In-situ RWHM: stone terraces in semi-arid Tanzania for cereal and horticulture crops.

Ex-situ RWHM: a rainwater storage tank for dry season irrigation in India.

In-situ RWHM: zai pits in Burkina Faso to regenerate degraded land.

Rainwater harvesting – more than sound water management

Rainwater harvesting and management (RWHM) is an effective approach to ensure that the production capacity of rainfed systems is sustained. Our author summarises some recent global and local knowledge related to this long-standing practice, with special reference to dryland crop systems.

By Jennie Barron

Rainfed agricultural systems dominate our global agricultural production. Globally, rainfed production systems constitute rainfed cropland (1.25 gigahectares – Gha) and rainfed pastureland (3.5 Gha). These areas support not only the produce of more than 60 per cent of nutritious food, but also a range of fodder, fibre, biofuel and other economically important crops for livelihoods and wellbeing. Given that rainfed systems cover in the order of one third of the Earth's land area, rainfed agricultural systems also affect a number of ecosystem services and functions in a range of highly populated landscapes. For example, such ecosystem services are related to water quantity and quality flows from field to catchment, carbon sequestration, nutrient (especially nitrogen and phosphorous) cycling and habitats for flora and fauna. Hence, it is of critical importance to manage rainfed agricultural systems both for crop production and for broader sustainability in order to maintain production and reduce negative environmental or climatic impacts.

Our rainfed systems are under imminent threat through land degradation, rainfall variability increase under climate change and conversion of highly productive rainfed land to other uses. This will undermine both rainfed systems and our ability to meet various Sustainable Development Goals such as SDG 1 (zero hunger) and other ecosystem services related to the SDGs on water (SDG 6), climate adaptation (SDG 13) and life on land (SDG 15).

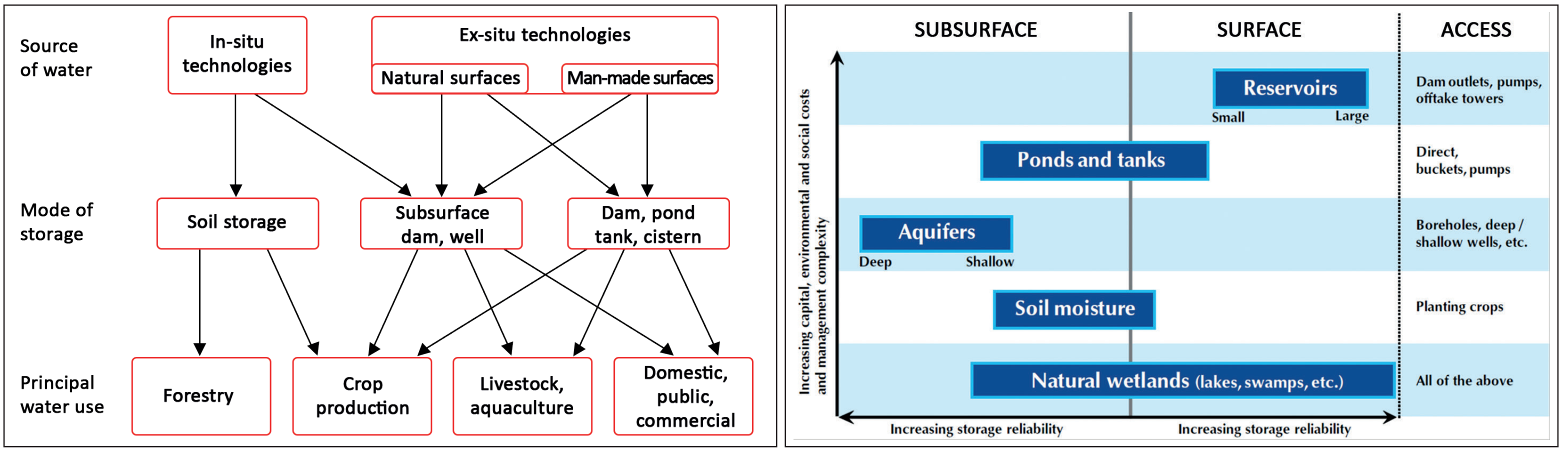
The practice of rainwater harvesting and management (RWHM) at field to landscape scale has been done in multiple rainfed systems, in some cases for thousands of years. The main aim is to reduce impacts of rainfall variability and improve crop productivity per area land, per unit rainfall and per unit labour (energy) input. It is an essential practice to secure the production capacity of rainfed systems in current increasingly variable weather conditions and in future conditions brought about by climate change, in particular in semi-arid and sub-humid climate regions (drylands). Globally, we have a wealth of experience to share and to inform best practices in RWHM. However, RWHM has often been treated as a water management approach, when essentially it is a combined effort of integrated soil, crop management and rainfall capture. Here, we outline new perspectives on how rainwater harvesting and management can contribute to safeguarding and increasing efficient use of rainfed agricultural systems for current and future human wellbeing and environmental sustainability.

