Overview of Best Practices

WAter HArvesting for Rainfed Africa (WAHARA)

Investing in dryland agriculture for growth and resilience

October 2011

Del 1.3 MetaMeta and Acacia Water

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Introduction

This document provides an overview of best practices in agricultural water management. It is prepared as an internal input in the WAHARA project – work package 1. This document contains an overview of the main techniques, their applicability and boundary conditions.

Over twenty cases are presented from different countries – each 'good practice' trying to describe the techniques and processes used – and as much as possible the costs and benefits quantified. Data on exact benefits are the ones most difficult to find, though of often useful orders of magnitude and proxies are given.

This is a first version of the document – the purpose is for it to be elaborated with input or leads from different partners. The document should also help to inform the selection of techniques in the different WAHARA pilot sites.

1. Rainwater harvesting tank for micro-irrigation in Amhara national regional state, Ethiopia

Introduction

The assessed rainwater harvesting tank was constructed with financial support of the CIDA-funded Sustainable Water Harvesting and Institutional Strengthening in Amhara (SWHISA) Project. Technical assistance was provided by a team of international and national consultants from Hydrosult Inc. (Canada) in association with Agrodev (Canada) and Oxfam Canada.

Location

The rainwater harvesting tank is located in the village of Mekabia in Yebucher Kebele within Goncha Siso Enesse Wereda, East Gojjam Zone of the Amhara National Regional State in Ethiopia. The coordinates are 10º 56’ 22” N and 38º 06’ 54” E. The location of Mekabia village where the rainwater harvesting tank is constructed is shown on the satellite map below.

Figure 1. Female household member in front of her house with roof made of corrugated sheets

Climate

More than 85% of the mean annual rainfall occurs during the *Meher* season from June to October. The average annual rainfall of about 1,200 mm. The mean annual maximum and minimum temperature is 19.1ºC and 8.6ºC. The altitude is 2,672 metres above sea level.

Population and Demography

A total of 52 households are living in Mekabia village and the total population is estimated to be about 208 persons based on average household size of 4 persons. All households belong to the Amhara ethnic group and they are members of the Ethiopian Orthodox Church. The average population density in the wereda is 169 persons per km^2.

Soils

Lithosols and vertisols are the dominant soil types in the wereda. Most of the soils are shallow due to steep slopes, low vegetation cover and limited soil conservation practices. Traditional methods of soil fertility regeneration practices, such as fallowing, use of farmyard manure and crop rotation, have been abandoned. Fallowing of arable land is not practiced any more as population pressure has forced farmers to crop every plot of available land every year. Crop residues are completely removed from farmland to be used either as animal feed, fuel and/or construction material. Cow dung is the major source of energy for cooking.

Livelihoods

The livelihoods of almost all households are dependent on a mix farming system of rainfed crop production and livestock raising. As most rainfall occurs between June and October, farmers can only grow crops once a year from June to November/December under rainfed condition. The major rainfed crops grown in Goncha Siso Enesse Wereda include wheat, teff, beans, maize, lentil, potato and barely. The cropping season usually starts shortly after the short rainy season in March/April with land preparation. The crops are planted from May until July and they are harvested between October and December. The yields of rainfed crops are low due to limited use of fertiliser and poor agronomic practices. As the livelihoods of most household is based on subsistence crop farming, they become food insecure in years with less rainfall or long dry spells during the cropping season. Sale of animals, temporary labour migration and obtaining loans are the most common mechanisms to cope with food shortage.

In addition of rainfed crop farming, livestock also plays a significant role in the livelihoods of the rural households. Oxen are used for land preparation, threshing and transport. Milk from cows is used for the production of different dairy products, which is either consumed within the household or sold locally. Manure of cattle is often the only source of energy for most households. Sheep, goats and poultry are also raised by most households.

Number of Benefiting Households

The rainwater harvesting tank is benefiting three households with a total of 15 members, including 6 adults and 9 children. Their houses are situated within a distance of not more than 100 metres from the rainwater harvesting tank.

Engineering Aspects

The rainwater harvesting tank has been constructed to provide water for micro-irrigation. It was constructed between March and June 2007 by a local contractor under supervision of the SWHISA Project. The walls of the tank are stone masonry and the floor is made of concrete.

The rainwater harvesting structure has a trapezoidal shape. The top of the tank measures 10 by 9 metres, whereas the bottom is 6 by 6 metres. The depth of the structure is 3 metres and the storage capacity is 120 m^3. A concrete intake structure with a silt trap is constructed in order to divert the runoff rainwater into the tank. A roof consisting of wooden poles and plastic sheets is covering the tank to reduce water losses due to evaporation.

The estimated size of the "catchment" of the rainwater harvesting tank is not more than a few hectares where the houses of the three benefiting households are situated.

Figure 2. Rainwater harvesting structure with intake structure, silt trap and plastic roof

Figure 3. "Catchment area" of rainwater harvesting tank

Command Area

The three benefiting households use the stored water to irrigate an area of 342 m^3 using a drip system with 37 laterals. The length of a lateral is 20 metres. Stored water from the tank is lifted in two barrels with the help of a treadle (pedal) pump.

Figure 4. Drip system with two barrels and laterals

Figure 5. Treadle pump used for lifting water from rainwater harvesting tank to barrels

The stored amount of water in the rainwater harvesting tank is sufficient to irrigate the command area during the entire irrigation season from December until May/June. The following crops are grown with irrigation water from the tank: cabbage, onion, beetroot, tomato and pepper. It was observed that methods to maintain soil moisture, such as mulching, are not used by the benefiting households.

It is estimated that about 60% of the grown vegetables is used for home consumption. The remaining 40% of the harvested vegetables is sold by the three benefitting households in Gunde Woyne town at a distance of about 5 km from their village. The total annual cash income from the sale of vegetables is about Ethiopian Birr (ETB) 1,000 (US$ 60). Therefore, the estimated value of the harvested vegetables grown with water from rainwater harvesting tank during the dry season is about ETB 2,500 (US$ 150) per year.

Construction Cost

The construction cost of the assessed rainwater harvesting tank was ETB 31,815 (US$ 1,905)[1], whereas the cost of the treadle pump and the drip system was ETB 440 (US$ 26) and ETB 2,285 (US$ 137). The contribution of the three benefiting households towards the construction cost includes the provision of free labour, stones for the walls as well as Eucalyptus poles and plastic sheets for the roof.

Average Construction Costs of Rainwater Harvesting Tanks

Under the SWHISA Project, the following three materials are used to line the walls and floor of rainwater harvesting tanks: a) stone masonry and concrete floor; b) cement (mortar) plastering; and c) geo membrane plastic sheet.

The average construction costs of a sample of 17 rainwater harvesting tanks[2] using the aforementioned materials for lining the walls and floor are presented in the following table:

Type of Tank	Life expectancy	Material Cost		Labour Cost		Total Cost	
		ETB	% Total Cost	ETB	% Total Cost	ETB	US$
Stone Masonry	25 years	16,711	64%	9,386	36%	26,097	1,563
Cement Plastering	20 years	10,781	46%	12,554	54%	23,335	1,397
Geo membrane plastic sheet	10 years	767	16%	4,076	84%	4,843	290

The storage capacity of these 17 rainwater harvesting tanks is 115 to 130 m^3 and the size of their command area ranges from 300 to 400 m^2.

One of the reasons that the construction costs of the rainwater harvesting tanks with stone masonry and cement plastering are so high is that the price of cement has increased from ETB 200-250 per bag of 100 kg to ETB 460 per bag, excluding transport cost at an average rate of about ETB 100 per bag. For many years, the government subsidised about 50% of the price of membrane plastic sheet imported from China.

Financial Feasibility

Based on the aforementioned construction costs and the size of the command area, it is obvious that rainwater harvesting tanks using geo membrane plastic sheet for lining of walls and floor with an average

[1] 1 US$ = Ethiopian Birr 16,7 (March 2011)
[2] Sample of 6 tanks with stone masonry, 5 tanks with cement plastering, and 6 tanks with geo membrane plastic sheet

construction cost of ETB 4,843 (US$ 290) are the only option that is financially feasible. Rainwater harvesting tanks made of stone masonry or cement plastering are too costly with average construction costs of ETB 26,097 (US$ 1,563) and ETB 23,335 (US$ 1,397) respectively.

Operation and Maintenance

The three benefiting households are fully responsible for the operation and maintenance of the rainwater harvesting tank and the installed drip system. Once a year the tank has to be cleaned by removing silt from the floor of the structure.

Training

Male and female members of the three benefiting households received training in the following topics:

- Operation and maintenance of drip system;
- Cultivation of irrigation crops (i.e. vegetables);
- Scheduling of irrigation; and
- Raising and transplanting of seedlings.

Other Use of Harvested Water

The water stored in the rainwater harvesting tank is not used for domestic purpose or watering of livestock. Each of the three households has installed its own dug-well with a depth of 16 to 19 metres, which is used to fetch water for domestic use.

Figure 6. Dug-well with cover used for fetching water for domestic use

Impacts of Rainwater Harvesting Tank

The reported impacts of the constructed rainwater harvesting tank and drip system for the three benefitting households are as follows:

- Improved health due to more diversified diet by consuming more vegetables;
- Purchase of chemical fertilisers for rainfed crops;
- More money to purchase basic food items, such as salt and cooking oil; and
- Improvement to houses.

Figure 7. Female household member in front of her house with roof made of corrugated sheets

Reported Problems with Rainwater Harvesting Systems in Amhara Region

Based on experiences gained with the construction of more than tens of thousands rainwater harvesting structures in the Amhara region, the following problems related to the functioning of rainwater harvesting structures have been identified:

- Siltation of the structure due to soil erosion;
- Loss of harvested water through evaporation and percolation;
- Inefficient utilisation of harvested water at field level;
- Pollution of harvested water caused by organic matter (i.e. leaves) and dead animals (i.e. rodents); and
- Accidents with children falling in the structure filled with water.

Mitigating Measures

These observed problems can be mitigated by implementing the following measures:

- Treatment of catchment to reduce siltation problem, including the planting of trees and construction of soil/stone bunds;
- Construction of intake structure with silt trap to avoid silt entering the rainwater harvesting structure;
- Construction of roof to prevent water losses due evaporation and pollution from falling leaves;
- Lining of the walls and floor of the rainwater harvesting structure in order to reduce water losses caused by percolation;
- Construction of fence around the tank to prevent children from falling in the rainwater harvesting structure; and
- Use of drip system to improve water use efficiency during the irrigation of the planted crops.

References

Field study, Olaf Verheijen 2011

2. Water harvesting systems based on mulching, Canary Islands

Introduction

In the harsh environment of the Canary Islands (Spain), farming without the possibility of irrigating is an ever challenge. More conducive to degradation processes, the unfavourable conditions - climate, soil, sparse vegetation and lack of water – have necessitated farmers to develop agricultural techniques to conserve soil and water and allow small amounts of cultivation. The systems either involve the covering of soils with volcanic materials, which act as mulch, or the harnessing of what little run-off exists in cisterns. In an attempt to describe the effects and benefits of mulching using volcanic ash various soil parameters were measured, which lead to point out the technical effectiveness of the methods. The systems are however in decline today due to socio- economic factors …

Location

In Lanzarote specifically four different systems based on surface mulching can be found. The systems are particularly determined by the characteristics of top layer of the soil.

So called *Natural arenados*, are used in areas that have a natural presence of tephra and are located near volcanic cones. They consist of planting holes of 3 metres diameter which are dug to reach the soil level where planting takes place and a layer of manure and ash is added on top. To protect the holes stonewalls, made from the basaltic outcrops, are erected in a semi-circle perpendicular to the direction of the prevailing wind. Harvesting both rainfall and dew in the pits some 2,400 hectares are under this 'dry farming' cultivation technique which is used for vines and figs. The vineyards and traditional techniques are now even part of the World Heritage Sites that include other areas of Lanzarote.

Artificial arenados are also constructed by farmers in areas that are not covered by volcanic materials. The pits area similarly constructed but in this case volcanic tephra is placed over the soil, which may be either natural to the area or brought in from other parts. Before the soil in the pits is covered by tephra, farmers mechanically mix in organic material (usually manure) at a depth of around 10cm. As over time the layer of tephra covering the soil mixes with the soil, the effectiveness diminishes and farmers remove the layer contaminated by the soil and replace it with a new layer. Again a layer of manure is placed on the ground before the new tephra is laid.

Even in the areas on Lanzarote that are covered by lava outcrops and aeolic sand farmers have proven that dryland farming is possible. Crops are grown in *cracks* in the lava as well as in holes in the sands, known as *jable*. Farmers use the cracks in the lava to access the soil underneath for growing deep-rooted plants (vines and figs). Besides natural protection against the strong winds the soil underneath tend to be superficially contaminated by tephra, which acts as mulch just. Where the aeolic sand layer is less than one metre holes are dug to the depth of the soil following which manure is inserted and like with the arenados the holes are protected by stone walls. Although the latter system is less effective, it does nonetheless permit dryland farming of crops, such as sweet potato, melon, watermelon and pumpkin.

Climate

The climate paramaters of the islands Fuerteventura and Lanzarote are typical of a very arid climate. Annual rainfall tends to be less than 150mm with considerable variations from year to year. Average annual temperature is around 20C – 21C with notable difference during the course of the day (sharp falls in tempareture at night). With plenty of sunshine (average 7.8 hours per day) and strong and constant winds all year round (average 20km/h) the evaporation rate is also high at approximately 2000mm/annum. However relative humidity is also high with a daily average excess of 70%, which given the possibility of condensation is conducive to water uptake and mulching practices.

Soils

Lanzarote's soils have an origin and dynamic that is determined by several factors, including an aridic moisture regime, scarcity of vegetation and the age of geological materials (either recent volcanic deposits or quartenary period aeolic formations). As a result of these factors the soils present very specific characteristics such as low organic matter content and low biological activity, alkaline reaction, horizons with accumulations of carbonates, soluble salts, sandy-loamy surface texture, modified soil surfaces: desert pavement and sealing crusts. The soils on the island are also affected and formed by Aeolian dust from the Sahara Desert as well as the frequent volcanic eruption from which airborne fragmental volcanic material (including ash) is deposited also known as Tephra (or pyroclasts).

Engineering Aspects

In all of the dryland farming systems explained a main role is cut out for tephra. Occurring naturally or applied by farmers, this volcanic material – commonly in Lanzarote to be basaltic rubble – its porosity favours infiltration of the islands's scarce rainfall and significantly helps reducing water loss through evaporation. Moreover the surface size of tephra, the high environmental humidity, adequate windspeed and the considerable drop in temperature at night combine to form ideal conditions for condensation[3].

The benefits derived from the mulching effect of the tephra layer extends to reduced salinity-sodicity in the root zone, favourable and even soil temperatures and reduced erosion. The ease at which infiltration occurs as effect of the tephra layer allows for a reduction in runoff, a high rate of infiltration and leaching of soluble salts in the soil, avoiding the accumulation of salts in the root zones. Acting as a buffer the tephra also reduces daily and seasonal temperature differences.

Agricultural benefits

In areas that would otherwise be deemed unfit for any agricultural production, particularly in dry years, production - using the described techniques of rain and dew harvesting as well as mulching - can still take place. The combination of land preparation and mulching techniques can produce in dry years with only 47mm of rainfall (such as 2000) the following: 2,361 kg/ha of onions, 6,063 kg/ha for potatoes and 1,775 kg/ha of grapes, with in averages years respective production being 8,043 kg ha for onions, 6,030 kg/ha for potatoes and 907 kg/ha for grapes, without using any form of irrigation.

References

Tejedor, M., Jimenez, C.C., Diaz, F. 2002. Traditional agricultural practices in the Canaries as soil and water conservation techniques. In 'Water harvesting in Mediterranean zones: an impact assessment and economic evaluation Proceedings from EU Wahia project final seminar in Lanzarote. Jan de Graaff and Mohamed Ouessar (Editors)

[3] Although research is still being carried as to the exact amount of water produced by condensation, as well as the uptake by the soil and the possible insulation effect.

3. Kitui sand storage dams, Kenya

Introduction

Large-scale implementation of groundwater recharge interventions has many benefits over single systems. The stored volumes of groundwater are generally larger, and the ecological damage caused by a single, much larger water source is prevented. Social benefits are also numerous, as has been seen in the Kitui District (Kenya) where over 750 sand storage dams have been constructed.

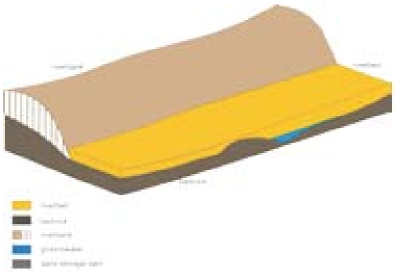
Figure 1. A typical sand storage dam during the dry season in the Kitui District

Description

The Kitui District is situated 150 km east of Nairobi. The size of the district is approximately 20,000 km2 including 6,400 km2 for the uninhabited Tsavo National Park. The area is semi-arid, with rain falling in two wet seasons. The rains usually fall in a few intensive storms and are highly erratic and unreliable. Most rivers are seasonal, only flowing during the wet season. During the dry season, surface water sources are scarce or absent. Walking distances to the few water sources increased as the dry period prolonged. The response to these problems was the construction of sand storage dams.

In close collaboration with local communities, Kenyan NGO SASOL took the initiative in the 1990s to ensure water availability for rural communities in the Kitui District through the construction of sand storage dams. In the decade that followed more than 750 dams were built, successfully providing communities with water for domestic use and small-scale irrigation.

These dams were built in the riverbed to increase the thickness of the natural sand layer in the riverbed, thereby enlarging the storage capacity of the riverbed aquifer. Furthermore, the sand storage dam obstructs groundwater flow through the riverbed, preventing the loss of water from the catchments. The construction of a sand storage dam leads to larger volumes of water stored in the riverbed, ensuring higher water quality and availability (usually lasting throughout the dry season).



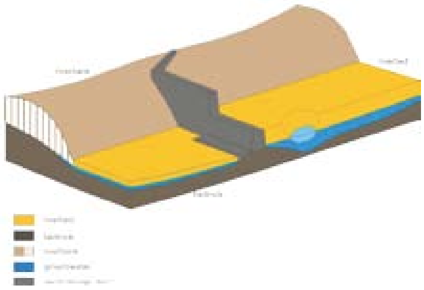


Figure 2. Riverbed without a sand storage dam Figure 3: Riverbed with a sand storage dam during the dry during the dry season (Hoogmoed, 2009) season. Water availability is considerably larger compared to a river without a sand storage dam (Hoogmoed, 2009)

Techniques used

The first step in the construction of a sand storage dam is site selection. The following are general indications on the appropriateness of a riverbed as a construction site:

- the riverbed has a width of approximately 20 m and contains coarse sand;
- the riverbanks are steep at both sides and have a height of approximately 1 m to 1.5 m;
- the banks preferably consist of clayey material or rock outcrops;
- the presence of groundwater (scoop holes in river beds) a few months after the rains have ceased is a good sign (i.e. downstream of this location a natural flow barrier is present and an (semi)impermeable layer prevents leakage to deeper aquifers).

