Mitigating desertification by making rainfall more profitable

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Abstract

Green water is rainfall that is stored in the rootable part of the soil. Due to continuous soil degradation the Green Water Use Efficiency (GWUE, transpiration / precipitation) is as low as 14% for Sorghum in Burkina Faso. Water losses are enhanced while plant available water is decreased leading to less transpiration and less primary production. This leaves the soil less covered with fewer residues returning into the soil. Physical soil qualities such as infiltration capacity and water holding capacity start to deteriorate triggering a negative spiral towards lesser and lesser biomass production and to desertification. Since an increasing population requires increased food production, more efficient use of rain in rainfed agriculture deserves our increased (scientific) attention. The key to mitigation lies in the field water balance. A range of land management practices is available to help improve GWUE. Examples are presented that can increase in-situ infiltration, reduce soil evaporation and increase water use in African drylands.

Keywords: Greeb Water Use Efficiency, mitigation, Afrika, water balance

Introduction

Terrestrial rain is the source of our global stock of fresh water, of which 65% is soil water (SW), i.e. rainfall that is stored in the rootable part of the soil and is known as 'green water' (Stroosnijder, 2009). SW is depleted by soil evaporation (E) and plant transpiration (T) and replenished by infiltration (I) of rainwater, Fig. 1. These processes form the field water balance: $P = R + E + T + U$, where P is precipitation, R is runoff and U unused water, i.e. the sum of the drainage (D) below the root zone and the change in soil water in the root zone over the cropping season, ΔSW.

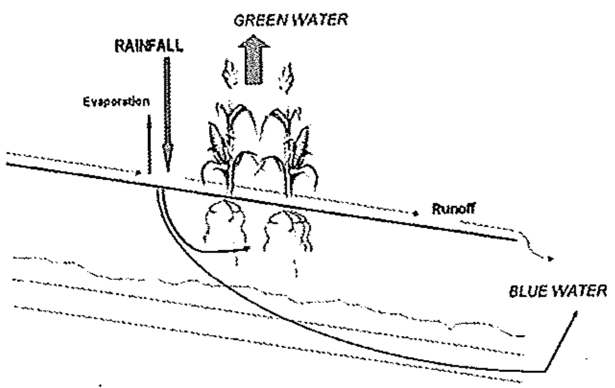

Fig. 1. Water stored in the soil and used by plants equals green water. Runoff and deep drainage, recharging the groundwater and feeding streams equals blue water (after Falkenmark and Rockström, 2004)

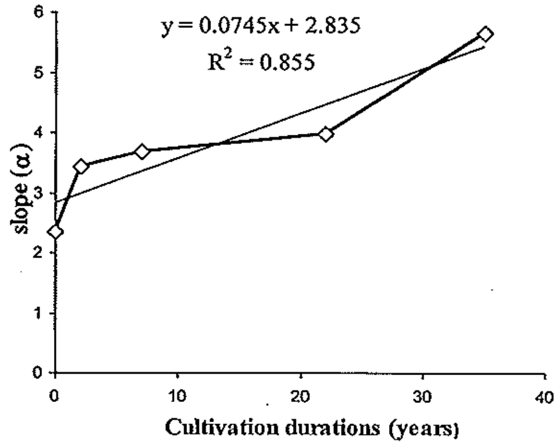

Fig. 2. Relationship between the slope of the cumulative evaporation versus the square root of days since last rain (α) and the duration of crop cultivation in Langano, Ethiopia

Research on food security is biased in favor of conventional irrigation and fails to address the problems and opportunities of rainfed agriculture (Van der Zaag *et al.*, 2009). The possibilities of further extension of irrigation are limited, since water resources of sufficient quality become scarce or too expensive. Since an increasing population requires increased food production, more efficient use of rain in rainfed agriculture deserves our increased (scientific) attention.