There is no universal definition of rainwater harvesting and management (RWHM). Instead, the concept of RWHM can be used for the collected technologies and practices for the active retention, infiltration and storage of rainfall and surface runoff at the local scale in agricultural landscapes (see Figure). The objective is to manage soil moisture or stored water (for supplemental purposes or irrigation) to bridge the natural occurrence of dry spells affecting crop production. These RWHM practices can also be referred to as sustainable land management (SLM) practices and, in the case of India, watershed management, constituting an important set of technologies at farm to community level to enhance soil and water use.

Estimating the potential

The selection of RWHM technologies all operate according to the principles of soil and water management, i.e. to retain rainfall, and store it in the soil or a water storage facility, and avail water in the root zone through various soil and crop management strategies (see Box on page 14). Both retention and storage principles need to be in place to ensure that the harvested rainfall is used optimally for crop and pasture production. The retained rainfall storage time of harvested water ranges from a few days (in the root zone of the soil) to a number of months (for local surface runoff storage in ponds, tanks or small reservoirs) to cover dry season periods.

A typology of rainwater harvesting technologies based on spatial scale of source of rainfall, and temporal turnover time in storage



Source left: after Douxchamps 2012/ McCartney et al. 2009

Source right: after UNEP 2009

Most farmers, especially in semi-arid and sub-humid climate zones practising rainfed agriculture with a highly variable rainfall amount and distributions, actively use RWHM principles to retain rainfall and maximise infiltration, through so-called in-situ RWHM (see Figure). Technologies include a range of artificial, sometimes mechanical soil bunds, soil pits, crust breaking and combinations with biological measures such as grass strips and mulching. For example, recent syntheses by Adimassu et al. (2016) for Ethiopia and Magombeyi et al. (2018) for the Southern Africa context suggest that without management of the agronomic aspects, in-situ RWHM may have only marginal crop yield benefits. The yield gain of RWHM is higher in low rainfall areas (<500 mm/year) than in rainfall areas exceeding 1,000 mm/year. A slightly different result was obtained by a meta-analysis evaluation of watershed work in India dryland systems that largely consisted of in-situ and ex-situ RWHM technologies for intensified crop production. The evaluation suggests that these interventions are most effective in the 700–1,000 mm/year areas (Joshi et al. 2008). Bouma et al. (2016) used a meta-analysis for cases in Africa and Asia and concluded that overall in-situ RWHM resulted in a yield increase averaging more than 70 per cent compared to a control context. However, the study did not differentiate between the physical RWHM vis-à-vis the combined physical context with biological and/or nutrient management examples. Thus, there may be specific design aspects to take into account to realise the yield benefits of RWHM technologies. Not applying some elements of RWHM in combination with agronomic practices in these regions of 300–800 mm/year may imply a yield loss of between 20 and more than 100 per cent.

Despite the lack of yield gain under RWHM practices in some cases, there is almost always a positive environmental and sustainability aspect with a reduced loss of sediment and surface water through runoff. The sources above suggest that soil loss could be reduced by 1.1 t per hectare and year (Joshi et al. 2008), or in Ethiopia, retaining more than 20 per cent of nitrogen and phosphor soil fertility using RWHM in combination with biological materials. In the case of Southern Africa, Magombeyi et al. maintains that RWHM practices retain up to 80 per cent of sediments and, on average, 60 per cent of surface water runoff for the Southern Africa region. These environmental benefits are typically not well accounted for when discussing RWHM. Hence, there is a need to recognise the farmer effort to manage field to landscape ecosystem processes more explicitly, in terms of implementing RWHM also for the benefit of the environment and ecosystem services.

Areas of ex-situ harvesting and storage such as small tanks, infiltration ditches and small reservoirs are increasingly being invested into to complement perceived or actual increased rainfall variability, and/or local water scarcity. Such storages of water have the added benefits of enabling use of water for multiple purposes – not just for crop water uptake as in in-situ RWHM, but also for irrigation, livestock, and, in some cases, even for domestic purposes.

Opportunities offered by RWHM and its future potential

Forthcoming climate change, with both rainfall and temperature changes for rainfed systems, means that there will be an increase in drylands of more than seven per cent, encompassing 3.3 to 5 billion people, as suggested e.g. by Koutroulis (2019). Even if not all food, fodder and fibre needs to be grown locally, these changes in climatic conditions expanding dryland conditions suggest that rainfall needs to be managed more carefully, unless more irrigation development, with associated freshwater outtake needs to be developed. The need to implement RWHM will be fundamental to secure sustainable and productive food as well as water supplies.