The selection of sites is a very important part of the implementation process, and it is advised that an expert is consulted on the matter.

When an appropriate site is selected, the design is made based on the cross sectional profile, peak river flow and required water yield. Then, the actual building can start. After construction, it can take between 1 and 10 wet seasons for the sand storage dam to become completely filled with sediment and water, depending on the characteristics of the upstream catchment. If a sand storage dam is properly constructed, it requires little or no major maintenance. However, if any cracks or weak points are observed in the sand dam, a technical engineer and mason should inspect the whole dam structure and execute repair works before the following rainy season, to prevent further damage. Also, the area upstream of the dam should be kept clean - removal of animal droppings, dead animals, rocks and tree (parts) - to prevent damage and water contamination.

Communities are involved in siting and the construction of sand storage dams through sand dam management groups, providing knowledge, labour and raw materials. After construction, these groups ensure the maintenance of dams and protection of the water quality as well as promote ownership and thus sustainability.

Results and impacts

In the Kitui District, implementation of sand storage dams led to the availability of better quality water within short distances from the homesteads. Since less time is needed to fetch water, school attendance has increased significantly and more time has been spent on other income-generating activities such as household industries (basket weaving, sewing). Apart from drinking water security, sand storage dams provide enough water to develop small-scale irrigation (food and cash crops, tree nurseries) and industrial activities (brick making). After the introduction of the sand storage dams, the percentage of households suffering from malnutrition has demised from 32% to 0%, and incomes have increased significantly.

Table 1. Measured social and economic impacts of sand dams in the Kitui region, Kenya (after Thomas, 1999).

Vulnerability categories	Vulnerability indicators	Before dam construction	After dam construction
Agriculture	# of cash crops	1.5	3
	% irrigated crops	37	68
Special aspects	Domestic water collection (minutes)	140	90
	Life Stock water collection (minutes)	110	50
Gender	Average walking distance women to water (km)	3	1
Economic	Income (US$/year)	230	350
Health	% households suffering from malnutrition	32	0

In the Kitui District, sand storage dams have been implemented on a large scale, and frequently in cascades. The hydrological benefits of implementation in cascades are the reduced loss of water due to leakage of a sand storage dam (since the downstream dam will obstruct further downstream flow), and the groundwater levels are raised more extensively compared to the implementation of single systems (ensuring more water availability and generating vegetation in a larger area). Due to the construction of many sand storage dams (in cascades) communities are not dependant on a single water source, therefore limiting environmental impact. Also, implementing sand storage dams (and other water harvesting techniques) on a large scale enables communities to share experiences and knowledge, which promotes community participation.

Figure 4. Groundwater abstraction from the riverbed by means of a scoop hole in the Kitui District

Concluding statement

The implementation of sand storage dams has proved successful in ensuring water availability for rural communities in the Kitui District, not only for domestic use but also for small-scale irrigation purposes. Upscaling of the technology through the implementation of a large number of the structures has many benefits over the implementation of a single intervention, in relation to the availability of water and socio-economical benefits. Sand storage dams are a sustainable means to meet the increased water challenges in semi-arid areas due to the less reliable and higher intensity rainfall events as an effect of climate change.

Upscaling Across Country Borders

The successful implementation of sand storage dams on such a large scale as in Kitui District (Kenya) has inspired several new projects. Sand storage dams are now being implemented across District and country borders to provide rural communities of water, also with respect to climate adaptation. An example is the construction of sand storage dams in Mozambique, which was initiated through a knowledge exchange visit to Kitui.

Another good example is the pilot project in Borana Zone (southern Ethiopia). Here, the focus lay on making optimal use of available water resources in catchments to enlarging their water retention capacity. To this aim, 10 NGO's were trained by the Kenyan NGO Sasol, the Rain Foundation and Acacia Water on implementation of sand storage dams. AFD (Action For Development, an Ethiopian NGO) has implemented sand storage dams for the benefit of communities living close to riverbeds. For communities living far from rivers surface runoff water was harvested in underground water harvesting tanks. The combination of applying several water harvesting techniques within a catchment, and thus making optimal use of the natural resources, proved to be very successful. Besides the sand storage dams built in the Borana Zone as part of the project, the on-job trainings and workshops resulted in several spin off projects by participating NGO's, in which community support and project funding was found to start implementation of sand storage dams in other regions of Ethiopia.

References

Borst, L., Haas, S.A. (2006), Hydrology of Sand Storage Dams, A case study in the Kiindu catchment, Kitui District, Kenya. Master thesis, Vrije Universiteit, Amsterdam

Gijsbertsen C. (2007). A study to upscaling of the principle and sediment transport processes behind sand storage dams, Kituï District, Kenya. Vrije Universiteit, Amsterdam.

Hoogmoed, M. (2007). Analyses of impacts of a sand storage dam on groundwater flow and storage. Vrije Universiteit, Amsterdam

Hoogmoed, M. (2009). Why build sand storage dams? An introduction to the concept. Presentation in Ethiopia, for NGO

Jansen J. (2007). The influence of sand dams on rainfall-runoff response and water availability in the semi arid Kiindu catchment, Kituï District, Kenya. Vrije Universiteit, Amsterdam

Lasage, Aerts, Mutiso, de Vries (2008). Potential for community based adaptation to droughts: Sand dams in Kitui, Kenya. Physics and Chemistry of the Earth 33 (2008). Pp. 67-73

Nissen-Petersen (2006). Water from dry riverbeds. Danish International Development Assistance (Danida)
Nzomo Munyao, J. Muinde Munywoki J., Ikuthu Kitema M., Ngui Kithuku D., Mutinda Munguti J., Mutiso S. (2004). Kituï sand dams: Construction and operation. Sasol Foundation, Kenya.

Orient Quilis, Hoogmoed, Etsen, Foppen, de Vries (2009). Measuring and modelling hydrological processes of sand-storage dams on different spatial scales. Physics and Chemistry of the Earth 34 (2009). Pp. 289–298

RAIN and Acacia Water (2009). A practical guide to sand dam implementation: Water supply through local structures as adaptation to climate change.

Thomas. 1999. Where there is no water – a story of community water development and sand storage dams in Kitui district Kenya. SASOL

www.sanddam.org

Africa Interactive (2009). Video: Sand dam training in Southern Ethiopia. Retrieved from: http://www.thewaterchannel.tv/

4. Using floods for irrigation and recharge, Yemen

Introduction

Shallow aquifers are often the best place to store floodwater. Compared to surface reservoirs the cost of storing floodwater in the shallow aquifer and soil profile is minimal. There is very little evaporation loss and the water can be reused immediately or at the time preferred – with no conveyance loss. The capacity to store floodwater obviously varies from aquifer to aquifer.

There is also a second dimension to the link between floods and groundwater storage. If there is intensive groundwater development, effective flood storage capacity in the shallow aquifer will increase as the top layers are no longer saturated. As a result, floods will either not occur or, if they occur, they will do so later in the flood season and less frequently.

Figure 1. Spate irrigation in Tihama

Description

One of the best examples of combining flood storage, recharge and agriculture are the so-called spate irrigation systems. These systems have a long history in arid areas in Pakistan, Iran, North Africa, Sudan and Yemen. They are on the increase in the Horn of Africa and other parts of Africa. Spate irrigation is the quintessential adaptation to extreme climate events. The central feature of spate irrigation is the usage of short duration floods that originate from episodical rainfall events in highland catchments. Floods – lasting from a few hours to a few days

– are diverted from dry riverbeds and spread gently over the land. The water is used in agriculture, with soil moisture often carefully preserved, as the floods usually arrive ahead of the cultivation season. The floodwater is also used for filling water ponds, for improving rangelands and tree stands, and for recharge. Spate irrigation systems have some of the most spectacular social organizations around. They require the local construction of diversion structures that are able to withstand flash floods and gently guide large volumes of water over large areas, thus slowing down erosion. In Yemen the spate irrigated areas located on the Red Sea (the Tihama) and the Indian Ocean coastlines are the grain baskets of the country (see figure 1). Here agriculture is at its most productive. The high water productivity comes from the combined use of floodwater and groundwater, with the spate flows being the main source of recharge. Groundwater in the coastal plains of Yemen is mostly of good quality and hence can be easily reused. The result has been that the spate irrigation systems sustain not only extensive areas of staple crops and a large livestock population, but they have also made it possible to grow large areas of high value horticulture, such as banana and mango orchards. This has even reached the point that groundwater overuse is a real concern.

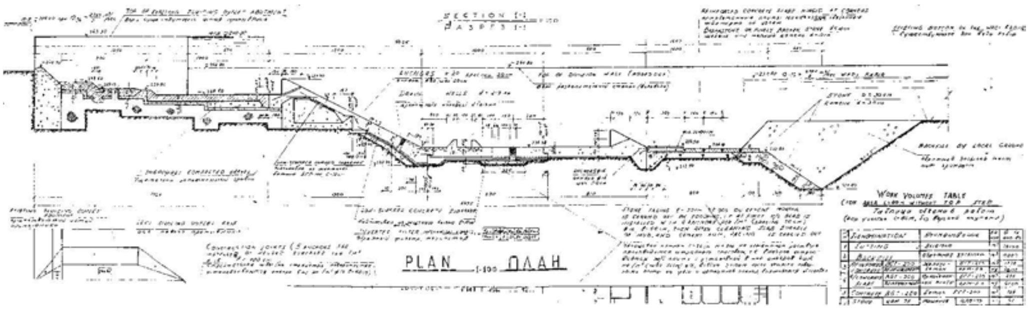


Figure 2. The Ras Al Wadi weir with weepholes provided

Techniques used

Most recharge in spate irrigation takes place through the riverbeds. Recharge from flood channels and farm fields is also important but is less significant. There are several ways to promote effective recharge. One is to keep the river bed armoured. Big boulders and stones will slow down the velocity of the floods and will enhance the replenishment of groundwater. A second action is to build structures that slow down the water. These are the regular spate diversion structures, but in some wadis in Yemen, such as Wadi Hadramawt, farmers have even built low weirs across the wadi specifically to increase recharge.

Since the 1980's a number of permanent concrete diversion structures have been built across some of the main ephemeral rivers in coastal Yemen. These structures were constructed to divert the flood flows to land, but some of them – for instance in Wadi Mawr or Wadi Siham – have inadvertently blocked the subsurface flow as well. These 'cut-off' weirs keyed into the bedrock or clay layers underneath the river. By doing so they had the unintended effect of increasing groundwater levels upstream of the weirs, and at the same time caused hardship for the users downstream.

A much better cut-off weir design was used in Wadi Tuban, where openings, so-called 'weepholes', were provided in the main body of the weir. These weepholes allow the subsurface flow to pass through the weir. Substantial flows emerge from these allowing the downstream wells to continue to function. Because of the weepholes, it is also possible to construct a relatively light structure. The Wadi Tuban weirs are relatively 'thin', which makes up for a substantial cost saving. If there was no underdrainage, the weirs would need to be much heavier to prevent them from 'floating away'.

Apart from these modern structures, traditional structures – soil and gravel bunds and deflectors

– also work very well. The traditional structures are typically built at a cost that is a fraction of the modern structures. Whereas a system provided with modern concrete headworks may cost 500 to 1800 Euro per ha, traditional structures may cost less than 250 Euro per ha. In many areas they work better: they provide more options to divert floodwater, they do not confuse the water rights and, because of their ability to breach in high floods, they are better equiped to keep such heavily silt-laden – and potentially damaging – big floods out of the command area. Smaller floods, however, are able to be utilized.

Figure 3. Water emerging from weepholes

References

Van Steenbergen, F., P. Lawrence, Maher Salman, A. Mehari Haile (forth coming). Spate Irrigation Guidelines. Rome: FAO.

www.spate-irrigation.org

5. Diverting short floods to infiltration basins in extremely arid areas, Niger

Introduction

Groundwater recharge by controlled flood diversion can safeguard and improve living conditions, even in extremely arid areas. Domestic water requirements, the needs of cattle watering and local irrigation can be met with low cost diversion structures and carefully sited infiltration basins. It makes it possible for settlements to develop even in the areas with the most fragile climate conditions.

Description

The oasis of Iférouane is situated in the Aïr Mountains in the central Sahara desert. It is located 1000 km north of Niamey, the capital of Niger (figure 1). With less than 50 mm of rainfall a year, Iférouane is extremely arid. In some periods even this low average is not achieved. For instance in the period 1940–1975 annual rainfall did not exceed 20 mm in this part of the Sahel.

The water demand in the oasis for human and agricultural purposes is met from traditional open wells. These are dug into the Quaternary sediments of the river valley that are intercalated by loamy material. The wells go down to a depth of 20 m. At a depth of approximately 10 m below the Quaternary sediments, there is a water-bearing granite/gneiss basement as well. The hydraulic conductivity of the sandy part of the aquifer system amounts to 3 to 5 m/day.

Until 1975, this groundwater buffer was only recharged by the occasional infiltration of surface water through the sandy bed of the local Kori Tamgak river during short flood periods. By 1974, after a stretch of extremely dry years, the groundwater table dropped and many wells fell dry. As a result, only one quarter of the gardens could be irrigated and the rest had to be abandoned. This threatened the very survival of the oasis.

Figure 1. Location of Iférouane in Niger

Techniques used

Various hydrogeological investigations, including runoff measurements, groundwater monitoring, soil infiltration tests and numerical modelling, were carried out in order to identify the best suitable method for the improvement of local groundwater conditions.

Among various scenarios, artificial groundwater recharge by diverting the occasional flush water from the Kori Tamgak into an infiltration basin was considered the most feasible measure. This infiltration basin was established upstream of the oasis in an area where infiltration tests showed the presence of highly permeable sandy and gravely material. Rock outcrops were also identified that could provide construction material for flood diversion works.

A low-cost barrage was constructed across the ephemeral river in 1975. The diversion works consisted of a ground sill, a diversion canal, protection walls and micro groins against flood erosion (figure 2). Low floods in the Kori Tamgak – below the level of the sill – are diverted to the infiltration basin, whereas the occasional high flood flush – that would cause damage and sedimentation in the infiltration basin - is allowed to pass over the sill and follow the original river bed (figure 3).

Impact

Consequently the groundwater tables started to rise immediately after the construction of the diversion works. After relatively 'high' rainfall of about 60 mm in 1976, the additional infiltration caused a remarkable rise of the groundwater level. In this year 13% of the flood discharge in the Kori Tamgak of 5.7 million m^3 was routed to the groundwater buffer through the infiltration basin. The rise of the groundwater level on the well adjacent to the infiltration basis is seen in the diagram.

During the last 30 years the groundwater situation has improved continuously and has created better living conditions and sustained agricultural development. Whilst only about 100 people were living in Iférouane in 1974, the population has grown from 1000 in 1984 to 3000 permanent inhabitants (Paschen, 2004). Currently, vegetables from Iférouane are exported to other markets.

45 Hydrogeological and engineering/geological investigations have made it possible to develop a workable concept of a low sill barrage and an infiltration basin. The decision to implement the infiltration basin in the extremely dry conditions of the oasis was further supported by model calculations, predicting the future effects on the groundwater table. By making effective use of the groundwater buffer, life in Iférouane changed from bare survival to a situation of growth and development.

Figure 2. Construction of diversion works

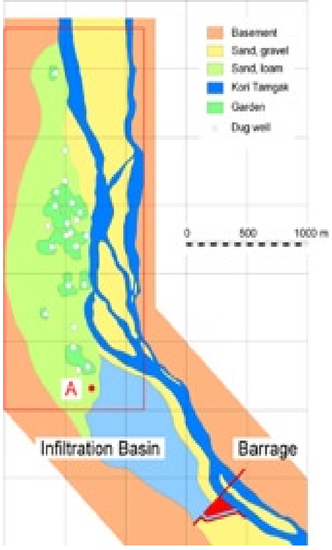


Figure 3. Schematic overview of the area after construction of barrage

Figure 4. flood flow entering the infiltration basin

References

GKW (1974). Technische Hilfe für République du Niger: Projets d'infrastructure à l'investissement humain / Arbeitsintensive Infrastrukturvorhaben, (Gesellschaft für Klär-anlagen und Wasserversorgung mbH), Mannheim.

Böckh, E., Kleine Bornhorst, A., Schmidt, G. (1975). Arbeitsintensive Infrastruktur-Vorhaben in Niger, Iférouane und Timia im Aïr / Niger, BGR, Hannover, Archive no. 67 668 and no. 67 669.

Böckh, E., Schmidt, G. (1984). Arbeitsintensive Infrastruktur-Vorhaben in Niger, BGR, Hannover, Archive no. 96

429.

Schmidt, G. (2002). Methoden der Grundwasser-Ressourcen Quantifizierung – Iférouane, BGR, Hannover, Archive no. 122 069.

Paschen, H. (2004). Trockenmauern in den Oasen des Aïr Gebirges, Bischwiller, France.

6. Subsurface dams - intercepting the groundwater flow for storage, Brazil

Underground dams (subsurface or groundwater dams) are dams cut in the alluvial cover to intercept groundwater flow out of the area to create local storage, making it available during periods of drought (figures 1 and 2). Where the geology and groundwater flows allow, subsurface dams are an efficient and cost-effective way to intercept and store groundwater water for use during the dry periods. These dams are found in many countries in different sizes and numbers. In this case, an example in Brazil illustrates some generic features of the construction and performance of subsurface dams.

Description

Approximately 500 subsurface dams were constructed in the 'alluvial cover' in the Pernambuco state in north eastern Brazil in the 1990s. The programme consisted of:

- small structures (up to 3 m depth) were built under 'Government drought emergency and job generating programmes' at sites selected by the municipal committees without technical advice and follow up. They were manually excavated, incorporating plastic membranes and large diametrical concrete ring wells;
- similarly-sized structures were constructed at the initiative of local NGOs with specialist advice, and were filled with compacted clay and without a well for water abstraction;
- much larger dams (up to 10 m depth) were sited based on technical criteria and constructed to support small-scale irrigated agriculture. For these dams, mechanical excavators were used and incorporated impermeable plastic membranes, improved large diametrical wells and some technical monitoring.

Techniques used

Subsurface dams are impermeable barriers (clay, masonry or concrete) obstructing subsurface flow. Groundwater can be abstracted through wells, boreholes or a collector drain (figure 1). Typical small dams have a storage capacity of some 10 000 m3 (average 4 m depth, 50 m width and 500 m length). Larger dams (for example in Yemen) may be 5–10 m in depth, have a width of 200–500 m or more, and be able to store 100,000–1,000,000 m3.

When constructing a subsurface dam it is important that the dam is founded on impermeable bedrock. Several dams built in a cascade increase the total groundwater volume stored and limit the effects of leakage. In rural areas, community participation is essential to obtain maximum socio-economic benefits. For example, community labour reduces and enhances the efficiency, acceptance and lifespan of the dams (figure 3).

Results and impacts

In 2002, the use and performance of the subsurface dams were evaluated by a World Bank team. The evaluation of 150 dams showed that:

- 50% of the dams inspected in Brazil are in active multipurpose use for domestic water supply, livestock watering and small scale irrigation;

- about one-third were not in active use due to siting or construction problems;
- more than 10% were functioning well but the stored groundwater was not used due to the availability of a reliable surface water source, underlining the importance of involving the communities in such projects to discuss the needs of the community.