The need to improve rainwater use efficiency in drylands

Continuous soil degradation in African agro-ecosystems affects a number of soil properties and results in a change in the partitioning of the rainfall over T, E, R and U. In degraded soils, a greater fraction of the rainfall will not infiltrate into the soil but flow away over the soil surface as runoff. Deteriorated water holding capacity of the soil will increase drainage of water below the root zone. These processes cause a decrease in SW available for primary production. A lower biomass leaves more soil exposed to high energy inputs at the soil surface and results in an increase in E which in turn further decreases SW. Soil degradation thus starts a negative spiral that leads in some cases to completely barren land in African drylands.

An indicator for the efficiency of rainwater use is the ratio T/P, the Green Water Use Efficiency. In case there is vigorous growth and high T the Green Water Use Efficiency (GWUE) is high. For cotton production in the Great Plains of the USA for example, GWUE > 50%. Zacharie *et al.* (2011) measure a GWUE of 14% for Sorghum in, Burkina Faso. This urges the need to improve the efficiency of rainwater use in African drylands.

The production the food that mankind needs costs a lot of water; 1 kg of water for every kcal of editable food (Falkenmark and Rockström, 2004). That is because crops need a lot of water to grow and produce. In tropical drylands many crops have a C4 photosynthesis path which is rather efficient in water use. The most efficient crop needs 200 kg water to produce 1 kg of biomass to be taken up as crop transpiration (T) from the stock of soil water (SW) in the shallow rootable part of the soil. SW is replenished by the infiltration of rainwater. In drylands rains come irregular causing long dry spells during which a crop survives grace to this SW. With SW large enough to bridge dry spells a crop will grow vigorous provided that no other production limiting factors (such as nutrient shortage, pests and diseases) are present. In that case much of the Green Water will be used for T. When, on the contrary SW is small the crop will suffer from frequent water shortage with reduced transpiration and growth as the result. If simultaneously other production limiting factors are at play then only a small fraction of the rainwater is used for biomass production.

Effects of desertification on the field water balance

How much water a soil can stock as SW and how much of this is available for plant growth (AW) depends on a number of physical soil properties such as texture, structure and bulk density. These properties are reflected in the soil moisture characteristic, i.e. the relation between soil water content and soil water potential. Two values of this relation are of special interest. FC, field capacity (i.e. water content at a pF 2.0 or - 10 kPa) and WP, wilting point (pF 4.2 or – 1.6MPa). For plants it is the difference that matters because it determines the amount of available water, AW = FC-WP. The maximum amount of available water in the root zone (MAW) is very important because it determines the survivability of plants in a dry spell (i.e. periods of consecutive days without effective rain). MAW is related to (RD * AW) in which RD is the rooting depth of the crop.

Land use changes, due to land development, often negatively affect various terms in the field water balance and MAW. Water losses such as R, D and E are enhanced while MAW is decreased. Zacharie *et al.* (2011) have measured the field water balance for Sorghum in Saria, Burkina Faso, during 2006-2008. With an average P of 780 mm, I is only 56% and is used as E = 50%, U = 26% and T is 25%.

In a non-degraded soil with average physical properties the rootable depth can be 600 mm and (FC - WP) = 0.13. Hence, MAW= 78 mm. With an evapotranspiration (ET) of 2.5 mm day^{-1} (E = 2 mm day^{-1} + T = 0.5 mm day^{-1}) this is sufficient for a dry spell of 4 weeks. In a degraded soil, the rootable depth is reduced because erosion has removed topsoil. Furthermore, the soil texture became coarser due to selective removal of the finer particles and the soil structure is degraded due to the decrease of soil organic matter. This leads to a rootable depth of 400 mm and an FC – WP of 0.10. MAW is then 40 mm, sufficient for only 2 weeks. The change in the length of the dry spell that plants can endure is what farmers mean by their 'drought' problem (Slegers and Stroosnijder, 2008).