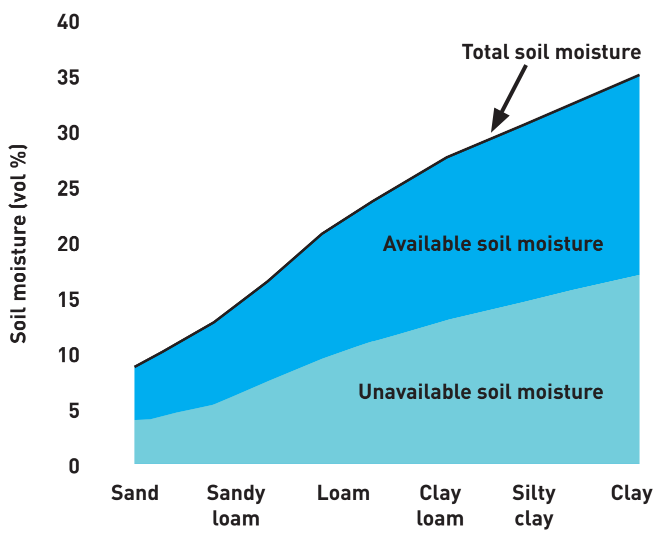
Already, there are a number of studies indicating that RWHM could potentially increase production and productivity and thereby ensure food security and sustainable land and water resources. For example, Rockström et al. (2009) modelled that better so-called soil moisture (green water) management through maximising use of rainfall can alleviate national water stress and food insecurity, and reduce populations under chronic water stress. A global study by Jägermeyr et al. (2016) differentiating between in-situ and ex-situ RWHM suggests that implementation on 50 per cent of current farmland could result in a potential 10-30 per cent yield increase. Under climate change, the benefits of RWHM on cropland can support an additional 10-30 per cent yield increase, compared to 'business as usual' without active RWHM, which would result in crop yield decreases of 5-20 per cent from current yield levels, in most dryland areas.

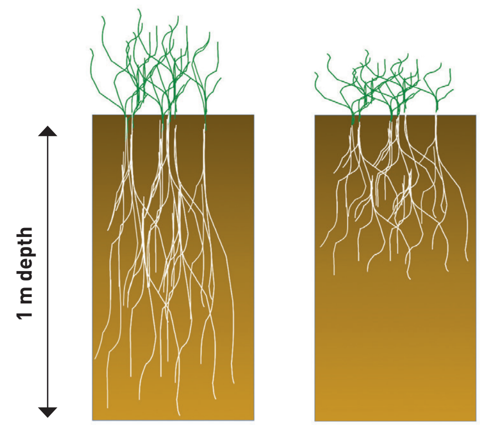
However, the success of implementation of RWHM does not only depend on the physical environment of water, crop and soil conditions. Including the aspects of social suitability combined with agro-ecological conditions, the study found that at least 15 per cent of global

THE IMPORTANCE OF SOIL TEXTURE AND ROOT DEPTH FOR YIELD INCREASE IN RWHM SYSTEMS

Two factors affect the available crop water for plants. Firstly, the soil texture and structure provides each soil with an inherent capacity to store the rainfall infiltrated into the soil. Different soils have different capacity to hold water in the root zone (left Figure). For example, a sandy texture soil will typically only be able to store a third to half of what a clay soil can store in the same root depth, due to soil texture and structure. Secondly, the plant root development in any given soil makes a critical difference for use of any infiltrated rainfall (right Figure). Guiding values of water storage per unit soil depth range from a maximum available amount of water of 6 mm per 0.1 m soil for sandy soil to 15-19 mm per 0.1 m soil for loamy clay and well-structured clay soils. A typical well-developed cereal crop has a crop water demand of 2-5 mm per day, depending on weather conditions and crop type. Therefore, a crop can easily utilise a soil moisture availability of 30 mm in six to eight days, and thereafter experience water stress, affecting final yield.

So it is critical to combine any RWHM technology with good soil health and good crop management. This combination will ensure that soil can hold the infiltrated rainfall and that crop root development can maximise uptake of available water once it is in the soil.





Max available water in root depth

	(mm) for 1 m	(mm) for 0.5 m
Sand	60	30
Loam	150	75
Clay	190	95

cropland is suitable for in-situ and/or ex-situ RWHM technologies, and that in these regions RWHM could increase yields with typically 50 per cent or more (Piemontese et al., in review). However, more importantly, the paper by Piemontese et al. discusses the current area under RWHM. Today, very little data exists on how much cropland is already under RWHM. There are different studies at local to national level assessing farmers' practices. For example, Conservation Agriculture could possibly be considered as a RWHM technology through the combination of no/low tillage with mulching and crop rotation, and it has been particularly successful in mechanised rainfed dryland agricultural systems in the USA, Australia, Brazil and Argentina, among other countries. The latest estimates suggest that 180 million ha, or 12.5 per cent of current cropland worldwide, is under RWHM.