Investment costs for subsurface dams depend on the size and may vary from 3500 – 7000 Euro for small dams and up to 70 000 Euro for large dams with storage capacities of 100 000 m3- 1,000 000 m3. The investment cost per m^3 storage volume is in the order of 0.35 –1.4 Euro/m^3.

The evaluation in Brazil provided a number of key issues for successful dam construction:

- proper site selection to ensure sufficient storage potential;
- assurance that there is sufficient depth to reach relatively impermeable bedrock;
- availability of a soil type with sufficient infiltration capacity;
- avoidance of a soil type that could lead to groundwater salinization;
- proper design and construction to avoid low-yielding abstraction wells;
- address the landownership issue.

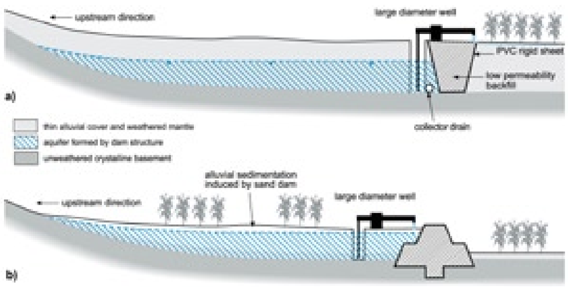


Figure 1. Typical design of subsurface dam (Source: GWMATE)

Concluding statement

Subsurface dams are a cost-effective means to store water for multiple use during dry periods. The main advantages are:

- losses from evaporation are much lower than those from an exposed water surface;
- the breeding of insects and parasites such as mosquitoes and bilharzia parasites is prevented;
- contamination of stored water, by people and animals, is greatly reduced, particularly as a well and hand pump are used to abstract water in a hygienic and controlled manner.

Large-scale subsurface dams can sustain water for small-scale irrigation in the dry season to generate income besides providing water for domestic use.

Essential factors for the success of small dams are the human factor (community participation and ownership), proper site selection and the use of low technology construction techniques and locally available materials. Successful involvement of the community and local labour is largely promoted by the provision of dedicated manuals and guidelines (figure 3).

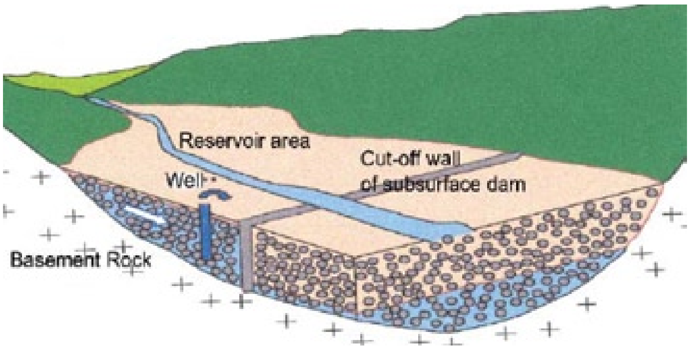


Figure 2. Conceptual diagram of a subsurface dam (Source: Vétérinaires sans Frontières, 2006)

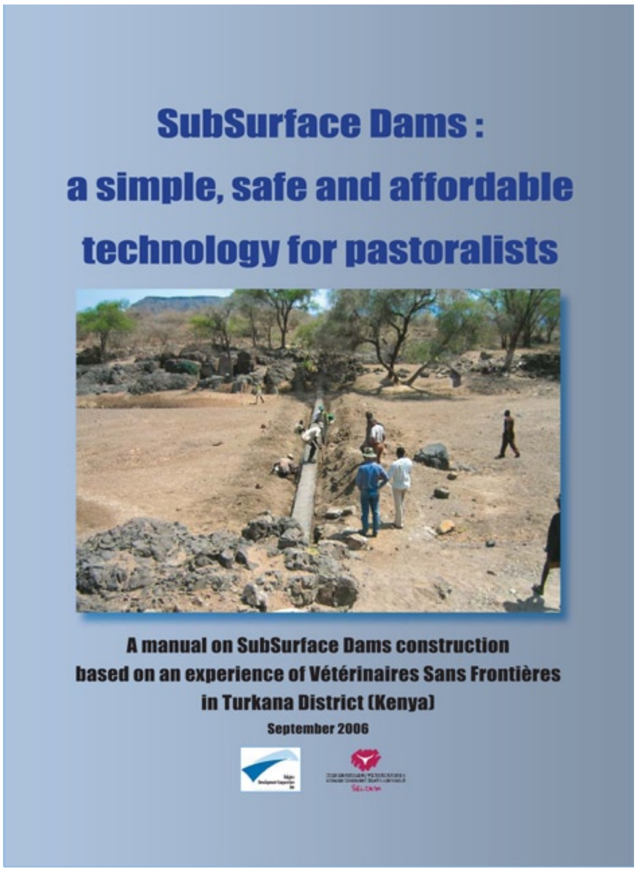


Figure 3. Example of a subsurface dam manual (Source: Vétérinaires sans Frontières, 2006)

References

GWMATE/World Bank (2004). Brazil, Kenya: Subsurface Dams to Augment Groundwater Storage in Basement Terrain for Human Subsistence GWMATE Case Profile series number 5 (www.worldbank.org/gwmate).

Vétérinaires sans Frontières / Belgium Development Cooperation (2006) Subsurface Dams a simple, safe and affordable technology (a manual for sub surface dam construction in Turkana District, Kenya).

7. Pulverised stone, a meal for plant and soil

Introduction

Rock dust is pulverized stone, often produced as by-product in the mining industry. It has no large scale application and as consequence is only stockpiled at mining sites. Agricultural usage of this dust is increasing however, due to its reduction of farmers costs and increase of yields.

Stone meal gains momentum due its beneficial spin-offs as compared to conventional marketed fertilizer. As multifunctional fertilizer it is able to supply, besides the macro nutrients (N, P and K) required for optimal crop growth, a range of micro-nutrients (e.g. S, Ca, Mg, B, Cl, Cu, Fe, Mn, Mo, Ni, Zn), while it also improves the physical, chemical and biological quality of the soil (Straaten, P. van. 2009). On the field level these effects have accumulated in multiple profits to the users, including an improved workability of the heavy clay soils (Ene and Okagbue, 2008), improved water retention and water holding capacity of the soil (sandy and clay soil) (Dumitru et al. 2001), increased (quality of) yields of the cultivated crops, higher farm benefit due to decreased application and purchase cost as regarded to conventional fertilizers. On a local and national level use of local available rock dust created employment opportunities, increasing GDP, while reducing import costs. This shift in focus leads in global level to reduced output of greenhouse gasses, through lower demand of conventional fertilizer will reduce production (+/- 1% of world energy use) and transport needs. Even mitigation of climate change is aimed, due to its capacity to directly sequestrate carbon and indirectly by stimulate tree growth, acting as carbon sinks.

Global occurrence

Evidence for the practice specifically accumulate in the lower economic developing countries on the African and South American Continent, where governments seek reduce expenditure on heavy subsidized fertilizer programs and farmers on their high input costs. One of the examples originates in Tanzania, where in 2008 a total of 30,000 tonnes of local available local rock phosphate were used in agriculture (Straaten, P. van, 2009). Large scale use of local available rock is further reported by van Straaten (2009): Sri Lanka uses 45,000 t/yr for tea, coconut and rubber plantations; Indonesia and Malaysia import over 2 million tonnes phosphate rock/year for use in the oil palm plantations; New Zealand imports 130 t/yr for application on the vast pastures; Mali and Burkina Faso mine smaller, but still considerable amounts of rocks at local level. Other examples on the global rise of rock dust applications include Mexico (Zacatecas), where government investigates suitability of different rocks to restore grasslands (Rubio et al. 2009). In Columbia a movement is rising on stimulation of stone meal use among small scale coffee farmers, in order to save their scarce financial resources (Mineralize.org). Other examples mentioned are Panama, where soil sites treated with basalt powder showed significant increased tree growth and Costa Rica, where jatropha production increased after soil rejuvenation with rock dust occurred as part of the Agroforestry project. Use of rock dust in Europe is large scale applied on forest soils (e.g. Black Forest, Baden-Württemberg and Odenwald) in order to increase pH on acidified soils (Sucker et al., 2009). It is estimated that for complete recovery 600,000 ha of forest of Baden-Württemberg needs annual application of 45 kg dolomite for the coming twenty years, accumulating at 60,000 ton dolomite at state level (Sucker et al. 2009, pp. 14). Further application of rock dust in Europe concerns addition of lime to acid inclining soils, like peat soils in the North of the Netherlands. Similar practices of crushed shell are reported from Japan and along the West Coast of the United States, where shells are also added in forests. Examples of usages of rock dust for other purposes are of smaller scale but numerous, such as an Austrian study indicated that of one fourth of the small scale farmers and home gardeners in Tirol used alternative soil additives such as lime, stone meal or turban (Vogl and Vogl-Lukasser, 2003). Further numerous individual initiatives are reported from Spain (one of two countries within EU, which have outlined guidelines for organic agriculture on national and district level) and UK (e.g. SEER Centre).

Cost and benefits

Costs

Farmers are able to save up 95% of the cost made under the conventional fertilizer regime.8

- Rock dust can be purchased at low price; crushed dunite (olivine), for example, costs in the order of a few tens of US$ per ton in the Rotterdam harbour.7

- Prices for conventional fertilizers are high, in the order of Urea (420 US$/t), Liquid Nitrogen (250 US$/ton), DAP (450 US$/t) and Potash (500 US$/t)9

Mining industry is open-minded for rock dust solutions, as it is currently only stockpiled

Benefits

Scientific and empirical evidence on the role of stone meal related to yields dates back from the sixties till present

Yield increase after rock dust application are widely mentioned in literature. One of the oldest studies is this of Arndt, W. and McIntyre, G.A. (1963) in which they studied the impact of rock and super phosphate application on sorghum yields, cultivated on clay loamy soil in Australia. Both fertilizer sources increased sorghum yield, with the yields response on the plots with rock fertilizer taking some longer if compared to the ready available superphosphate. More recent research include the five year experiment of Goreau et al. (2011) in which basalt powder accelerated tree growth and biomass on impoverished tropical soils in Panama. A more elaborated list of the impact of rock dust on yields is provided in table 1.

Table 1: Improved yields after rock dust application for various crops

Crop	Rock Type	Application rate (t/ha)	Yield response	Reference
Barley	W.M.F. Fertilizer (trade name)	n/a	Increased return of 172US/ha compared to conventional fertilizer	Western Minerals (2007)
Birdwood grass and legume	Rock Phosphate	5-10	Increased yield from 2.4 to 13.1 & 3.1 to 14.7 t/ha	Norman, M.J.T. (1965)
Clover	Granite powder	20g/kg soil	Increased resp. from 1482, 2280, 3798 to 390, 3682,	Coreonos et al. (1996)

			6746 mg/pot	
Clover	Basalt dust	0-40	Increased yield	Dumitru, I. et al. (1999)
Lettuce	Basalt dust and compost	n/a	Similar yield to completed organic fertilizer	University of Massachusetts (Mineral solutions, 2004)
Lupine	Granite	n/a	Increased yield with 1/20 of conventional fertilizer cost	Oldfied, B. (1997)
Maize	Rock dust	n/a	10% higher yield and 20-50% higher germination rate	Rodriguez, G. (ReMineralize.org)
Okra	Compost, Feldspar and Rock Phosphate	N, K and P: 45, 143, 143 K2O units/ha)	Rock fertilizer 6.9-7.9 ton/ha; control and NPK resp. 3.6 and 6.7t/ha	Abdel-Mouty and El-Greadl (2008)
Olive and orchards	Basalt crusher dust	n/a	Increased tree growth and health	Olives' Australia (Mineral Solutions, 2004)
Onions	Feldspar (Ksp.)	114, 228 and 342 K2O units/ha	Feldspar yields resp. 20.3, 22.5 and 27.8 t/ha Chemical yields resp. 18.5, 27.8 and 34.2 t/ha	Ali and Taalab (2008)
Radish	Basalt rock	0-20 t/ha	Up to 50% increase in dry weight	Dumitru, I. et al. (1999)
Rice	Phlogopite mica, feldspar,	Resp. 0.2, 0.5 t/ha	Resp. 93.3 and 69.8 g/pot vs 41.1 control pot	Weerasuriya et al. (1993)
Ryegrass	Granite powder	20g/kg soil	Increased resp. from 2099, 3749, 3641 to 3234, 4894, 3990 mg/pot	Coreonos et al. (1996)
Sorghum	Rock phosphate	5, 10 and 25 t/ha	0.9, 1.3 and 1.4 t/ha vs. 0.7 t/ha control plot	Arndt and McIntyre (1963)
Sugar Cane	Basaltic rock	10-90 t/ha	Increased yield following years	D'Hotman de Villiers (1961)
Tomatoes	Feldspar powder and compost (+bacteria)	0,120,240 and 360 kg K/ha	Yields 27.1, 42.3, 51.7, 58.8 t/ha vs. only compost yields of resp. 27.2, 30.9, 34.2 and 32.3 t/ha	Badr (2006)
Tomatoes	Basalt	0-40 t/ha	Increased yield	Dumitru, I. et al. (1999)
Trees (Not specified)	Granite	15-20 t/ha	Five times faster growth	Oldfield, B. (1996)
Tree growth	Basalt powder	n/a	Length 14m vs. 6 local soil; Biomass 47kg/tree vs. 6kg/tree local soil	Goreau, T.J.. et al (2011)
Wheat	Stonemeal, with lupine as green manure	7 years, 440 kg/ha	15% higher yield than conventional fertilizer, resp. 9,076 vs 7,891 t/ha	Jost and Samobor
Wheat	Rock dust	2 years, 250 kg/ha (lupine as	Wheat yield of 2.2 t/ha without pesticide and conventional fertilizer	Oldfield, B. (1997)

		green manure)	application	
Wheat	Volcano dust	After eruption	Increased yield	Fyfe et al. (2006)

References

References

Able, R.J. (1997). Update on remineralization studies

Arndt, W. and McIntyre, G.A. (1963). The initial and residual effects of superphosphate and rock phosphate for sorghum on a lateritic red earth. Australian Journal Agricultural Research 91963), Volume 14, pp 785-795

Barral Silva, M.T.; Silva Hermo, B,; Garcia-Rodeja, E. and Vazquez Freire (2005). Reutilization of granite powder as an amendment and fertilizer for acid soils. Chemosphere 61 (2005), pp. 993-1002

Coroneos, C.; Hinsinger, P. and Gilkes, R.J. (1996). Granite powder as a source of potassium for plants: A glasshouse bioassay comparing two pasture species. Fertilizer Research 45, pp. 143-52

Ene, E. and Okagbue, C. (2009). Some Basic geotechnical properties of expansive soil modified using pyroclastic dust. Engineering Globally 107 (2009), pp. 61-65

European Patent Office. European Patent Application, Bulletin 2009/13, March 25, 2009. Artificial turf assembly. Domo Zele NV (Applicant), Clerq de, J. (Inventor)

Goreau, T.J. et al. (2011). Basalt powder restore oil fertility and greatl accelerates tree growth on impoverished tropica soils in Panama. Presentation held at Syposium on Soil Ecology and Restoration August 22nd 2011

Fyfe, W.S.; Leonardos, O.H. and Theaodoro, S.H. (2006). Sustainable farming with native rocks: the transition without revolution. Anais da Academia Brasileira de Ciencias (2006), Volume 78, Issue 4, pp. 75-720

Gillman, G.P.; Burkett, D.C. and Coventry, R.J. (2002). Amending highly weathered soils with finely ground basalt rock. Applied Geochamistry 17 (2002), pp. 987-1001

Humphrys, C. and Jossi, W. (2009). Control of ppollen beetle n orgnic farming ith pant protecting agets. Pflanzengesunfheit: Insektenreguliering: oster

Mineral Solutions (2004). Exploitation and use of quarry Fines. Report Number 087/MIST2/DACM/01; MIST project reference: MA/2/4/003

Norman, M.J.T. (1965). The response of a birdwood grass – Townsville Lucerne pasture to phosphate fertilizer at Katherine, N.T. Australian Journal of Experimental Agriculture and Animal Husbandry, Volume 5, May 1965

Okagbue, C.O., Onyeobi, T.U.S., 1999. Potential of marble dust to stabilize red tropical soil for road construction. Engineering Geology 53, 371–382.

Rubio, A.F.A.; Echavarria, Ch. F.G. and Reumayor, R.A.F. (2009). Chemical study of mineral elements in rocks to improve degrade soil in Zacatecas. Presented at VI Symposio Internacional de Pastiales, November 4-7 2009

Samobor, V.; Horvat, D.; Kesteli, B. and Jost, M. (2008). Effect of stone meal on control of seed-borne diseases in wheat. Agronomski Glasnik, Volume 6, 2008. Presented at 2nd Mediterranean Conference on Organic Agriculture, Dubrovnik, April 2-4, 2008

Straaten, P. van (2009). Rocks for Crops: Use of alternative rocks and minerals for food, feed and bio fuel crop production in the world.

Vogl, C.R. and Vogl-Lukasser, B. (2003). Tradition, Dynamics and Sustainability of Plant Species Composition and Management in homegardens on Organic and Non-Organic Small Scale Farms in Alpine Eastern Tyrol, Austria. Biological Agriculture and Horticulture (2003), Volume 21, pp. 349-366

Weerasuriya, T.J.; Pushpakumara, S. and Cooray, P.I. (1993). Acidulated pegmatitic mica: A promising new multi-nutrient mineral fertilizer. Fertilizer Research 34: pp. 67-77

8. High altitude surface water retention dams, Ocoña Basin, Peru

Introduction

Climate change can trigger the development of new approaches in water management. Retention of stormwater runoff will augment water availability throughout the year and improve living conditions. In regions with a distinct dry season, the retention of stormwater runoff during the wet season can make a big difference to local agriculture and the livelihoods of the rural population. An important element is safeguarding the interests of land and water users in the entire basin.

Description

In high-altitude catchments in the Ocoña Basin of Peru, streamflow is intensively exploited and no other water resources are available in the dry season. Here medium-scale retention dams located high in the catchment area are used to increase water availability throughout the year for local agriculture.

The Ocoña River Basin lies in the Southwestern Andes in southern Peru, and forms a fertile barrier between the Sechura and Atacama Deserts. The uppermost limits of the catchment basins are delineated by the Huanzo mountain range, containing a number of high-altitude glaciers, including the Coropuna (6445 m), Solimana (6095 m) and Firura (5500 m). The population of the Ocoña River Basin is approximately 70,000 people, mostly living in poverty or extreme poverty (less than $2/day or $1.25/day, WB - International Comparison Program 2008). In several high-altitude catchments such as Arma-Chichas and Churunga, farming activities are sustained by irrigation systems that use meltwater complemented by rainwater. Groundwater resources are inadequate or currently unexploited.

