of Agriculture in Tanzania, to demonstrate the emerging evidence. Figure 4(a) shows how Gross Margins (GM) per hectare can be improved through RWH. While farmers without RWH are confined to growing sorghum those with RWH could diversify to rice and vegetables leading to an increase in GMs from 108 US$/ha to 2,166 US$/ha – a 20-fold increase. Figure 4(b) shows that these increases are also reflected in the return to labor and therefore contributing to poverty reduction. Those who adopt RWH and switch to high value crops achieve a fourfold increase in incomes from 16 US$ per person day spent in farming to 71 US$. These are significant improvements by any standards.

How much rainwater harvesting is within the limits of green water management?
The previous sections have summarized the evidence for technical and economic benefits from improved management of green water flow through rainwater harvesting. It is clear from Figure 2 that every watershed will have an upper limit of the water that can be harvested, retained and utilized within the boundaries of the watershed. There is a need to assess this limit as a way of establishing feasibility of RWH in any given catchment. A good starting point is an assessment of how much water which would otherwise be lost through surface evaporation from bare soil could be saved for beneficial use if concentrated by RWH into a small cultivated field or storage reservoir. It is well known that concentration cuts down evaporation losses by reducing the surface area exposed to evaporative demand. A second level of analysis would assess the amount of run-off into saline sinks in excess of what is required for environmental flows (the brown part in Figure 1). If these two components on the partitioning of rainfall in a particular watershed are known, then they can be used to decide the extent of RWH and storage requirements. This can then be compared with the requirements (e.g for dry spell bridging).

The amount of water that should be harvested and stored for bridging dry spells can be estimated from improved knowledge of length and severity of dry spells. As shown by Barron et al. (2003), dry spells are often of 15 days duration in the semi-arid areas of Eastern Africa. If we design storage to cope with 20 days in an area where PET is 5 mm/day we need a storage capacity of 100 mm-ha for every one hectare under cultivation. Assuming that a small watershed will normally have 100 households with say 1 hectare each, the total storage requirement will be 10,000 mm-ha, or 100,000 m$^3$. Therefore, storage systems up to 100,000 m$^3$ in a single small watershed will be within the limits of rainwater harvesting, supporting the upgrading of rainfed farming systems. However, the
upper limit will be determined by the availability of water that can be harvested without negatively affecting downstream and environmental commitments. Planning frameworks for integrated watershed management should therefore include several small-scale storage systems (25,000–100,000) to support higher productivity of labor, water and land as suggested by Evenari et al. (1971). Locating these small-storage facilities along a catena from up- to downstream, will enable farmers to benefit from free gravitational energy, instead of costly systems of water pumping.

**Figure 4** Improvement of GMs with runoff farming systems (after SWMRG, 2004). (a) Returns to land in US$ per ha (average of six seasons); (b) Returns to labour in US$ per person-day input (average of six seasons)

**Linking systems innovations in green water management to markets to overcome economic and environmental limitations**

*Food security through income security*

After discussion of the technical and environmental possibilities, let us now turn to economic pre-requisites for effective management of green water flows by smallholder agro-entrepreneurs. The experiences of both the successes of the green revolution in Asia and
the past performance of the *cash crop* sub-sector in SSA, show a high correlation between markets and success in agriculture modernization. Farmers rarely adopt innovations and technologies that do not bring them more incomes or benefits. In general adoption of production enhancing technologies (such as RWH) where there are poor linkages to cash markets, are very rare (Christensen, 1994; Hatibu *et al.* 2000). Where they have occurred, they have led to *fallacy of composition*, which means that less income is earned as more is produced (Robbins and Ferris, 2002). It is perhaps for this reason that farmers who have adopted RWH often shift to high value crops or vice-versa. But even this has a limit as farmers can quickly flood the market of even the high value crops leading to falling prices and returns. A strategy is needed for marketing-orientation of production where food crop enterprises are designed to produce products that respond to customer and consumer demands in different opportunities. However, one would ask – where are the market opportunities for dryland farming in the SAT? Before answering this question, let us first deal with a common worry that pre-occupies every individual and nation – food security.

It is well recognized that food security is the basic and most critical requirement for development. But food security has often been confused with food self-sufficiency. Agricultural development agenda in nearly all countries in the world are still driven by desire for food self-sufficiency. The difference is the level at which this is pursued. While in developed countries it is pursued at national or regional (e.g EU) level, policies in SSA are advocating food self-sufficiency at household level. While a high proportion of food security at national level could come from internal production, trying to achieve self-sufficiency at household or even district level is counter-productive as it stifles commercialization and limits the exploitation of comparative advantages. Therefore, innovations and technologies for smallholders should be designed to promote food security at household levels through increased incomes and purchasing power. This will allow for exploitation of comparative advantages, increased local trade in food commodities, and contribute to the commercialization of smallholder agriculture.