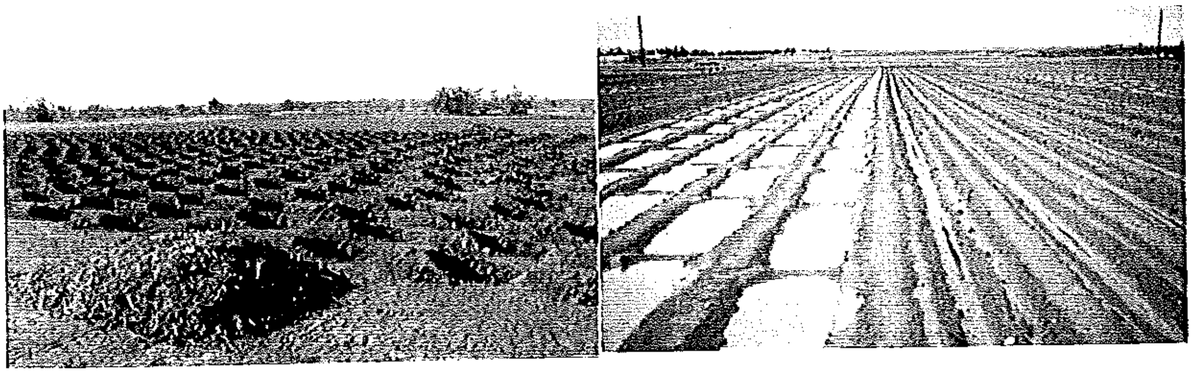

Fig. 3. Examples of in-situ areal rainwater conservation practices; left Zai in Burkina Faso, right tied ridges in Ethiopia

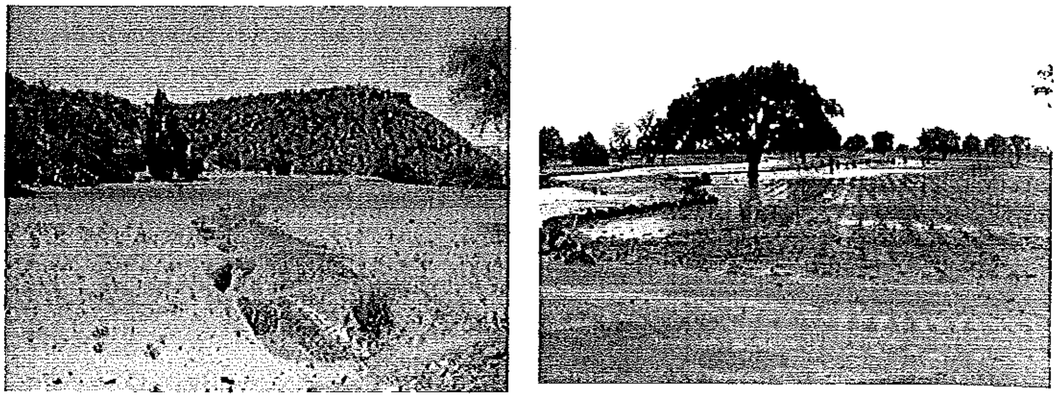

Fig. 4. Examples of in-situ line rainwater conservation practices. Left infiltration pits in Zimbabwe, right stone lines in Burkina Faso

Mitigation strategies and examples

How can the efficiency of rainwater use be improved? According to the field water balance we can increases I, reduce E and reduce U. A range of land management practices is available to help improve GWUE.

Increase in-situ infiltration, I

Infiltration can be improved in-situ which is called rainwater conservation (RWC), or water can be harvested form one area and used in another area, RWH. In-situ measures are suitable to correct water deficiencies at a short time scale such as during dry spells. RWH measures aim at storage for longer periods, e.g. to prolong a short growing season. Examples of RWH source areas are fields, roads and roofs. Examples of RWH storage mediums are farm ponds, closed reservoirs (for sanitation) and sand dams.