According to the Tyndall Centre for Climate Change Research, Peru will be one of the three countries hardest hit by climate change because of the country's high dependence on glaciers as a source of water. The most important effect of climate change in the Ocoña River Basin is retreat of glaciers. The consequent reduction in baseflow during the dry season severely affects the agricultural potential of the area. Stormwater runoff during the wet season and excess baseflow can be retained by dams placed at strategic locations in the catchment. The stored water can subsequently be used in the dry season to supplement the irrigation water supply in the region.

Figure 1. A retention dam at Lago Palcacocha, near the Coropuna Glacier

Techniques used

The Ocoña River Basin contains three sub-basins. User commissions are active in each sub-basin, with the exception of the Arma sub-basin which has an irrigation commission coordinator. These commissions have formed the Platform for Integral Water Management for the Ocoña Basin,which aims to coordinate the integrated management of the water resources in the basin.

The user commissions coordinate actions to create surface water storage in order to increase availability of water resources during the dry season. The medium-sized Palcacocha dam has been constructed at the Churunga catchment close to the Coropuna Glacier. Behind the dam an artificial lake has formed and water from this lake can be released into a stream leading to an intake point for the three major irrigation systems of this sub-catchment.

A bigger storage dam has been planned for construction in the upper part of Arma River in the Arma-Chichas sub-catchment (project Arma). Water from this dam will be guided by gravity through a series of canals to a nearby sub-catchment for agricultural purposes. Because of the high elevation of the dams, evaporation is relatively low.

Impact

Although impacts of the Palcacocha dam are yet to be thoroughly evaluated, stormwater runoff already collects in the dam, from which subsequently throughout the year the irrigation systems in the catchment are fed. It is strongly suspected that the lake behind the dam recharges groundwater as well.

Water availability throughout the year for irrigated agriculture in the Ocoña Basin is being severely threatened by glacial retreat due to climate change and the subsequent diminishing baseflow. By capturing and retaining excess water resources high in the catchment through the construction of dams, water can be distributed more evenly throughout the year and the region.

The integrated approach in the Ocoña Basin ensures that all activities aiming to improve water availability in the Basin are carefully coordinated. It also safeguards sustainable water use for all upstream users without creating negative side effects or compromising downstream users.

References

ADAPTS (2008). Desk study Ocoña Basin. ADAPTS (2009). Mission report Churunga and Arma-Chichas catchments. AEDES (2005). Population and Livelihood Census. Tyndall Centre for Climate Change Research (www.tyndall.ac.uk)

9. Harvesting rain in dry areas, Sub-Saharan Africa

Many areas in Sub-Saharan Africa such as Burkina Faso, Mali and Senegal are severely affected by water shortages. Often groundwater is polluted (due to geological layers) or too deep to be a feasible water supply. Women and children in particular invest many hours per day in fetching water, walking long distances and/or queuing in line at boreholes, which often have limited capacity, are depleting or are even non-functioning. This reduces their time for agricultural, economical, educational and social activities. In some areas people do not have access to boreholes and collect water in the traditional way, i.e. from an open pond, which is usually also used by their cattle.

Health problems due to limited and contaminated water affect many people all over the world, not to mention the burden of fetching this water. A general misperception is that most areas in Sub-Saharan Africa receive very little rainfall, while in fact annual rainfall can be sufficient to cover the annual water demand. The challenge lies in how to substantiate the long dry season based on short and intense rainfall periods when most of the water is lost through runoff. If the rain could be stored, sufficient water would be available for drinking water, and many other uses such as livestock, agriculture and other sustainable activities.

The potential of rainwater harvesting

In areas where other water sources are not available or unreliable, rainwater harvesting can provide a simple and effective option for safe and sufficient water supply. An example of the potential of rainwater harvesting at household level is given in the box below.

Rainwater harvesting can provide sufficient water, especially in areas where little or no water sources are available, and reduces pressure on groundwater resources. The family living in Tonka will not only benefit from the water itself, but also from the fact that it is available at their doorstep, thus reduces time and the daily burden of fetching water. Especially women and girls would have time to spend on other activities, such as women's groups or school. The calculation given is for one household only, while there are also families living in larger compounds, which increases roof size and therefore rainwater harvesting potential.

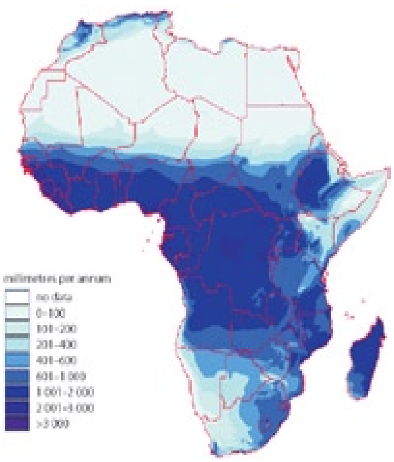


Figure 1. Annual total rainfall in Africa (Source: UNEP)

In the village of Tonka in the Koulikoro Region, Mali, a household of 10 family members spends three to four hours per day to fetch water from a distant borehole, which is often not functioning due to groundwater depletion. They mostly use water from an open pond formed during the rainy season, which is also used by animals. What could this family gain from harvesting rainwater?

Annual rainfall is approximately 650 mm per year (rainfall period between May and October) and their roof area is approximately 30 m^2.

Rainwater harvesting potential = 0.8* x (30 m2 x 650 mm)/1000 = 15.600 litres per year

With an average dry season of seven months, 15.600/ (7 x 30) = 74 litres of water are available per day. The family consists of 10 people, which means that each family member could have 7.4 litres of water per day from rainwater harvesting.

Studies have shown that rainwater collected from corrugated iron roofs, are very applicable for drinking if operation, management and maintenance is carried out. If water is needed for other purposes, like livestock breeding, kitchen usage and gardening, water quality is not much of issue. In this case the family could have a rainwater harvesting tank for drinking and an additional pond for catching surface runoff for other purposes.

* here the runoff coefficient of a corrugated iron roof is approximately 80%, taking into account 20% water loss.

Roof area = 30 m^2 Annual rainfall = 650 mm Household size = 10 people

Water per person during 7 months dry period = 7,4 litres per day

Figure 2 and 3. Beneficiaries in front of their tank and drinking the water in the village of Sébi Kotane, Senegal

Keep it simple!

Rainwater harvesting systems are decentralized, meaning they are fully managed and operated at household level, providing people with great independence. Households are responsible for maintaining, managing and conserving their own water source. As people invest in their own system, through cash, materials and/or labour, the sense of local ownership is high, which increases sustainability of the system. There are many ways to store water at different scales. Roof water harvesting at household level is one option that delivers water at the doorstep.

Roof water harvesting systems are simple and straightforward: the rainwater is collected on a (preferably corrugated iron) roof and led through a gutter- and filter-system into a storage system or infiltrated into the groundwater for recharge. If the water is used for drinking purposes, the piping system towards the storage system is equipped with first flush and filters, to prevent contamination (like dirt or debris from the roof) from entering the storage system. A first flush system helps to divert the first millimetres containing most potential contamination. Studies have shown that a properly operated and maintained first flush is often sufficient to provide water of potable quality. In the storage facility, it is important that no light enters the system, because this could lead to bacterial growth. It should also be protected from people and animals entering the system. Water stored in a closed system is known to enhance bacteria die-off, improving water quality.

Rainwater harvesting can also be used for irrigation, livestock and groundwater recharge. High water quality standards are not applicable for these uses, and other (and often cheaper) techniques can be employed. Depending on the water needs and the rainwater harvesting potential, an integrated plan can be made for the optimal use of rainwater.

Some results and impacts of roof water harvesting

- water source at the doorstep;
- better quality and quantity of water compared to existing sources;
- higher school attendance by children, especially girls, due to time saved in fetching water. Children are also more healthy and able to participate in classes due to the availability of safe and sufficient water;
- more time for agricultural, economical, educational and social activities, not only through saving time in water fetching, but also as there are less occurrences of water-related diseases, especially amongst children.

Collect, store and use

There is a huge potential for rainwater harvesting in Sub-Saharan Africa, especially in areas where other water sources are insufficient, unavailable and/or unreliable. The only task is to collect the rainwater, store and use it. The challenges are to upscale the successes already achieved, to provide low-cost and durable storage options and to reach out to people who still depend on unreliable water sources.

References

RAIN Foundation - www.rainfoundation.org

10. Multiple aspects of rainwater, Nepal

Nepal is rich in water resources however access to water is not always ensured. Particularly rural communities living in mountainous regions tend to suffer from water scarcity due to the difficult terrain. Women and children invest many hours per day in fetching water, mainly from natural springs located downhill, which tend to recede more downwards during the dry period. Next to their domestic water needs, small-scale agriculture, kitchen gardening and livestock are other water consuming activities, which mostly depend on water availability during the rainy season. These activities are suffering from the lack of winter rains over the past couple of years in Nepal.

Another factor controlling livelihood standards in rural Nepal is the use of fuel wood for cooking and heating, which leads to serious health problems due to the air pollution in houses. The demand for fuel wood and the reduced water resources have both led to a decrease of forest areas in Nepal. Next to this, the collection of fire wood is another time consuming activity, again mainly for women and children.

For many areas in Nepal, especially in upper hill areas, rainwater harvesting is the only feasible option for having sufficient water supply, since piped water supply is extremely expensive in this type of terrain. Many NGOs in Nepal have become aware of the potential for rainwater harvesting and, although there was some initial hesitation to use rainwater as drinking water, projects have been implemented on a large scale. Roof water harvesting is most common in Nepal.

BSP-Nepal, an NGO, in collaboration with SNV- Netherlands Development Organization, initiated and implemented biogas plants at the household level by using animal dung and human faeces to produce biogas. This programme effectively improved health standards and reduced deforestation, since wood was no longer used for cooking. Significant time was saved for women who no longer had to collect firewood (not to mention the burden of carrying firewood to their house in this mountainous terrain). The biogas programme has led to the successful implementation of more than 205,000 biogas plants in 75 districts and the training of more than 60 construction companies in constructing biogas plants and rainwater harvesting systems. The success of the programme was commercializing the implementation of biogas plants, through cooperating with private construction companies in Nepal and setting up an attractive financial model. This model consists of 30% Government subsidy, 60% user’s loan through Micro-Finance Institutes and 10% direct user contribution in cash and kind.

Figure 1. Rainwater harvesting tanks in Bubeyrakhe, Nepal

Owner of a 14 m^3 rainwater harvesting tank and a 6 m3 biogas tank in Sarangkot, Palpa district, Nepal

When BSP-Nepal addressed my household for taking part in a project with biogas and rainwater harvesting, I immediately saw their potential. Since BSP-Nepal could only assist in financing a

6.5 m^3 tank, my family financed the remaining money to have a larger 14 m^3 tank. The water is used to operate the biogas tank and my wife can now cook on a gas stove! I have also made this greenhouse for tomatoes, which we use for our own consumption and also sell at the nearby market. I am now saving money to have another rainwater harvesting tank, so that I can expand my production and increase the family income.

Figure 2. Owner of a rainwater harvesting tank and a biogas tank in Sarangkot, Palpa district, Nepal

However, to operate the biogas plant, water is needed, which is scarce or hard to procure in mountainous areas. Currently, BSP-Nepal is combining biogas plants with rainwater harvesting tanks in areas where other sources of water are not feasible, making water available for biogas production, drinking (and other small domestic uses) and irrigation. The construction companies receive intensive training on the implementation of rainwater harvesting tanks (mostly 6.5 to 10 m3 tanks) and their work is regularly monitored and evaluated. In order to make rainwater harvesting a more financially-attractive solution for the poor rural populations, BSP-Nepal is currently looking into micro-finance options for rainwater harvesting as well.

The Swiss INGO Helvetas is implementing rainwater harvesting systems in three regions of Nepal. Their projects depict the combination of sanitation with water supply through rainwater harvesting. People with access to improved sanitation are still limited, especially in rural areas of Nepal. To address this, Helvetas combined the water supply projects with sanitation.

To come towards a more integrated approach of water resources management, Helvetas Nepal has developed a so-called Water Resources Management Programme (WARM-P), which is based on 30 years of experiences in water and sanitation, to address source conflict, water supply and its multiple uses and management at the village level. Due to the fact that existing water sources are often over-exploited and not well-managed within and between communities, Helvetas felt the need to facilitate communities to organise and prepare water resources management plans for multiple uses of water at the village level. Hence, WARM-P not only supports communities in water supply and sanitation, but also in preparing and implementing a Water Use Master Plan (WUMP) by the communities. The WUMP is a tool in guiding an integrated plan, and mapping all available and potential water resources in an area. The WUMP has a strong social and technical component, based both on the needs and on the local circumstances of a village as well as the physical factors controlling available water resources for its maximum uses. Rainwater harvesting is one of the options for water supply in WUMP and WUMP can therefore be seen as a first step towards Integrated Water Resources Management at the village level.

Ganga Chand

Owner of a 6.5 m3 rainwater harvesting tank in Bubeyrakhe, Dailek district, Nepal

First I had to walk many times a day up and down the hill to fetch water from the spring with a large can. Now I only need to just go outside of my house and fetch the amount I need from my own tank. I am very proud and happy. My husband is now working as a paid mason in a rainwater harvesting project of Helvetas Nepal in a nearby village, since he was trained in constructing rainwater tanks during the construction of tanks in our village. The rainwater harvesting tanks have changed a lot for me and my family.

The demand for rainwater harvesting systems is growing due to the successes achieved by NGOs all over the country. Since the beginning of 2009, the Nepalese Government has recognized rainwater as being an important source of water for domestic and productive use as well for groundwater recharge.

References

BSP-Nepal - www.bspnepal.org.np Helvetas-Nepal - www.helvetasnepal.org.np RAIN Foundation - www.rainfoundation.org

11. Conjunctive use of groundwater and surface water in large-scale irrigation, Morocco

In many large-scale irrigation systems there is now 'a conjunctive reality' where a large – and sometimes even the main – portion of the water at the farm gate comes from groundwater and not from direct surface supplies. There is a high density of wells in the surface irrigation systems, largely fed by seepage water, which is subsequently used and reused – an example of extending the water chain.

Description

In conjunctive systems water is used from surface supplies and from groundwater management. In many of India's mega-irrigation systems the larger part of the water comes from such shallow wells (Shah, 2009). The same is the case for Pakistan (Van Steenbergen, 2007). A telling example of how the intense use of the groundwater buffer made it possible to live comfortably through a period can be seen in the drought in Pakistan in the period 1999–2003. During this period the outflow from the main reservoirs dipped by 20%. However, contrary to what one might expect, there was no reduction in agricultural production but a modest increase. The explanation is the more intense use of groundwater – in the Punjab Province increasing from 42% to over 50% of farm supplies. In the Sindh Province many new wells were developed and, as a result, a huge waterlogged area disappeared. Whereas this area stood at 2.2 million ha, it was reduced to less than 0.5 million ha after three years of drought. The conjunctive use of surface and groundwater in large-scale irrigation systems not only made it possible to survive the drought, but also set the scene for a far more productive resource management system. Intriguingly climate variation triggered better resource use and higher productivity.

The Tadla system in Morocco is another example of a conjunctive irrigation system. The Tadla irrigation scheme is located 200 km south-east of Casablanca in Morocco. It covers an irrigated area of about 100,000 ha and is managed by the regional agricultural development authority of the Tadla (ORMVAT). Annually, between 323 (2001/02) and 1003 million m3 (1991/92) of surface water is diverted to the scheme. The Tadla irrigation scheme is an important producer of agricultural commodities at a national scale, including milk and meat. Groundwater use in Tadla took off after 1980, when cropping patterns were liberalized. Earlier crop choices, input supply and marketing were controlled by the state irrigation agencies and cropping was homogeneous. Under the new regime farmers were allowed to choose their own crops. The irrigation supplies by the ORMVA irrigation agencies were more demand driven yet at times of drought many restrictions were enforced. It was however the access to groundwater that made it possible to have a diversified system also

Figure 1. Using groundwater and surface water for irrigation purposes in Morocco

able to shift to higher value farming systems and introduce new horticular crops. Another prime example is the upsurge in dairy farming based on the cultivation of alfalfa, which has the highest water productivity of all. Intriguingly, as water productivity increased, the area under cultivation also expanded. Surface water resources in Tadla decreased under reduced rainfall, particularly in the period 1980–1992. The quality of surface irrigation was also under pressure: the capacity of reservoirs was reduced under the impact of sedimentation, canal networks were getting old and inefficient irrigation techniques lead to important loss of water resources.

Techniques used

Irrigated agriculture in the Tadla plains is now characterized by a conjunctive use environment. Farmers increasingly use groundwater resources in addition to available surface water resources. There are between 8,000 and 10,000 wells in the surface irrigation areas, with a well having a typical discharge of 15 l/s. In the zone outside the irrigated perimeter there are also more than 4,500 pumping locations, of which more than 1,300 wells pump from the Eocene aquifer (Hammani, 2007). Pumping levels vary widely between years due to the large variations in rainfall, but are estimated in the order of 140 Mm3 – or 15% to 50% of total farm gate water delivery. All this signifies the importance of the groundwater buffer both for increased production and for drought mitigation. There are some drawbacks with respect to the conjunctive system. Firstly, there is concern that groundwater use may have exceeded sustainable supply. Water used to be pumped from shallow depth consisting mainly of accumulated leakage from the surface irrigation system, but now increasingly the deeper Eocene aquifer is tapped. Secondly, there are equity issues. There is a bias in ownership: particularly larger farmers have a well of their own, and other farmers access additional water by buying it from well owners or from unsanctioned surface irrigation supplies. Thirdly, groundwater governance is altogether missing. Quite typically groundwater pumping is only possible with official authorization, but almost all farmers install their well without a permit. Current unenforced regulation creates a vacuum and a blind spot in policy implementation.

The conjunctive reality of Tadla represents many large-scale irrigation systems. The use of the groundwater buffer underneath the surface irrigation systems has ended drainage problems and has facilitated a move to higher value agriculture. It has helped overcome dry periods, dry spells as well as shortcomings in the irrigation infrastructure.

Although conjunctive use is commonplace, conjunctive management is not. There is much to gain by improvements in dovetailing surface irrigation supplies and buffer management, for example:

- In planning new surface irrigation systems, the condition of the aquifer underneath should be taken into account. Buffer characteristics have a large impact on the scope and ease of reuse of seepage water and hence the overall efficiency of the system and ability to deal with droughts;
- In general the high efficiency, productivity and resilience of conjunctive systems should be appreciated. Sometimes water is diverted from well-functioning conjunctive systems to new areas – where the scope for reuse is less and, as a result, the irrigation supplies are used only once and then effectively lost;
- In large irrigation systems, surface water distribution should be dovetailed with groundwater use. In parts of the command area where there is intense use, surface water irrigation duties could be increased to maintain the ideal balance between recharge and reuse of shallow groundwater. In other areas where the scope for conjunctive use is less - for instance in areas with saline groundwater – irrigation duties could be decreased;
- In areas with saline groundwater it may make sense to curtail surface supplies and invest in drainage for another reason. Avoiding oversupplies of surface irrigation water (as is currently the case in some systems) will create more storage space in the upper layers. This will allow for the formation of a sweet/ brackish water lens, fed by seepage and rainfall, which could then serve as a source of drinking water. Though far from perfect, such sources are much better than using highly-polluted surface irrigation water, as is now the reality in several such systems;
- Special measures can be considered to increase the recharge of the groundwater buffer in large-scale irrigation systems. High monsoon flows in the river can be partly routed through irrigation and drainage canals so as to replenish the groundwater buffer;
- In conjunctive management more attention is required for water quality. The intense and repeated use of water will affect the water quality and care should be taken that salinity and pollution loads remain limited.