Evaluation of watershed development projects in India concluded that in order to succeed there is a need for “watershed plus” – that is, greater success was obtained in watershed management projects that were complemented by good linkages to markets (Kerr *et al.*, 2002). The “more people less erosion” case study of Machakos-Kenya showed that: *improving road connection between Machakos and Nairobi and the canning plants, encouraged increased production of vegetables, which in turn was the reason for the adoption of terracing* (Tiffen *et al.*, 1994). We now turn our attention to the issue of trade.

**The role of trade and local food markets**

The concept of virtual water trade provides a framework for explaining the production of food in areas or periods with adequate water resources and then transferring that food to water scarce areas or periods (Allan, 1999). This concept provides a framework under which two countries or parts of a country which suffer alternating drought and wet years at different times, to arrange “futures” food exchange mechanism that will ensure that each has a guaranteed market for its surplus food produced in years with good rains and a secure source of food to bridge shortages or complete crop failures in years with bad rains. Such a system will also reduce the pressure to invest heavily in expensive water storage structures and irrigation systems to deal with severe droughts. This will also allow a virtual transfer of water from years with good rains to years with droughts for a particular locality. In this section of the paper we discuss how such a system will work and what institutional frameworks are necessary to support it.
When you look at the statistics of the food shortages and famines in SSA, it is evident that coping strategies based on individual or communities alone are not capable of dealing with the enormity of the vulnerability caused by climate variability. This ability will be reduced further by the increasing incidents of extreme events as a result of climate change. It is for this reason that it is suggested that coping strategies should be built around national and regional platforms rather than household and community levels alone. The hypothesis is that if well linked to trade opportunities, most vulnerable communities will be able to pay for own recovery after climate-induced crisis. This is because in many parts of SSA there is a number of people chronically affected by climate-induced crisis, but a look over a period of 5–10 years reveals that these are not the same people all the time. This means that communities move out of crisis to good years to bumper years and back to bad years and crisis again. Lack of trade facilities even among these communities mean that none of them can fully exploit their good/bumper years. Trends show that while one part of the country or sub-region suffers from food shortage and is receiving food aid from the west, another part of the country or sub-region is forced to abandon bumper harvests to rot in the field for lack of markets. There are no mechanism, policies, infrastructure and food handling systems which will enable food trade that will even-out supply and demand within one country or sub-region, while helping households and communities to build up their assets to be able to effectively deal with the next crisis when it arrives.

Therefore, local, national and regional food trade is an important Adaptive Strategy to climate variability and change. Food trade especially at local level offers more sustainable opportunities for dealing with climate variability. It should therefore be given adequate attention in strategies for developing rainfed agriculture in semi-arid areas so as to achieve sustainable income and food security. The following frameworks are proposed.

- Global, regional and national level strategies that are grounded on good and modern science such as modeling and forecasting of climate trends leading to a good understanding of vulnerability-livelihood–trade interactions.
- National and sub-regional strategies for effective response to opportunities, potentials and obstacles to food trade as a way of coping with climate variability. This will require integrated and optimum management of water, nutrients, and improved varieties, coupled with enterprise development and optimal mix of cereals, livestock, vegetables and other products. This should be facilitated by relatively well developed rural infrastructure, affordable means of transportation, and increased value-adding processing of agricultural products.
- Enabling legal and institutional framework – with respect to food exchange and futures markets.

Conclusions and recommendations for future actions
A framework is urgently required in which investments in RWH systems for agriculture would be directed equally to all components of an integrated production to marketing chain to support the farmers’ efforts to improve rainfed agriculture, in ways which increase the ability to exploit opportunities for income generation. It has been widely observed that markets are a major constraint facing farmers, leading to low investments in proven innovations. Interventions are therefore required in developing trading and marketing linkages at local, national and regional level, so that the availability and demands of markets can dictate what products and enterprises are to be given priority in rainfed systems. It is suggested to pay particular attention to a framework for deliberate development of food trade supported by food-exchange mechanisms between areas with
bumper harvest with those with shortage or total crop failure caused by drought or other climatic variables – based on the concept of virtual water transfer.

At policy level, national food policies and strategies should move away from trying to achieve self-sufficiency at household or even district level as this is counter-productive as it stifles commercialization and limits the exploitation of comparative advantages. Improvement of food security at household levels should be through increased incomes and purchasing power of smallholder producers, in order to increase local trade in food commodities and contribute to the commercialization of smallholder food production enterprises under rainfed conditions.

At technical level emphasis should be given to the integration of green water management innovations, improved land husbandry, and rural infrastructure development. For example, crop, pasture, and rural infrastructure are frequently damaged by water logging, flooding, wash away, and sedimentation. These damages are often most acute in semi-arid areas where there is generally a shortage of water for domestic and agricultural use. Potential therefore exists for combining rainwater harvesting, improved drainage, and strategic storage of water, designed to avoid failure of rural and irrigation infrastructure while increasing water availability for domestic, livestock and irrigation needs. Another technical aspect that requires urgent attention is the promotion of techniques for ensuring high efficiency and productivity in the use of water. The principles of how this can be achieved are already known but require adaptation to the socio-economics realities and technical skills of planners, agro-entrepreneurs, farmers’ support agents and the farmers themselves.

References