There are no global estimates for a range of RWHM technologies. But some national statistics can provide guidance. In Ethiopia, sustained public investments, farmer in-kind contributions through labour and international development programmes have invested in various soil and water conservation measures that have acted as RWHM for more than 40 years. Adimassu et al. (2018) estimated that 20 per cent of crop area was under terraces alone, not accounting for other common RWHM practices or the combination of soil and water conservation combined with biological practices such as mulching or manure application. In Burkina Faso, Morris & Barron (2014) suggested regions in the 400–800 mm/year rainfall area implemented RWHM through soil and water conservation on 10–30 per cent of cropland, whereas in rainfall higher than 800 mm/year, corresponding coverage was mostly 0–10 per cent of crop area. Data by Wang et al. (2018) indicates that more than 11 per cent of cropland in China is under terrace practices acting as RWHM. These snapshots only focus on RWHM on cropland, and in particular the in-situ technologies of terracing (Ethiopia, China) and 'zai' pitting and stone bunding (Burkina Faso). There is an urgent need to understand which croplands in the world are already under RWHM practices, and to assess the yield levels achieved. This would help to advance and target RWHM practices more efficiently, both to improve already existing RWHM practices to maximise their benefit and to ensure that new developments in RWHM are being implemented by farmers to secure rainfall use and benefits.

Practices come at a cost and require a mindshift

Despite RWHM being a common practice (albeit not well documented for the range of technologies being used in various regions), there is little understanding on the costs related to implementation and maintenance. Lasage & Verburg (2015) summarised for ex-situ household or communal water storage in the order of 100 to 1,000 USD (2009 value) per construction, with a 0.1– 10 USD cost per cubic metre of water storage. Often this price did not include in-kind labour supported by beneficiaries in the household or community. Adimas-

Ex-situ RWHM: a small reservoir for dry season irrigation and other purposes in Ghana.

su et al. (2018) estimated the investment cost, accounting for in-kind community labour in the order of 1.2 billion USD per year across four regions in Ethiopia, or in the order of 150 USD per hectare. However, this is still only about a quarter of what erosion costs Ethiopia, which is estimated to be 4.3 billion USD per year. In work by the International Food Policy Research Institute (IFPRI – 2017), a cost of 179 USD per ha was used for implementing soil and water conservation practises in the sub-Saharan context. Hence, there seems to be a real cost for implementing RWHM even for a smallholder farmer, despite potential benefits in yield. In these estimates none of the positive environmental and ecosystem functions, such as reduced sediment transport and infiltrated and possibly recharged groundwater, was accounted for.

As RWHM evolves over time, it is also important to consider today's thinking and approaches in taking action for RWHM implementation. Since promotion and implementation initiatives of RWHM have developed over time, we may need to reconsider how and where RWHM makes a difference going forward. An example of evolving discourse is presented by Douxchamps et al. (2014), where RWHM technologies as well as the considerations for implementation and partners have changed over 40 years. Today, it is increasingly important to consider multiple technologies, as well as suitability not only for the agro-ecology but also for the household and community context. Going forward, RWHM must further be assessed in terms of its relevance and feasibility for women and youth, as well as with regard to reducing the manual labour input, which is a challenge for the most vulnerable and disadvantaged. Issues such as secured land tenure may also be of importance for the scaling of RWHM in various regions.

Conclusions

Rainwater harvesting and management encompasses a range of technologies in-situ and ex-situ to retain rainfall and store water in the soil or in small structures such as tanks or reservoirs. The main aim is to increase yields through reducing intra- and inter-seasonal dry spells, which can lower crop yields significantly. Both local/national meta-analyses and global modelling are showing the same range of benefits and opportunities of yield increases in existing low rainfall areas, as well as under a future increase of drylands and increased climate variability. However, new research also suggests that RWHM needs to be explicitly combined and aligned with other best practices in soil and crop management in order to maximise the value of the additional water retained. For example, two substantial meta-reviews from Ethiopia and Southern Africa have demonstrated that ensuring the use of biological measures in combination with physical measures increased yields, whereas RWHM did not necessarily show substantial yield returns if good agronomic practices were not in place, especially in agro-ecological conditions of less than 500 mm rainfall/year. These reviews also demonstrated the value of seeing RWHM as 'working with nature', and enhancing nature's capacity to retain water both for root zone soil moisture and for recharge of groundwater. One huge benefit of implementing RWHM is the control of sediment loss through the physical structures that have been implemented; in the order of 20-60 per cent could be mitigated. Given this service to nature and the environment, one should consider whether farmers ought to be better compensated for these practices in cases where sediment control is desirable. More effort should therefore be made to assess the added value and benefit for RWHM, and compensate farmers for the positive environmental benefits also achieved through RWHM implementation.

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