References

El Haouari, N. and F. van Steenbergen. (2009). The blind spot in water governance: conjunctive groundwater use in MENA countries. Paper at 11th Mediterranean Meeting, RCSAS, Montecatini, 26-28 March 2009.

Gohar, S. and F. van Steenbergen. (2007). Groundwater Management in Pakistan. In: John Briscoe, Pakistan's Water Economy. Annex 12. Karachi: Oxford University Press

Hammani, A., Kuper, M., Bouarfa, S., Debbarh, A., Badraoui, M. and Bellouti, A. (2004). Evolution de l'utilisation conjointe des eaux de surface et des eaux souterraines dans le périmètre irrigué du Tadla (Maroc). INCO-Wademed Seminar, 19–21 April 2004, Rabat.

Kuper M., Le Gal P.Y., Sraïri M.T., Moulin C.H. and L. Puillet (2005). Increasing irrigation water productivity through supply chain management of agro food products: the case of dairy farming in the Tadla irrigation scheme (Morocco). In: M.S. Bachta (ed.) Les instruments économiques et la modernisation des périmètres irrigués.. Actes du Séminaire Euro Méditerranéen. 21-22 novembre 2005, Sousse, Tunisie.

Shah, T. (2009). Taming the anarchy: groundwater governance in South Asia. Washington: RFF Press.

12. Tal Ya trays

An innovative technology has been developed that conjugate in the same product the advantages of mulching, dew and runoff collection. Tal-ya, an Israeli based company, introduced in the market these Polypropylene trays that have promising features. These squared, 55x72cm hard-plastic trays have a concave shape and a white colour. Due to the closed environment that is created when the trays are placed around the stem at the base of a plant, a controlled microclimate is created. The temperature is more stable, the evaporation is under control and the weeds growth is constrained. With these characteristics the trays have a similar effect to plastic mulching, but the positive effects don't stop here. In fact, the special shape of the trays concentrate the dew that is present even in the more arid areas and convey it directly to the roots of the plant. Additionally when it rains the trays convey the water straight to the roots zone.

Use

The trays are put in place together with the plants. Both annual plants and perennial species can be used with this technology. In the former case, the trays have to be placed every year at the beginning of the growing season, while when used with trees the structure is left in place for up to 10 years. The maintenance is minimal and when worn they can be safely disposed because made of recyclable plastic. It can be coupled with several dry farming techniques such as brackish water irrigation and drip irrigation. Thanks to the reduced evaporation, salts present in brackish water do not surface because capillarity suction is heavily reduced. Furthermore, the localized dew conveyance helps to wash down the salts.

Cost

The ex work price is 2 $. The investment is paid back after 1-2 years.

Benefits

The manufacturer claims the trays as miraculous. The water savings are maximized thanks to the multiple action of the tray. ET is drastically reduced, competition with weeds is absent and extra water is gained from dew. All together these aspects lead to a 50 % saving on water needed to irrigate. Due to the diminished and localized application of water the nutrients are washed away from the soil to a smaller extent and bring a saving of 50% on fertilizers. In addition the favourable conditions in the root zone favours the development of the roots, symbiotic bacteria and fungi for a better nutrients uptake and improved growth. The plants give an early harvest and they are also partially protected from damages due to fast temperature drops.

References

Tal-Ya water technologies ltd. (2011). Advantages of the use of Tal Ya trays in the agricutlural system.

Kafkafi, U. (2009). Low root temperature influence on water uptake. The Robert H Smith Institute Of Plant Sciences And Genetics In Agriculture, 1–4.

13. Re-greening - improved indigenous soil and moisture conservation, Niger and Burkina Faso

Introduction

For long the Sahel remained a by-word for resource degradation and destitution. In the devastating drought of 1969-1973 many lives were lost and livelihoods destroyed: trees and livestock died, water levels dropped and yields for staple crops such as sorghum and millet declined. At desert fringes sand dunes expanded. Areas with high population pressure – such as Niger and Burkina Faso – were particularly hard-hit.

From the 1980's onwards however the Sahel has also been the scene of a transformation. Sahelian farmers themselves have steadily turned some of the world's most arid lands into productive farmland – aided by a period of reasonable rainfall. In Burkina Faso and Niger farmers applied traditional systems of agroforestry, water harvesting and soil management, modified them to suit the changing circumstances and applied them at scale. In Burkina Faso an estimated 200,000 to 300,000 hectares were re-invigorated by farmers developing zaï planting pits and stone bunds – yielding an extra 80,000 ton of food annually – enough to feed 500,000 people. In Niger 5,000,000 hectares were rehabilitated with improved agroforestry systems – making use of the dormant root systems. This has added an estimated 20% to the income of 4 Million people.

The scale at which these changes emerged and the process of innovation and adaptation dispels the notion that prospects for arid, land-locked areas are small and that investing in them does not pay. To the contrary the experience in Niger and Burkina Faso is the basis for Africa Regreening Initiatives elsewhere in the continent. Building on the farmer-led transformation the idea of a 'Green Wall for the Sahara' was also proposed by former Nigerian president Olusegun Obasanjo and presented to the Community of Sahel-Saharan States and to the African Union. The African Union

– European Union adopted action plan includes a priority to cooperate to address land degradation and increasing aridity, including the "Green Wall for the Sahara Initiative" as part of regreening the Sahel.

Techniques

The techniques used in the regreening of the Sahel were not new – but they were improved upon and modified to suit current challenges. Most of the experimentation and dissemination was farmer-led. An iconal personality for instance is a Burkinabe farmer called Yacouba Sawadogo who began organizing farm visits and semi-annual market days to promote planting pits. Yacouba also operate a seed exchange. Farmers brought samples of the crop varieties they cultivated in their zaï, deposited the seeds with Yacouba and then with his advise selected the seeds they wanted to plant that season. In the words of a leading soil scientist: 'Yacouba had more impact than all soil and water researchers combined'. Another example is the farmer starting a zaï school – training fellow farmers in the zaï technique on a gravelly area next to the road. This grew to a network of 20 schools with 1000 members – each group charged with improving its own piece of degradated land. The process was also supported by governments and NGOs. For the development of the specific compost pits training sites were established for instance, that included a hectare of cultivated land to visually convince trainees. Depending on the extent of the support programme the trainees would be able to take home compost and build and apply it to their own pilot plots. Particularly in Burkina Faso women's groups became an explicit feature of the development wide acceptance of zaï compost farming. Earlier large scale projects set up shortly after the drought emergencies had misfired – as they failed to engage the land users.

Figure 1. Zaï pits, Burkina Faso

Zaï

Planting pits known as zaï consists of 'mini-basins' that store rainwater for plant growth and concentrate crop nutrients. Planting pits are excavated in grids. Planting pits of around 20 cm in diameter and 10-15 cm in depth may come in at 10,000-15,000 pits per hectare. Their dimension and density vary from area to area – depending on the crop grown, the soil conditions (they do not do well on hydroscopic soils for instance) and the need to harvest water. Larger pits and more spacing between them for instance allow more water to be harvested. The innovation developed through farmers experiments in Burkina Faso was to increase the depth and diameter of the pits and to add manure to them. Once excavated, the pits capture other material – for instance wind-blown soil and leaves. Termites are attracted to the organic material in the pits. They form an army of 'soil engineers': digging small tunnels that improve the soil structure and cause water infiltration to double, and converting organic material and making nutrients available to the plant roots. The pits with the organic material will retain water in dry spells, allowing crops to survive. Sorghum is the preferred crop because of its adaptation to temporary inundation that may occur in the planting pit. Zaï are well combined with stone contour bunds. These reduce the speed of runoff and allow even more retention of water and soil.

Stone contour bunds

Stone contour bunds had been in use in Burkina Faso traditionally too, but the challenge was always to follow the contour lines, especially where the landscape is flat. Following the introduction of a low-cost water spirit for measuring land levels it became much easier to determine the correct alignment of stone bunds. Mastering the skill of using the level did not take more than two days. The better aligned stone bunds allow runoff to spread effectively and evenly through the field and trickle through the small opening between the stones. The practice improved soil condition by trapping sediments and organic matter within the plots and not allowing these to wash away with the rain.

Modified traditional agroforestry

At the same time in Niger farmers developed innovative ways of regenerating and multiplying valuable trees whose roots have been lying dormant underneath their land. Based on their experience in managing local woodlands, farmers starting experimenting with a process which became known as farmer managed natural regeneration (FMNR). Among the mature root systems in the field farmers would choose tree stumps based on the usefulness of the species. The tallest and straightest stems would then be selected, nurtured and protected. At the same time other stems would be removed.

Figure 2. Stone bunds with Sorghum, Burkina Faso

To further promote their growth and production the selected stems would be pruned whilst continuously other stems would be removed. The removal of stems enabled the growing of other crops between and around trees creating an ingeniously modified agroforestry system. The trees generate a number of important benefits. They improve the local micro-climate: they reduce wind speeds and evaporation – reducing the impact of drought and heat. The trees also provide fodder for livestock (enough for half of the year). They provide fruits, firewood and medicinal products. Some species add nitrogen to the soil.

Costs and benefits

The benefits in terms of food security and farm productivity have been substantial. They explain the speed with which innovations have spread from farmer to farmer. Most of the improvements are done by farm labour in the off-season. Though these labour inputs are substantial, there are no opportunity cost for them. This was in itself an innovation – as traditionally work on zais was unheard off in the dry season.

Zaï and contour bunds

Establishing zaï structures consists of two main activities namely the digging of the pits at the beginning of the dry season; and covering of the bottom of each pit with 3cm clay layer. Zaï pits or planting pits1) come in different sizes and density (pits / ha), and therefore the amount of labour and costs also vary. Where zaï is combined with stone contour bunds, these also need to be constructed. Below are typical ranges of costs for the establishment and maintenance – including the replenishment of manure – of the pits and bunds.

Without these measures productivity is extremely low: 80 kg of sorghum/ha. Zaï and stone bunds can raise yields to 300 to 400 kg/ha in a year of low rainfall to up to 1500 kg/ha in a good year. Experiments show that it is particular the concentration of nutrients that makes the difference.

Further spin-offs of the new zaï systems include the development of market in manure. Cattle grazes after harvesting. Herders have started to systematically collect the manure for sale since an increase in demand has led to a doubling of the price.

Zai and contour bunds: establishment input and costs per ha	
Input	Cost (USD)
Labour 2 – 150 days for pits 25 person days for stone bunds	27 - 175
Equipment and tools: hoe, knife, digging stick bucket, lorry	50
Materials: clay (0.5 m^3)	0
TOTAL	77 - 175

Table 1. Establishment costs and recurrent inputs for Zai and contour bunds

Zai and contour bunds: recurrent inputs and costs per ha/per year	
Input	Cost (USD)
Labour 20 person days for the manure 1 person day for the stone bunds	21
Equipment tools: wheelbarrow rental	6
Materials: ash and wet straw	0
Agriculture: manure (100 kg)	2
Compost transportation	2
TOTAL	31

Table 2. Recurrent inputs for Zai and contour bunds

Agroforesty

The costs of implementing the innovative agroforestry system concerns mainly own labour and relates to the time spent on stemming, pruning and cutting the trees. The benefits are considerable. In Niger in the past 20 years over 250,000 ha/year have been replanted in Niger, adding up to 5 million ha. At an average of 40 trees/ha this implies a total of 200 million new trees. The trees generate a range of benefits; reducing wind speed and evaporation, they produce at least a six-month supply of fodder for livestock, firewood, fruit, and medicinal products that farm households can consume or sell. Certain trees species (Faidherbia Albida for instance) also enhance fertility by adding nitrogen in the soil. If each tree produces an average annual value of USD 1.2 (firewood, fodder, fruits, medicinal products, improved soil fertility, increased crop yields, etc.) this means an annual production value of USD 240 Million. This does not yet include the value of the timber or the carbon sequestered by the standing tree stock. If 4 million individuals are concerned by re-greening, this means an average annual benefit of 60 USD per capita, whereas average annual per capita income in Niger is in the order of USD 280.

References

Biochar. (2011) Biochar Discussion List [online] Available at: http://biochar.bioenergylists.org [Accessed 14 May 2011]

Critchley, W. (2010). More People, More Trees – Environmental Recovery in Africa. Practical Action Publishing.

EC and AUC. (2009). Scope and Pre-feasibility Study on the Great Green Wall for the Saharan and Sahel Initiative (GGWSSI). Project Number: 5008206.

Reij, C., G. Tappan, and M. Smale. 2009. Agroenvironmental transformation in the Sahel: Another kind of “Green Revolution.” IFPRI Discussion Paper. Washington, D.C.: International Food Policy Research Institute.

WOCAT. (2007). Where the land is greener – case studies and analysis of soil and water conservation initiatives worldwide. Editors: Hanspeter Liniger and William Critchley.

14. Soil and water conservation at scale, Tigray, Ethiopia

Introduction

Land degradation has been a main factor in food insecurity in much of Ethiopia – in particular in the highlands, which are densely populated and intensively cultivated. Tigray region, in northern Ethiopia, was a notorious area of food insecurity and parts of it are remembered for the horrifying images of the 1984 famine.

Tigray has a population of 4.4 million and a land area of 5.3 million ha. Twenty percent is cultivated and, nowadays, almost all of it by small holdings. In the varied topography, rainfall averages differ: in the highland areas (between 1500 m and 2300 m) it is close to 900 mm; in the lowlands it varies from 500 mm (in the eastern part) to 1200 mm (in the western part). Besides the rainfall averages, variability is important: rainfall in the region is erratic and unpredictable. Soil erosion has been severe in Tigray. In several places parts of the subsoil have been removed from the sloping land.

Figure 1. Soil and water conservation board on local planning. (Photo credit: Tigray Bureau of Agriculture and Rural Development, 2011).

Box 1: Landscape transformation in Abreha Weatsbeha

Abreha Waetsbeha – located near Wukro – is part of the Sulo catchment. Intensive soil and water conservation has been implemented here over the past five years. As elsewhere in Tigray, the work is implemented both by voluntary labour and labour inputs from the Productive Safety Net Programme. The work in Abreha Weatsbeha consisted of:

- Semi-circles for tree planting.
- Field bunds with trenching – to maximize the capture and infiltration of rainfall run-off.
- The development of gully plugs, overflow channels and rainwater infiltration ponds close to the mini-escarpments surrounding the village.

Area closure to allow the regeneration of trees and grasses. A special feature is the development of new farmland in areas previously used for grazing. This concerns sandy tracks close to the foothills, which are now closed to animals. This makes it possible for wild weeds to emerge. These weeds are regularly ploughed so as to increase the organic content and improve the fertility of the sandy soil. Another feature is that, with the soil and water conservation activities, indigenous trees have come back. There is already a long and well-enforced system not to cut any live trees, but with the soil and water conservation activities many new trees have come up. The recent programme has caused groundwater tables to rise in a spectacular fashion. This has encouraged shallow well development. In the past three years at least 200 shallow dug wells were developed in Abreha Weatsbeha – often located at very close proximity to one another. Excavating one of these large diameter wells costs USD 300 – and is done with some encouragement (in the form of food aid) by the local government. The water is pumped out to the adjacent farmland by treadle pumps or rope pumps and in some cases by monoblock diesel pump sets. The dug wells, however, take up much space and are prone to collapse in the sandy soil. Replacing them with low-cost, manually-drilled shallow tube wells would improve secure access to groundwater.

Figure 2. Using treadle pump to acces the new shallow groundwater. Source: Tigray Bureau of Agriculture and Rural Development (Phtoto credit: Tigray Bureau of Agriculture and Rural Development, 2011).

There has been a remarkable landscape transformation in Tigray in the past three years. Soil and water conservation activities addressed more than 50% of the agricultural land in this short period, building on the steady progress made during the prior ten-year period. The activities have caused crop production to increase by 50%-100% and a large range of innovations to take root. This soil and water conservation programme is very much a story of scale begets scale and success breeding success.

Soil and water conservation in Tigray

Soil and water conservation programmes have been practised in Tigray for a long time, but were often interrupted and not implemented at scale. Several techniques were introduced over the years: afforestation, bench terracing and stone bunds. Programmes were often associated with food-for-work programmes. From 1974, the World Food Programme (WFP), for instance, supported terracing and reforestation – undertaken by the Extension and Project Implementation Department (EPID). The long-term uptake of soil and water conservation was often limited, and particularly in the socialist Derg regime the programmes were considered top-down and forced upon. The Tigray Peoples Liberation Front (TPLF) and its outreach wing the Relief Society of Tigray (REST), however, recognized the importance of soil conservation and made it a cornerstone in its programme in Tigray, particularly after it took power.

The area of land that was rehabilitated between 1988 and 2002 in Tigray amounted to 602,000 ha, more than half of what was previously addressed in the country as a whole. The main purpose was reducing erosion through trapping and retaining sediments. In spite of the effort, the results were often unsatisfactory due to lack of effective community engagement, limited sense of responsibility over assets created and unmanageable planning units.

From 2007 the programme was thoroughly revived and reoriented. Particularly from the year 2009 onwards a new thrust in soil and water conservation was introduced in Tigray. The new impetus had several elements:

Soil and water conservation was to focus on cultivated and uncultivated land. Cultivated land should be primarily conserved by the farmers who cultivate the land, and watersheds should be conserved by public mobilization.

There was – in addition to erosion control - more emphasis on harvesting water and retaining moisture. In this practice this meant several new techniques. For instance in low rainfall zones infiltration ditches were added to the stone bunds.

Area closure was introduced systematically – areas with soil and water conservation were closed from animals for at least five years to allow grasses and other vegetation to grow again.

Other new elements introduced were gully treatments and new grasses and fruit trees on the treated lands.

The work was undertaken through free labor in the offseason and through contributions from the so-called Productive Safety Net Programmes. Under the first arrangement every able-bodied community member was required to work 40 days in 2009 and 2010 free of any payment. In 2011 this was lowered to 20 days (as it had been prior to 2009), as a large part of the watershed programme had been completed in the two preceding years. In contrast to the earlier initiatives, the programme was very popular as the starting point was local planning and the results were significant. There were norms as to what was to be done in a days work – for instance 5 m of stone bunding. The norm for women was half of that for men. The work was done in the off-season: January and February. In addition to the free labor, contributions from the so-called Productive Safety Net Programme were integrated with the soil water conservation programme. Under this programme chronically food insecure people were earmarked to provide work against payment in cash or kind.