RWC practices can be applied over the whole surface of a field and are then called areal measures. Another strategy is to block runoff water at regular intervals in the field. Such practices are called line measures. Advance of areal RWC measures is that runoff initiation is suppressed so that soil detachment is minimized (no runoff no soil loss!), soil depth is conserved and fines remain in place. Areal measures can be agronomic, soil or physical measures. Examples of the first category are crop choice and management and the use of organic amendments. A classical example of a physical measure is terrace formation (Posthumus and Stroosnijder, 2010). Fig. 3 gives two examples of in-situ areal rainwater soil conservation practices; left Zai in Burkina Faso (Slingerland and Stork, 2000), right tied ridges in Ethiopia (Araya Alemie and Stroosnijder, 2010).

Line RWC measures can be barriers made of soil, stone (Zougmore *et al.*, 2000) or vegetation. Kiepe (1995) found that infiltration below hedgerow barriers in Kenya was three to eight times higher than under the crop in between the hedgerows. Other examples of in-situ line rainwater conservation practices are given in Fig.4; left infiltration pits in Zimbabwe, right stone lines in Burkina Faso.

Reduce soil evaporation, E

The most common method to reduce E is to apply a mulch of crop residues, dead grass or tree branches (Mando and Stroosnijder, 1999). Mulch triggered soil fauna and improved water use efficiency from 1 kg mm^{-1} without fauna to 2 kg mm^{-1} with fauna in Burkina Faso. But mulch effect is controversial in literature. Under certain conditions E is indeed reduced but in other circumstances there is no effect. And, there are additional drawbacks such as competing claims on crop residues, danger of nitrogen fixation, stimulation of pests and diseases.

Soil evaporation occurs in two stages. During a short time (1-2 days) after wetting the soil, actual evaporation (Ea) equals the potential evaporation, Eo. Thereafter, the soil surface dries out and a common relation during that stage is that ΣEa is proportional to √Σt(after wetting) or √ΣEo. Fig. 5 gives some examples of new and traditional mulching; left plastic mulch in China, right dry soil mulch in Syria. In Mediterranean climates dry soil mulch is a traditional practice. Winter rainfall is stored in the soil for use by a crop in summer. Frequent tillage prevents weeds to use stored water and keeps the soil surface in a dry crumbled state that almost eliminate soil evaporation.

Increase water use, decrease unused water, U

It is important that the extra water conserved or harvested is used. Besides water, plants also need nutrients. Both production factors need to be in balance. Water conservation/harvesting without attention for nutrient supply does not make sense. Water–nutrient synergy can improve water use. Zoumore *et al.* (2003) found that in case permeable barriers combined with the use of compost Sorghum yield in Burkina Faso was 2.3 times higher than in the control plots and in plots with barriers only.

Trees and shrubs can play an important role in landscape restauration by using this extra water. Fig. 6 gives two examples; left Eucalyptus boundary plantings in Ethiopia, right Parkland in Mali. Land use changes in Ethiopia has disturbed the field water balance with as result an excess of water. Selamyihun Kidanu *et al.* (2005) found that *Eucalyptus globulus* planted along field boundaries grow very fast using this excess water. An on-farm trial at Ginchi showed wood production rates between 168 kg ha^{-1} y^{-1} for four years old trees to 2900 kg ha^{-1} y^{-1} for twelve years old trees. Due to competition, significant depression of tef and wheat yields occurred over the first 12 m from the tree line.

Fig. 5. Examples of mulching against soil evaporation; left plastic mulch in China, right dry soil mulch in Syria

Fig. 6. Examples of making use of conserved rainwater; left Eucalyptus boundary plantings in Ethiopia, right Parkland in Mali

However, in financial terms, the tree component adequately compensated for this crop yield reduction and even generated additional income. Obviously, farmers adopted fast and in recent years, *Eucalyptus globulus* planted along field boundaries has come to dominate the central highland landscape of Ethiopia. In the Sahel parklands are favorable land use systems. Scattered trees, with annual subsistence cropping in between, provide shade for human and cattle, additional income from useful product and organic fertilizer. These trees use water from deeper layers where staple crops like Sorghum cannot come and as such increase the fraction of rainwater used for primary production.

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