From 2009 to 2011, 568,000 ha were treated under the soil and water conservation programme and, in addition, farmers also invested considerably in their own land improvement (leveling, terracing, soil amelioration) and in some places well development. Key to the success of the programme has been local planning and implementation – something that was missing in the earlier efforts. Under the aegis of the regional Bureau of Agriculture and Rural Development (BoARD) a system was set up and capacity was developed, as follows:

- The Tigray Bureau of Agriculture and Rural Development provided training and planning support to the districts (woredas).
- Woredas gave training and support to village clusters (tabias).
- Tabias (in coordination with Woreda representatives) offered training to farmers at sub-catchments. The main activities were carried out at this level.
- Organizations like farmers' unions, womens' associations and youth associations were involved in the planning and implementation of soil and water conservation activities.

The strong local-driven implementation meant a trend break with earlier soil and water conservation efforts – where people mainly participated to receive food for survival. In the past there was often little awareness of the effect that soil and water conservation activities could achieve. Implementation at scale also meant a change in environment – as witnessed from the reemergence of springs, the regulation of local flows and the growth of indigenous trees – causing larger momentum. It created an effect of 'success breeds success' – as it encouraged experimentation with new crops (fruit trees) and new land management methods (mice control). Importantly the collective mobilization programme was complemented by individual investment in land improvement and well development.

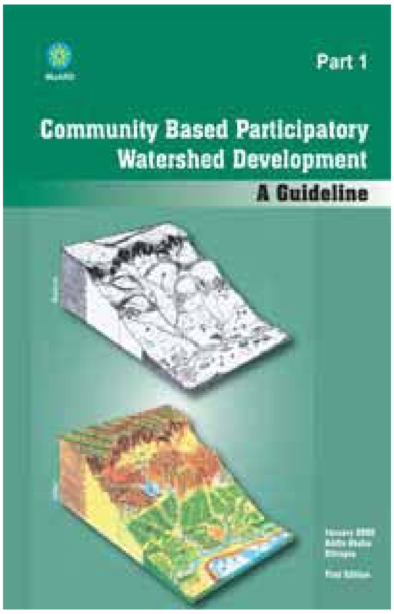


Figure 3. Guideline “Community Based Participatory Watershed Development” and as basis for local planning

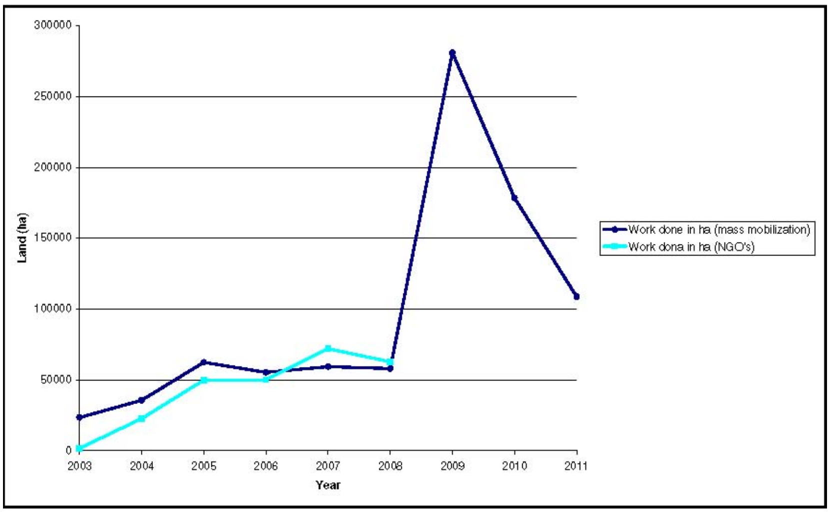


Figure 4. Accelerating landscape improvement in Tigray 2003 - 2011 (Source: Tigray Bureau of Agriculture and Rural Development, 2011)

Table 1. Water recharging/conservation structures implemented in watersheds of Tigray until 2008 (Source: Tigray Bureau of Agriculture and Rural Development, 2011)

No	Type of structures	Unit	Quantity
1	Percolation pits and ponds	Number	9052
2	Micro-basin	Number	4031663
3	Large semi-circular structures	Number	31627
4	Eyebrow basin	Number	532974
5	Herring bone	Number	190043
6	Sediment storage dam	m^3	6675
7	Rockfill dam	m^3	162469.5
8	Gabion check dam	m^3	573775.1
9	Stone check dam	m^3	1232015
10	Cut-off drain	Km	26158.87

In addition to soil and water conservation activities, different water harvesting and recharging structures have been constructed in Tigray. As can be noted from Table 1, some of the structures constructed so far include percolation pits, micro-basins, rockfill dams, check-dams, etc.

Costs and benefits

There are records of soil and water conservation activities carried out in Tigray up to 2011, but interestingly the data are not comprehensive. The programme has been carried out in a very decentralized fashion and, although it is there for everybody to see, there are no neat central statistics. Table 1 is an overview of the type of activities implemented up to 2008. After this, work accelerated and there has been more emphasis on recharge and infiltration.

Table 2. Day-equivalent activities under the Productive Safety Net Program (Source: Tigray Bureau of Agriculture and Rural Development, 2011)

No.	Type of soil and water conservation activity
1	Terracing in soil (5 m long)
2	Terracing in rock (3 m long)
3	Stone bund (4 m long)
4	Deep trench (1 m deep)
5	Eyebrow basin (2 I brow)
6	Micro-basin (4 micro-basins)
7	Half moon (4 half moons)
8	Pit (for tree planting) (15 pits)

Figure 3: soil and water conservation, Tigray (Source: Tigray Bureau of Agriculture and Rural Development, 2011)

Above (Table 2) is the official norm of the work to be done in a day by an adult man under the Productive Safety Net Programme. The renumeration for a day work under the programme is ETB 10 (USD 0.50) or 3 kg of grain – which is below the normal daily rural wage.

The benefits of this very recent programme remain to be quantified – but the following key observations have been made by farmers:

- Enhanced water infiltration and increase moisture to their farmlands.
- Increased crop yield (50-100%) due to improved moisture conditions, especially areas with limited rainfall.
- More secure base flows of local streams and reduced sedimentation.
- Reduced flooding of farmlands.
- Emergence of new springs at lower parts of the catchments and rising of groundwater levels.
- Change in the micro-climate around the treated watersheds and around closure areas.

There are a number of useful lessons from the programme in Tigray. First, as mentioned, is the importance of scale and speediness of implementation – provided of course the right thing is done. Second is the central significance of local planning and local implementation, and the importance to see buffer management as more than the control of soil erosion. Related to this is, third, the value of a decentralized and somehow disorganized process of implementation – there were no formal designs and much of the activities were recorded at the lowest level of administration only, but somehow this worked. Finally, the role of tradition: many new practices were created, improved and implemented. There is sometimes a tendency to see traditions of having to be rooted in a long past, but the Tigray programme shows that traditions can be created in a short interval too.

References

Tigray Bureau of Agriculture an Rural Development (2011). Soil and water conservation report.

TheWaterChannel. (2011). Land, Water and Livelihoods: Watershed Movement in Tigray [online video] Available at: http://www.thewaterchannel.tv/en/videos/categories/viewvideo/1029/ integrated-water-resource-management/land-water-and-livelihoods-watershed-movement-intigray [accessed 18 August, 2011].

15. Water retention through 'monkey cheeks', Thailand

Water retention for flood and droughts

Although there is no shortage of rainwater in Thailand, drought is still a major problem in many areas especially in the north-eastern region. This is due to the low capacity of rainwater conservation. According to Hydro and Agro Informatics Institute (HAII), only 5.7 per cent of rainwater is stored.

The term 'monkey cheek' was coined by King Bhumibol Adulyadei of Thailand as a metaphor to promote local water retention systems and is part of the 'New Theory' agriculture. It refers to monkeys filling up their cheeks with excess food. The food is stored and chewed and eaten later. Monkey cheeks essentially are 3R: Recharge, Retention and Reuse. The monkey cheek programme was initially started to solve the flood problems of Bangkok, but has subsequently been replicated all over the country, especially in the north-east. The north-east is the driest area – but is also an area that is not suitable for the construction of large dams. Monkey cheeks come in large and small. Larger projects of the Royal Irrigation Department (RID) in 2010 included developing 197 monkey cheek projects with a total storage capacity of 117 Mm3. In addition there are numerous storages at community level.

Figure 1. One of the monkey cheeks at Ban Limthong (Photo credit: Hydro and Agro Informatics Institute (HAII), Bangkok)

Ban Limthong

An example of a village that followed the 'monkey cheek' initiative is Ban Limthong in north-east Thailand. It is located in Nongbood subdistrict, Nangrong district, Burirum Province. There are 108 households totaling

563 people. Wet season rice cultivation is the main crop. Mushroom, tapioca, cowpea, watermelon, cucumber and other vegetables are grown for additional income.

Ban Limthong is situated in the upper Lam Plaimas River Basin. The average monthly rainfall in Nangrong district is 1,380 mm – but the difference between the dry and wet season is large. Where there are rice fields in the rainy season, an expanse of sandy soil dominates the landscape of the village during the dry season. Due to its relatively high location, water supply in the canal to Ban Limthong dried up – requiring long walking distances even to collect basic supplies. Competition for water among surrounding villages was common with the risk of crop failure in a below average rainfall year. In contrast, during rainy season the excessive amount of water often flooded and destroyed farming areas. In Ban Limthong this caused indebtedness and out-migration.

The Government stepped in during these periodic disaster periods. Each year water was trucked in during the dry period, but this was never enough. During floods, sandbags and pumps were distributed. A reservoir was built, but it was in an inappropriate location and it yielded very little.

Investing in water retention

Sharing problems of increasing debts and water shortages brought together a group of villagers led by Sanit Tipnangrong or Na Noi who became involved with the local Suksapattana Foundation. Over time more villagers joined, including those from neighbouring villages. The Ban Limthong group collected information on the demand of water within their own village and worked together with the surrounding villages. Hydro and Agro Informatics Institute (HAII) has supplied these communities with data and the use of information technology in surveying and planning. HAII arranged for handheld GPS devices and satellite images of the area. In addition, a number of field surveys were undertaken that were used to collect data, analyse community water resource issues and develop solutions. Villagers developed plans for water retention systems, in particular

(a) the construction of an irrigation canal system to divert water from the upper river basin, (b) the construction of series of monkey cheek ponds to store water in order to increase water storage capacity and prevent flooding, and (c) small farmer storage ponds. The canal system will be connected to monkey cheeks as well as agricultural areas. The demand of water for drinking and household consumption was set at 120 L per person per day and 5.2 Mm^3 per year for agricultural use.

Irrigation Canal System

The plan for the irrigation canal system was submitted to the district office of the Royal Irrigation Department in 2006 and was built over the two subsequent years. The unlined canal was 3,600 m long and approximately 3 m deep. The water storage capacity is 121,000 m^3 per year.

Monkey Cheeks

The monkey cheeks store water during periods of high rain. They work with gravity flow – the ponds fill when water runs higher in the irrigation canal and floodgates close as the water level in the ponds exceeds that in the canal. In the dry period when the water level of the canal decreases, the water from monkey cheeks is slowly released into the canal. In Ban Limthing, seven monkey cheeks were placed at different points throughout the irrigation canal system. Seven such monkey cheeks were constructed - each relatively modest in size (see Table 1) – combining a storage capacity of 65,700 m^3. Added to the capacity of the canal, the total water storage is 186,700 m³. A levee was made around the edges of the monkey cheeks by compressed soil. These levees are typically 10 m wide and 1.5 m high.

Figure 2. Small storage reservoirs and canals interconnected to create buffer (Photo credit: Hydro and Agro Informatics Institute (HAII), Bangkok)

Table 1: Constructed Monkey Cheeks

	Dimensions in m (width, length, depth)	Capacity (m³)	Excavated area (m^2)
Monkey cheek 1	60, 60, 3	10,800	3,600
Monkey cheek 2	40, 50, 3	6,000	2,000
Monkey cheek 3	30, 80, 3	7,200	2,400
Monkey cheek 4	80, 80, 3	19,200	6,400
Monkey cheek 5	40, 60, 3	7,200	2,400
Monkey cheek 6	30, 100, 3	9,000	3,000
Monkey cheek 7	30, 70, 3	6,300	2,100

Small farm ponds

After the irrigation canal and monkey cheeks were built, distribution channels were constructed in order to distribute water to the farming areas that are further away. In order to be able to efficiently manage the water and their farmland for all-year-round agriculture, villagers also built small ponds at each farm according to the 'New Theory' agriculture (see Box 1).

In order to implement this component, Development Cooperation Foundation has set up a revolving fund, amounting to USD 17,000 for the village. In order to take part in the fund, villagers need to be a member and pay a small entry fee. Members can submit their project plan to the fund. After the approval of the project, they will be supported in preparing the area. Moreover, the members need to attend the training programme about how to manage and utilize the pond for maximum benefit. The money lent can only be used for constructing a pond at their farm or other expenses according to the written plan submitted to the fund. Additionally, the members are able to borrow extra investment money with low interest rate for farming activities. The fund aims to lend about THB 20,000 (USD 666) for each pond construction. The aim is to support the construction of 10 farm ponds per year. The members are expected to repay the amount within four years or about THB 660 (USD 22) per month. The fund committee is responsible for fund management and annually reporting back to the Foundation.

Costs and financing

The construction of an irrigation canal system at USD 92,000 was supported by the Royal Irrigation Department. The construction of monkey cheeks was supported by the Coca Cola Foundation Thailand. After reviewing the plan from the villagers, the Coca Cola Foundation approved the budget of THB 1,400,000 (USD 47,000) to support the cost of construction. HAII contacted the Mobile Development Unit of the Thai Military to support the provision of the equipment and machinery necessary for the construction and carried out the project according to the plan. The revolving fund for the farm ponds amounted to USD 17,000.

Box 1: 'New Theory' Agriculture in short

'New theory' agriculture is the concept developed by His Majesty the King of Thailand to efficiently manage water and land in a small agricultural area (average size 16,000 – 24,000 m2) for the utmost benefit. According to the 'new theory' agriculture, land should be divided into four parts with the ratio 30:30+30:10.

The first part: 30 per cent is reserved for a small pond which should be built to hold 19,000 m^3 of rainwater. This amount is considered to be enough for agricultural use for the whole year for a small farm. Growing eatable aquatic plants and aquaculture in this area are recommended as it provides farmers with extra income and food.

The second and third part: 30 per cent + 30 per cent is the agricultural land. The first half is used for rice farming and the second half is for field crops, herbs, fruit trees depending on the condition of the land and the market. Yields are used for household consumption and the surplus can be sold.

The fourth part: 10 per cent is as allocated to a service area such as houses, roads, canals, storage areas, home gardening and livestock.

The villagers who are the owners of the lands where the irrigation canal system and the monkey cheeks were constructed gave their consent to allow the lands to be used for public benefit. Therefore, there were no costs for procuring land. The 'Community Water Committee' was established to spearhead the project, make a plan, and later to look after and manage the community water facilities. The committee has also expanded into a collaborative network with nearby communities. A database of water users was made and administrative fees were collected from those on the list. The money collected was spent on the maintenance of the village water supply system and other public benefits. Vetiver grass has been planted on the edges of each monkey cheek and the bank of the canal to keep them sturdy and prevent soil erosion. This also reduces the costs in dredging and maintenance. The 3 m-long roots of vetiver grass also help reduce water evaporation and keep the soil moist.

The landowner is appointed as the person responsible to take care of the monkey cheek in their land together with five members (villagers). Each group maintains the monkey cheek and uses the area around it to implement mixed farming, experiment with 'new theory' farming, and carry out a cultivation plan for year-round harvesting. Lessons learned and the data collected was shared among the villagers. Successful cases are replicated.

Benefits

The combined system of monkey cheeks, irrigation canal system, distribution channels and small ponds at farm level solved flood and drought problems that plagued the community for decades and created a stable buffer.

It provided villagers with sustainable water supply for agricultural and domestic use all year round. Rainwater that is captured is not only used for growing rice and crops but also for livestock, fish and frog farming that yield extra income. Cultivation is all year round. They no longer suffer from the risk of delayed rain and crop failure due to water shortage. At household level the increased buffers have allowed for greater income that is also more stable and predictable.

The benefits of the canal and monkey cheek systems accrued to farm household in Ban Limthong and surrounding villages – totalling 1,038 households. Water is provided to 608 ha. Their standard of living has improved as they have more saving and debts are gradually resolved. No time is lost in fetching water. Many who have left to work in the city came back to work in the field and be with their families.

The table shows economic effect for an average household (based on a sample of 15). The monkey cheeks buffer development programme added THB 105,500 of net returns per family – equivalent to USD 3,500 – meaning that the investments have a payback period of approximately three years.

Moreover the system doubles up as a flood protection device. Furthermore, the system is a solution to water pollution problems that often occur in the canals with low water levels. When the water from monkey cheeks is released, it flows along the canal system and helps circulate clean water to dilute standing water.

Table 2: Improvement of average income of a household per year (Baht) - based on sample of 15

	Before implementation	**2007**	**2008**	**2009 (new theory agriculture)**
Income	6867	102984	148490	164949
Expenses	7600	46233	71163	59356
Total balance	-733	56751	77327	105593

References

Hydro and Agro Informatics Institute (2010). The 3rd Competition of Community Water Resource Management according to His Majesty the King's Initiatives. Bangkok

Hydro and Agro Informatics Institute (-) From Learning to Water Resource Management, Ban Limthong. Bangkok

Hydro and Agro Informatics Institute, 2006. Analysis Report Solutions to Community Water Scarcity Problem. Bangkok: HAII.

16. Harvesting sediment with warping dams, Loess Plateau China

Introduction

The Loess Plateau covers an area of 640,000 km2 in north central China and is home to more than 50 million people. The middle stream of the Yellow River crosses the Loess Plateau. The intense use of the Plateau and the lack of conservation measures have lead to large-scale degradation of the vulnerable land formations – loess being highly erodible. The Plateau has one of the highest erosion rates in the world and the Yellow River itself is named after the colour of the suspended fine loess sediment. The river is estimated to receive a staggering 1.6 billion tons of sediment every year. In the 1990s, the Chinese Government started one of the largest landscape transformations in the world – with the aid of the World Bank – the rehabilitation of the Loess Plateau. The objective of the programme was to increase agricultural income and to improve ecological conditions in the tributary watersheds of the Yellow River. The main elements of the programme were the construction of terraces, protection of sloping lands from grazing, and support to farmers in income

Figure 1. Warping Dam in Gansu province, China. (Photo credit: WorldBank office Beijing)

Box 1: Warping

Warping is building up land with moisture-rich soil along rivers and streams. The technique is not unique to the Loess Plateau but has also been used in England - for instance along the Humber and Thames - where silt-laden water was forced to settle in embanked areas, thus producing fertile new land. The same was done along the Yssel River in the Netherlands, where so-called worpgronden (warping lands) were developed. In many flood-based farming systems land is developed from sediment: sediment is a constant blessing and not a nemesis as in many perennial irrigation systems.

generating farming activities, such as feedlot livestock development, the introduction of dairy cattle and irrigated agriculture (World Bank, 2005). By reducing the sediment flow into the Yellow River flood risks downstream are reduced drastically and a substantial sum is saved on raising dikes in the Yellow River.

Warping dams

Warping dams are dams built on gullies to harvest and intercept sediments and thereby create new land. The dams are of considerable height - typically up to five metres. The construction of warping dams to harvest sediment, build up land - as well as in the long run to ensure better water retention -has been a main feature of the programme.

As history has it, the first warping dam originated through a natural landslide 400 years ago in Shanxi Province. Sediment was deposited in front of the dam creating warping land, and grain yields increased due to the fertile soil. The dam was heightened by local people to 60 m and farmland of 53 ha developed behind it (UNESCO, 2004).

The construction of warping dams gained popularity after the Chinese Government built a warping dam for experimental and demonstrational purposes in the 1950s. In the late 1970s several warping dams were destroyed due to inadequate construction methods combined with unusually large floods (Zang et al., 2003). From the 1990s construction of warping dams accelerated as part of the West China Development Plan.

In the Loess Plateau Watershed Rehabilitation Projects of the World Bank (2005) the construction of warping dams - alongside other types of sedimentation control dams (Box 2) – also played an important role. In total 1272 warping dams, 264 key dams, 3719 check dams, and 171,278 ha of terraces and several vegetative measures were developed under the Rehabilitation Projects. The total cost of these two projects was USD 300 million. This is estimated to have reduced sediment load by 82 million tons.

Construction

The development of a warping dam consists of two stages: (a) the land development stage, and (b) the consolidation and management stage. The land development stage takes several years (on average 3-5 years, but sometimes more than 10 years). By then warping dams have collected enough sediment to start farming. After this consolidation starts. Stabilization is necessary when the dams are completely filled with sediment, in particular the creation of controlled water overflow structures. This can be done by changing the existing spill ways into a circular shape, redesigning the top of the shaft as spillway, constructing a side spillway, or designing an earth dam as overflow dam. There are many factors to take into account while constructing warping dams. The density of dams depends on natural factors e.g. slope, gully density and the possibility of retaining silt for farmland (Box 3). The number of dams depends on the slope and width of the gully. In the

Loess Plateau, 2-5 dams can be found per km2 in areas with a slope of 2-3% and a gully density of 3-7 km/ km^2 (UNESCO, 2004).

Table 1. Classification of warping and key dams

Classification	Gully length Km	Storage capacity 10^3 m^3	Height of dam m	Warping area ha
Small	0.3	10-100	< 15	< 1
Medium	3-5	100-500	15-30	1-15
Large	> 5	500-5000	> 30	> 15

Source: UNESCO 2004

The development a warping dam requires an area approach. It is important to look at existing measures and natural factors in the area (e.g. cropping systems, slopes, upstream and downstream users, and rural road plans). It is also important to see the key dams and warping dams as a combined sediment management system.

Benefits

One part of the benefits of the warping dams is in the upper catchment. The sediment captured by warping dams, or warping land, is rich in organic matter and has soil moisture concentrations that are up to 80% higher than in the sloping land. Yields from warped land can be up to 2-3 times higher compared to terraced land and up to 6-10 times higher compared to sloped land (UNESCO, 2004). In the Loess Plateau warping dams are also used to connect roads in villages. This additional benefit enhanced the popularity of the warping dams.

In addition there are important downstream benefits. From an analysis of over 1000 warping dams from a typical watershed in the Loess region (UNESCO, 2004) it appeared that the average of retained sediment per dam is 2.78 km^3. Data from Shaanxi Province show a decrease of 51% of sediment transported in the Yellow River after the warping dams were constructed.

The benefits of warping dams are usually shared by the ones who invested (financially or by labour) during the construction of the dam. The maintenance and management is mainly carried out by a village authority, but other forms of property rights occur, such as contractual agreements between households and local government and leasing arrangements to private companies.

Box 2: Three types of sediment control dams

1. Key dams are the largest dams (15-30 m high) - controlling catchment areas of 10-15 km2. They are typically located close to the outlet of watersheds. Besides retaining sediment, key dams can be used to control small floods and to serve as water supply reservoirs as well.
2. Warping dams are smaller in comparison to key dams (around 5 m high). They are usually constructed in the wider parts of a gully downstream of a key dam. Their purpose is solely to intercept sediment and create flat arable land.
3. Check dams are small dams (1-2 m high) built of rock or brushwood. Check dams slow the flow of water in steep tributary gullies and prevent the undercutting of gully sides. The sides of the deeply incised gullies in the Loess Plateau generate 50 per cent of the sediment run-off. Sediment control dams intercept this sediment at the source. To restore any loss in storage capacity due to sediment, the height of dams can be increased periodically.

Figure 2. Series of sediment control dams (Photo credit: World Bank Office Bejing)

There are opportunities to self-finance the sedimentation control dams. The argument has been made that if warping dams of required standards would be built with private funds and be paid USD 0.12 per ton of trapped sediment, then many village cooperatives and individual tractor owners would be encouraged to devote their labour and resources to the building of warping dams, without further assistance from the government. Under the same arrangement county governments would be subsidized for their rural road projects which usually involve high earth structures across gullies with sediment trapping functions.

Box 3: Examples of benefits

Inner Mongolia

Lijiageleng is a village of 26 households in Inner Mongolia near the Yellow River's northern bend. The villagers owned 17 ha of farmland which generated a per capita income of USD 60 - remaining at poverty level. After the development of a warping dam and 16 ha of terraced irrigated land, the per capita income rose to USD 276 in two years.

Northern Shaanxi, China

The construction of a 35 m high key dam - controlling a catchment of 3 km2 and with a storage capacity of 800,000 m3 - cost around USD 60,000. The dam can retain 150,000 m3 of run-off and it traps 37,000 tons of sediment. A short overview of benefits:

- Clearing costs of coarse sediment (sediment that can not be flushed out to sea) is estimated at USD 0.24 per ton. As roughly half of the sediment trapped in the key dam is coarse, the dam saves USD 4,440 to the national economy annually.
- To transport one ton of fine sediment to the sea, 20 m3 of water is needed. Reducing sediment by 18,500 tons per year saves 370,000 m3 of river water which can be used for other purposes. This is in addition to the intercepted run-off by the dam, and gives a net gain of 215,000 m3 in water supply.
- Direct agricultural benefits from the dam were valued at USD 6,000 per year.

Source: yellowearth.net

References

EEMP. (2005). Loess Plateau Rehabilitation - Interview with J. Vogele [Online video] Available at: http://www.thewaterchannel.tv/index.php?Itemid=53&option=com_hwdvideoshare&task=viewvideo&video_id=69 [Accessed 14 August 2011].

Liu, J. (2010). Hope in a changing climate. Environmental Education Media Project (EEMP). [Online video] Available at: www.thewaterchannel.tv. [Accessed 23 August 2011].

TVE Life. (2005). Rehabilitating of the Loess Plateau [Online video]. Available at: http://www.5min.com/Video/Rehabilitating-the-Ecosystem-of-the-Loess-Plateau-460502042 [Accessed 22 August 2011].

UNESCO (2004). Warping Dams – construction and its Effects on Environment, Economy, and Society in Loess Plateau in Region of China.

WorldBank 2005. Implementation completion report second loess plateau watershed rehabilitation project

Zang Yu, Cui Peng, Li Fa-bin and Wang Qing. (2003). Optimization Design of Warping Dam in Wangjiagou, Shanxi province. Wuhan University Journal of Natural Science. Vol 8. No. 3B.

17. Flood water spreading, Iran

Introduction

In the Fars Province in Iran an extraordinary programme of floodwater harvesting has been implemented since 1983 – changing the desert landscape into a verdant environment. Water and sediment from occasional floods in this arid environment have been utilized to:

- Recharge groundwater by spreading floodwater gently over a large area;
- Develop lands for spate irrigation – using the silt to build up soil and prepare land for direct irrigation;
- Introduce integrated farming systems of field crops, tree crops, honey bees and livestock;
- Develop Eucalyptus camaldulensis plantations on the newly-formed lands to function as windbreaks and shelterbelts, to sequester carbon, produce honey, and serve the urban markets with timber.

The floodwater spreading programme is a good example of turning a menace – silt-laden floods - into an asset. The floodwater carries high volumes of sediment – up to 5%, which is not unusual for ephemeral rivers. If storage dams were built in this environment their reservoirs would choke rapidly. Instead, through floodwater spreading the silt is used as an asset by building up fertile land in a sandy desert that is under the constant threat of wind erosion. The floodwater is also used to recharge groundwater and to spate irrigate land directly.

Figure 1. Floodwater diverted to one of the infiltration basins during a rain fall event in 1983 (Kowsar, 2009)

A series of techniques are applied to spread the water and sediment over a large area - in particular combinations of conveyance spreading canals and level-silled channels (LSCs). The simplest version of a floodwater spreading system is a single, level-silled channel that receives the floodwater from one or more sources and allows the water and sediment to spread gently over the debris cone and alluvial fan. A full floodwater spreading system on the other hand may include a diversion weir, a conveyance canal, a wasteway, a conveyance-spreader channel (CSC), a number of LSCs, flood outlets (sometimes with masonry drops), trail dikes and a tail drain. If the system also functions for artificial recharge, an infiltration pond is added to the end.

The main feature in floodwater spreading systems are therefore LSCs. These are actually long stilling basins, closed at both ends, with the down slope edge exactly on the contour. The channel converts small, concentrated flows into sheet flows. The control section of the LSC is a level sill adjacent to its down slope edge, which allows the silt-laden water to spread gently before the sediment settles down. The soil excavated from the channel forms the bank immediately on its upstream side. Water enters the LSC through the gaps installed in the bank at 100 to 400 m intervals. The usually turbulent water loses most of its kinetic energy after entering the basin. When the channel is filled up, the surcharge spills along the entire length of the sill in a slowly flowing thin sheet. The LSCs are made with bulldozers, graders or front-end loaders. They are not intended to impound – only to briefly capture and to spread both water and sediment.

The dimensioning of floodwater systems depends on the expected normal flood levels and the use of the floodwater. There is no theoretical basis for determining the layout and space between consecutive channels, but two criteria are important. Firstly, the flowing water should not gain erosive velocity. Secondly, water should be distributed evenly over the space between the channels.

Box 1: Conveyance spreader channels (CSCs)

Conveyance spreader channels (CSCs) are larger than level-silled canals. The main function of the conveyance spreader channel is to convert concentrated flow from the upland to sheet flow. They can be kilometres in length. The CSCs receive floodwater from ephemeral or permanent rivers, drainage lines, depressions and watercourses, and surplus water from small reservoirs. As torrents with high velocities and heavy bed loads can hinder the functioning of the spreading channels, sometimes earth or rock buffers are added to retain the floods and send the reduced velocity, desilted water through gaps into the CSCs. Construction of the CSCs is similar to the level-silled channels, with one important difference. CSCs follow a very mild slope, their cross-sectional area is larger and usually they do not have bends or turns.

Box 2: Speeding up sedimentation

Assuming that a 30 cm layer of fine-textured soil is required to reclaim the sandy expanse in the Gareh Bygone Plain (3,000 m3 per ha), 18 Mm3 of sediment are needed to rebuild the land. Taking the average annual diversion at 10 Mm3, it requires about 90 years reclaiming the whole area. One idea to expedite the recovery is to break the marl and siltstone bedding on the watershed and generate even higher silt loads.

An integrated approach was involved – combining the development of new land from sediment, irrigation and recharge, and the planting of species to promote the development of agro-ecological niches. Another welcome development is the emergence of sowbugs – a crustacean that improves the infiltration of the land and builds up the soil structure (Box 3).

Knowing what to do where

In the floodwater spreading it is important to know what to do where. An important message is that – contrary to conventional wisdom – it is neither possible nor wise to always 'catch the water where it falls', as some catchments produce floods rather than recharge. Moreover, in some parts of the catchment recharge is undesirable as it would add to salinity. In the words of Professor Sayyed Ahang Kowsar, the lead scientist of the artificial recharge programme, 'Basins with impermeable outcrops are different from ones with permeable surfaces. Iran can consider itself fortunate to be blessed with flood-producing impermeable watersheds. Without this it would be impossible to live in such dry environments. The natural recharge for the alluvial aquifers materializes only by floods. The diffuse recharge is utterly insignificant.'

An example of knowing what do to where, is the Helleh River. The Helleh River has a drainage basin of 8,600 km2, making it the second largest river in the Fars and Bushehr provinces. The discharge of the Shapur River, the most important tributary of the Helleh, however, is saline. This affects the use of the Helleh water for irrigation. At the source, the Shapur River is supplied by karst springs and is fresh. Salinity, however, builds up as a number of tributaries join the river course. Diverting the saline discharge of these tributaries through a pipeline system to the Persian Gulf was suggested at one stage but not taken up due to the high cost. For the same reason the construction of a large reservoir on the Helleh River to store floodwaters and dilute the saline inflows was rejected. Moreover, much precious water would be lost from evaporation from the reservoir and sedimentation would be an issue.

Instead of the reservoir and pipeline options, a more promising alternative is the careful management of the water buffer in the Shapur River so as to increase the baseflow of the Shapur River and eliminate the saline outflow. In general, in semi-arid, high temperature areas storing water in shallow aquifers is more cost-effective than constructing surface reservoirs.

An important portion of the Shapur's floodwaters originates in a 770 km2 area upstream of the Tchegan Gorge. Promoting more intensive recharge in this part of the catchment would increase the freshwater baseflow of the Shapur. The floodwater spreading/recharge sites are best placed at a distance from the main stream of the Shapur River. This would ensure that the subsurface flow reaches the Shapur at a time when it is most needed. For example, if the recharge occurs in December and the irrigation season starts in April, then the distance should be adjusted according to the aquifer parameters so that the recharged water would not reach the Shapur baseflow before April. This requires an understanding of faults and fissures that affect the shallow groundwater flow. The same method may be used for harnessing floodwater in other tributaries.

At the same time the saline outflows should be reduced. The flow from the saline springs in the Jareh and Dalaki tributaries should be diverted to leak-proof evaporation ponds to prevent this water from joining the main river. In addition to the evaporation ponds closure of the saline outflows may be considered. The Shekastian Drainage Basin is covered by an impermeable formation. In this area the saline discharge of these tributary rivers is not from local rainfall, but most likely from underground karstic streams flowing through local faults dissolving salt plugs in the process. Stopping the discharge of these saline springs may be achieved by diverting the flow of freshwater before they reach the salt plugs, for instance, by grouting and inducing new springs to issue freshwater.

Box 3: Tunnelling in fine sand: a brilliant feat of engineering

The sowbug, or Hemilepistus shirazi. common in the Gareh Bygone Plain, is a crustacean, 20-25 mm long and 5 mm wide, blackish gray and with seven pairs of legs. Like rain worms or termites in other places, sowbugs function as eco-system engineers in this arid area – keeping the flood recharge alive and gradually improving the quality of the soil deposits. Sowbugs live in damp places, forage on vegetation and digest soil organic matter. They are also common in the arid flood spreading areas of Gareh Bygone. They prefer the moist subsoils and by burrowing they ensure the soil in the flood spreading area is not sealed with fine sediment.

Figure 2: The H. reaumuri (sowbug) entering his hole (Source: Kowsar, 2009)

Their burrows, 7 mm in diameter and up to 180 cm deep, serve to aerate and to punch the soil profile. In Central Asia, during its active life period of about three months, sowbugs will move not less than 1.5 tons of soil. This burrowed soil has more organic matter, a better structure and is more resistant to erosion than the soil from which it was derived. Sowbugs cement their burrows with body fluids. An extremely thin coating of a greyish material lines the narrow tunnels in very fine sand that would collapse otherwise. The organism lives for about one year. The white brood pouch under the abdomen of the female swells in March. The eggs form larvae in the pouch, and 60-70 sowbugs, very similar to their parents, are released from the pouch in May. They are very active in the spring and autumn. They come out of their burrows in the cool air of early morning and late afternoon. Sowbugs easily loose water through their skin. The digging deep into the soil is to reach a humid surrounding and prevent dehydration.

The emergence of the sowbug in the Gareh Bygone Plain helped to increase the infiltration rate of the topsoil layer in the artificial groundwater recharge zones. Sedimentation with silt and clay particles in infiltration basins often results in clogging of the top layers, inhibiting infiltration and drastically reducing soil moisture and recharge rates. The burrowing of the sowbug, however, results in large macropores and prevents such clogging. Instead, it increases the infiltration rate in the recharge zone up to 50 mm hr-1, equivalent to 500 m3ha-1hr-1.

The burrows of the sowbug are connect to a larger macro network – consisting also of the root channels formed by the decayed roots of the eucalyptus and acacia trees as well as the openings created in the very topsoil by dung beetles. Dung beetles are triggered indirectly by the presence of fodder trees and livestock. The manure produced by the livestock on site and carried by floodwater provides the ecological niche for the dung beetle. By loosening the soil the dung beetles initiate the start of the infiltration web. The typical infiltration rate found for the vegetative sites of the infiltration basins reached maximums of 93 mm/ hr, the infiltration rates for the crusted non-vegetative sites in the infiltration basins were much lower at 4 mm/hr. A more detailed inspection of the soil revealed the high intensity of macropores around the tree, formed by the sowbug in the first metre of the topsoil and by decayed roots in the soil beneath. Further research reported by Kowsar and Pokpavar (2004) revealed average infiltration rates of 77 mm per hour in sowbug-infested soils and only 27 mm per hour in the controlled sites. The main conclusion of the study was that the macropores, formed by the sowbug and the decay of roots from eucalyptus trees, had stabilized and greatly improved the hydraulic conductivity of the top layer of the soil, therewith establishing the key structure in order to recharge the aquifer. In the Gareh Bygone Plain, no negative impacts of the sowbug have been reported, however the sowbug is reported as pest in other cases, for instance in saffron cultivation. As sowbugs consume living plant material and plant detritus, care should be taken if sowbug species are introduced in agricultural areas.

References

Colloff, M.J., Pullen, K.R. and Cunningham, S.A. 2010. Restoration of an ecosystem function to revegetation communities: The role of invertebrate macropores in enhancing soil water infiltration. Restoration Ecology, 18 (S1), pp. 65-72.

Jones, C.G., Lawton, J.H. and Shachak, M. 1997. Positive and negative effects of organisms as physical ecosystem engineers. Ecology, 78 (7), pp. 1946-1957.

Khanmirzaei, A., Kowsar, S.A. and Sameni, A.M. 2011. Changes of Selected Soil Properties in a Floodwater-Irrigated Eucalyptus Plantation in the Gareh Bygone Plain,Iran. Arid Land Research and Management, 25 (1), pp. 38-54.

Kowsar, S.A. 2009. Desertification Control through Floodwater Harvesting: The Current State of Know-How. The Future of Drylands (4), pp.229-241. Available at: http://www.springerlink.com/content/m83420014j436280/export-citation/ [accessed on 14 August 2011].

Kowsar, S.A. and Pakparvar, M. 2004. Assessment methodology for establishing an Aquitopia, Islamic Republic of Iran. In: Proceedings of the Second International Workshop, 29 November - 2 December 2003, Shiraz, I.R. Iran, pp. 40-55. UNESCO: UNESCO-MB Drylands Series No. 3.

Rahbar, G. (no date). The effects of spate irrigation on soil infiltration rate in Kowsar aquifer management station. Mimeo.

18. Using natural landscapes, Turkmenistan

Introduction

Natural surfaces – called takyrs – are used to harvest water in the extremely dry Karakum Desert in Turkmenistan. Takyrs are large stretches of desert landscape that are characterized by flat or gently sloping topography. They are deposits of clay material aggregated in local drainage zones. In Turkmenistan these areas cover a surface of 19,000 km2. Of this 11,300 km2 is occupied by takyrs that are larger than 1 km2. Impermeable by nature, they have a low infiltration rate and, because of their sheer size, deliver substantial volumes of runoff even from the scarce amounts of rainfall they receive. Where the use of surface streams and aquifers is not an option, takyrs are effectively used to harvest water. It is thought that takyrs in Turkmenistan can produce 350-450 Mm3 per year. Only a small part is utilized at present for productive use.

Buffer systems

The Karakum Desert covers most of Turkmenistan. It is characterized by a warm dry summer and by a short winter. Rainfall is usually 110-200 mm per annum - concentrated in the cooler winter months. The desert population has developed different buffer systems to save runoff during the humid periods and survive the long dry part of the season. Though the main activity is cattle herding, households also engage in small-scale farming for home consumption and supplementary feed.

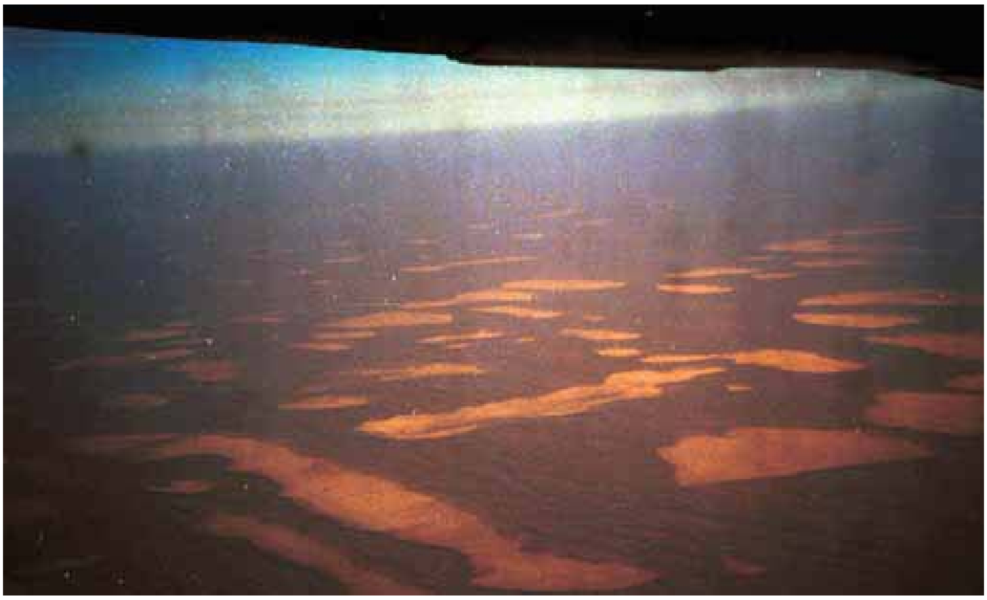


Figure 1. Takyrs from the air (Photo credit: W.P. Spaan)

The peculiarities of takyrs make them a perfect surface to produce excess water. Different techniques are used to store the run-off for later productive use: soils, shallow aquifers, closed reservoirs and open ponds. All the techniques make use of the low permeability of the natural landscape to concentrate the rainfall water. Often two or more methods are used conjunctively operated to gain the most out of the small amount of rain available. The main storage techniques are:

Khaks

These are artificially made depressions that collect water from takyrs during the rainy spells and store it in open-air reservoirs. They are mainly used to water livestock for 2-4 months after the winter. Due to the high evaporation rate of the environment these ponds can be used productively in the first part of the dry season only. They are not suitable to provide water for human consumption because the water in the open storage gets easily contaminated. The investment necessary to construct a small khak is around USD 350; a large system can cost up to USD 960.

Sardobs

Water can be alternatively stored in closed cisterns. These sardobs used to be built of lime mortar and bricks with a covering dome. Modern versions make use of concrete. Sardobs collect surface run-off. A typical cistern has a capacity of 500 m3. When larger storage is needed, two or more structures are built in the same location. These constructions yield clean water, suitable for domestic use and in the drier months for livestock's watering. The freshwater obtained can be mixed with brackish aquifer water to water livestock for a longer period. The construction of one unit can cost up to USD 8750.

Chirle

An alternative is to store excess water in the sandy soil shallow aquifer underneath the takyr and to withdraw the amount needed with one or more wells. The run-off water is collected in a depression excavated at 2-12 m in diameter from where it recharges the permeable sandy layers underneath the impermeable takyr. The concentrated water is preserved in a freshwater lens above the saline aquifer and it stays separated from the salty water due to its lower density. One or more wells can be dug in and around the depression. Contrary to the other technologies used in the Karakum Desert, the storage capacity of these so-called chirles is flexible. When only one well for human consumption is in use, the structure costs USD 2500. When ten wells are dug, the cost increases up to USD 21,000. In case the wells are also utilized for livestock water or to improve the rangeland the cost rises to USD 36,500. Despite the first investment, maintenance costs are relatively low at USD 115-192 per year. The costs are usually shared by many households and the community maintains the chirles.

Oytak farming

Oytaks are natural takyr depressions covered with a layer of sandy soil that, during the rainfall, becomes moist and can be used for farming. Oytaks are traditionally used to produce fodder, but alternatively they can be used for crops and trees cultivation. Often oytaks gain water from the natural sloping surface of takyrs, but in certain cases the run-off water can be conveyed through furrows. When plants are growing, oytaks tend to act as sand traps and to decrease the surface area of the takyr. The construction of one furrow unit requires minimal structural work and has a cost of USD 24.

Modern takyr cultivation

Mechanized farming has potential in this harsh environment. A system of parallel furrows can be excavated perpendicular to the takyr slope to form a series of consecutive smaller catchments. Each catchment is confined in the lower side by a furrow in which the plants are grown. This system relies

Figure 2. Chirle well in Madau, western Turkmenistan (Photo credit: Luuk Fleskens)

Figure 3. Oytak after runoff event (Photo credit: Luuk Fleskens)

Figure 4. Oytak in Central Karakum (Photo credit: Luuk Fleskens)

on the fact that by reducing the catchment area a better runoff coefficient is obtained and the water is thus used more efficiently. In other arid regions similar farming practices are used to improve rangeland productivity, and typically an inter-furrow distance of 7-12 m is used depending on the climatic characteristics. When the climate is milder even fruit trees and melons can be cultivated using an interspace of 20-25 m. These modern systems require substantially higher investment and technological input than the traditional techniques, but they are potentially profitable.

Benefits

These different water buffer systems provide freshwater for human consumption and for economic activities in difficult desert conditions. Furthermore, with larger investments there is potential for larger-scale desert farming by using modern takyr cultivation. A household that has a directly available source of freshwater from one of the water harvesting techniques will save money otherwise used for trucking water or for pumping deep brackish water. In addition farmers will benefit from increased yields, healthier herds and lower dependency on piped water.

In a situation where herding is the main way of living, water brings potential for better conservation of the natural resources, but also some concerns. When water is concentrated in few spots, the animals tend to be concentrated in the areas immediately surrounding them. The risk of overgrazing and soil degradation is thus magnified. On the other hand without animal trampling around and breaking the surface crust, the soil tends to create a biogenic crust that can favor desertification processes. Nevertheless, pressure on natural resources caused by overgrazing can be decreased by augmenting the available sources of water and by spreading the herd on a larger area.

For agricultural production, modern takyr cultivation seems to always be profitable. High Internal Rate of Returns (IRR) were estimated: 130 for melon production, 38 for quince, 41 for grapes and 30 for pomegranates (Fleskens et al., 2007). When cultivating melons using oytaks the IRR is 99, based on average yearly conditions, assuming no external labor is hired and the average production of melons is 1200 kg.

For human consumption only sardobs and chirles can be used. Sardobs showed an IRR of 14. For chirles with a single well the IRR was 6.9, and when 10 wells where in use it was 8.6. These conditions refer to a situation where no external labor is needed and where the closest source of freshwater is 20 km away.

When the water harvesting techniques are used to create new rangelands in the central part of the Karakum, sardobs showed an IRR of 49, chirles of 61 and a small khak of 583. These figures are based on a number of assumptions: all the labor needed is provided internally and no rangeland degradation will take place. In case the water is used to create improved rangelands, the IRR always show positive values that guarantee a positive return.

Future

Investment in water harvesting from the natural landscape under a range options is profitable. Looking at the cost of water collected with the different methods, khaks appear to be the cheapest alternative in terms of cost of water per volume. Nevertheless, khaks can be used for only a few months per year and they produce contaminated water that is not safe for drinking. On the other hand, sardobs are the cheapest way to produce safe drinking water. This is particularly true when alternative sources of drinking water are more than 10 km away. The water harvesting systems for productive purpose all have very attractive prospects.

After the breakdown of the USSR, the central state investments in desert development ended and only few new structures has been constructed. There is a large unutilized potential – even in this inhospitable environment – to make more use of the natural harvesting basins. Local farmers associations may play an important role in managing the needed capital and in creating instruments to favor the construction of water harvesting structures.

Reference

Fleskens, L., Ataev, A., Mamedov, B. and Spaan, W. P. 2007. Desert water harvesting from Takyr surfaces: Assessing the potential of traditional and experimental technologies in the Karakum. Land Degradation & Development, 18(1), pp. 17–39.

19. Fanya juu terracing, Tanzania and Kenya

Introduction

Fanya juu terrace systems have developed steadily in several parts of East Africa. One area where their spread has been spectacular is the Machachakos District in Kenya – where 85% of the land is now terraced. There are however several other areas where they are making an entrance. One area is the Makanya catchment in northern Tanzania. This catchment of 300 km2 is part of the Pangani Basin. Its population still largely depends on subsistence agriculture and the area is characterized by high rainfall variability – ranging from 400 to 800 mm annually.

Rain comes in two seasons. The long season (masika) lasts from March till May, whereas the shorter season (vuli) is from October to December. The maximum rainfall for any season is 400 mm. With the amount of water often heavily constrained, conservation measures are of crucial importance to raise yields and provide food security. Conservation measures in Makanya include hand-hoeing, terracing, intercropping, small flow diversions and irrigation from micro-dams.

Fanya juu: to throw it upward

Fanya juu literally means 'throw it upwards' in Kiswahili. The terrace systems are created by excavating a trench along the slope and applying the excavated soil material immediately uphill of the trench (Figure 1). This is repeated several times along a slope and as a result a system of benches and trenches is created. Next, nature is expected to do its work. The purpose of this system is to catch the flow of soil and water during run-off events before the benches and infiltrate water in the trenches. Over a period of 3-10 years terraces are formed with horizontal gradients.

Fanya juus can be developed on areas with slopes between 5 to 60% and climates similar to Makanya. As slopes get steeper the fanya juus become more costly to develop per surface area and less economical. Spacing of the trenches and bunds depends on slope and soil depth (Box 1). The construction by hand takes 90 days per ha on a typical 15% slope – or more (150-350 days/ha) in areas that are prone to erosion and have unstable soils. This translates in a cost of USD 60-460/ha. Bunds are best stabilized with grasses, which can be used for fodder too. Annual maintenance consists of building up the bunds from below and trimming grass.

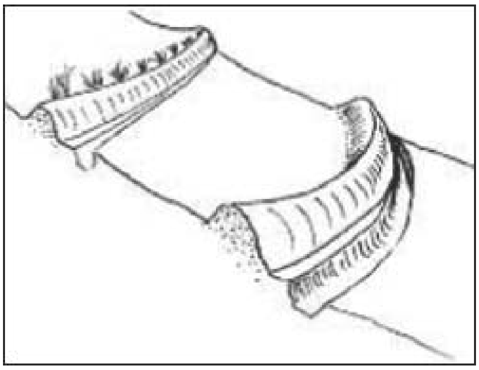


Figure 1: Diagram of a trench of a fanya juu terrace system (Source: WOCAT, 2007)

Box 1: Designing fanya juus

The spacing of fanya juu depends on slope and soil depth. It is usually between 5-20 m. On land with less than 5% slope it is 20-30 m, but terraces get smaller as land gets steeper: 15-20 m on land with a 5-10% slope; 10 to 15 m on a slope of 10% or more; and 5 m on even steeper slopes (10% or more).

The height interval between two terraces is 1.7 m. As a rule of the thumb the distance between two terraces is 100 times the height interval between two terraces divided by the land gradient (in %).

The infiltration ditches are typically 60 cm deep and 75 cm wide.

The bund has a typical height of 0.4 m and a base of 0.5-1 m, and can vary to a height of 0.5 m and a base of 1.5 m. On land that is very steep the bund is placed downhill from the trench. This practice is called fanya chine. It prevents that on very steep slopes the soil bund washes into the trench. The design of fanya juu also depends on the soil type. In sandy loamy soils an infiltration trench is useful. In 'black cotton' soil - with large water holding capacity - this is not required.

Figure 2. Fanya juus in Masingi, Kenya (Photo credit: MetaMeta)

Cost and benefits

Against the typical establishment costs of USD 60-460 per ha, fanya juu avoid uncontrolled run-off and improve the retention of soil moisture. This makes it possible to have earlier planting dates and a prolonged farming season, enabling higher yields of existing crops and providing opportunities for farmers to introduce new crops and new varieties. The fanya juu also help over dry spells. Crop yields typically increase by 50%

(UNEP, 2000). Moreover, along the trenches horticulture crops can be grown: papaya, banana and fodder. Fanya juu protect against erosion and have the lowest soil loss of all soil water conservation systems. In a study of Kwalei, Tanzania soil loss from these systems was estimated at 2.7 ton/ha for the two seasons. In comparison to areas without protection, annual soil loss was estimated at 25 ton/ha, in grass strip areas it was estimated at 15 ton/ha, and for bench terraces 6 ton/ha. Fanya juu are economic investments in agricultural production – particularly when the land is not too steep or instable.

Box 2: Part of a large buffer management plan

The accelerated development of fanya yuu terraces is planned as part of sub catchment plans - that are being prepared by Water Resources Users Associations throughout Kenya. These WRUAs consist of prominent farmers and local leaders, a mix of women and men selected and trained by the Water Resources Management Authority and local chiefs. Their prime task is to enforce local water resource management - avoiding encroachment and unauthorized water diversions, protecting springs and river banks and promoting better buffer management. The WRUAs have registered as a Society. This provides the legal coverage to undertake activities, such as setting up nurseries, the development of sand dams, subsurface dams and local storage, terracing, and the promotion of roof top water harvesting.

Figure 3. Benedict Nbungi, chairperson Matuata WRUA. Priorities in the Matuata WRUA are awareness, creation and rehabilitation of small local storage, deepening of shallow wells, awareness creating, tree planting and fanja yuu terracing (Photo credit: MetaMeta)

Box 3: Optimizing soil moisture in the Fanya Juu systems

The soil moisture in fanya juus was investigated by Muharika et al. (2010). In order to assess the impact of fanya juu systems on the soil moisture content in the root zone around the structure, tubes were installed at gentle- and steep-sloped sites in the Makanya catchment (Figure 4).

Tube A represents the soil moisture in the 'controlled' situation, as no fanya yuu was constructed uphill. Tube B measures the moisture level, and so the impact, on the trench-site of the fanya juu. Tube C estimates the moisture level in the root zone in the middle section of the fanya juu, while the impact close to the bund is measured by Tube D. The research showed the following:

Moisture levels in the rootzone around the fanya juu bench and trench structures are higher than those located at a distance. In the beginning of the rainy seasons, specifically, for the gentle-sloped areas (with large distances between the bunds) the moisture content around the fanya juu structure was around 17% and 12% in the area in the middle of the structures and upstream of those. In the dry spells the moisture level around the fanya juu structure was 3% higher than the other sites.

At the steeper-sloped areas generally lower soil moisture levels were measured – but again the moisture levels closer to the structures were 3-5% higher. The distribution of moisture is critical as crops may move into the moisture-stressed conditions in parts of the fields.

For moisture optimization the distance between fanya juu structures needs to be smaller (smaller than the distance recommended for the purpose of soil conservation) in order to enlarge the hydraulic potential of these structures. On steep slopes, particularly with shallow soils, the water of the trenches drains more as sublateral flows rather than adding moisture to the root zone.

Another major conclusion is that in both sites with the fanya juu structures more than 50% of the water captured does not benefit local use as it is lost to deep percolation. This loss leaves room for other local water conservation structures, like micro-dams, to improve water retention in the area.

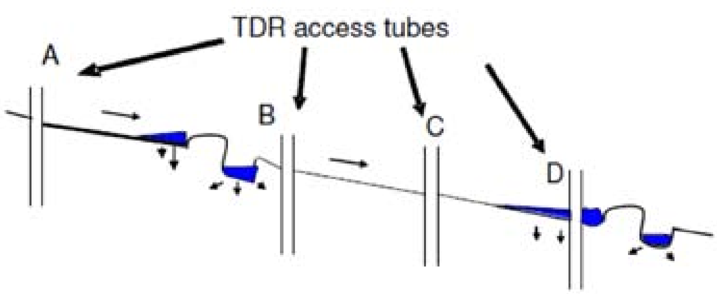


Figure 4. Placement of the TDR tubes along the slope (Source: WOCAT, 2007)

References

Critchley, W. 1991. Looking after our land – Soil and water conservation in dryland Africa. Oxford: Oxfam.

Herweg, K. and Ludi, E. 1999. The performance of selected soil and water conservation measures – case studies from Ethiopia and Eritrea. CATENA, 36 (1-2), pp. 99-114.

Hudson, 1988. Fanya Yuu terrace able to develop in less than 7 years.

Infonet-biovision. 2010. An introduction to soil conservation measures. [Online] Available at: http://www.infonet-biovision.org/default/ct/265/soilManagement [Accessed 23 March 2011].

IIED (2011). Climate Change Adaptation technology: Fanya Juu Terraces. [onlline video] Available at: http://www.thewaterchannel.tv/index.php?option=com_hwdvideoshare&task=viewvideo&Itemid=4&video_id=1019. [Accessed 23 August 2011].

IWMI. 2006. Fanya juu – Overview of technologies. [Online] Available at: http://westafrica2.iwmi.org/projects/Adoption%20Technology/RainWaterHarvesting/50-Fanya%20juu.htm [Accessed 23 March 2011].

IWSD. (no date). Sourcebook of alternative technologies for freshwater augmentation in Africa. [Online] Available at: http://www.unep.or.jp/ietc/publications/techpublications/techpub-8a/index. asp#1 [Accessed 23 March 2011].

Kiome, R.M. and Stocking, M. 1995. Rationality of farmer perception of soil erosion: The effectiveness of soil conservation in semi-arid Kenya. Global Environmental Change, 5 (4), pp. 281-295.

Makurira, H., Savenije, H.H.G. and Uhlenbrook, S. 2010. Modelling field scale water partitioning using on-site observations in sub-Saharan rainfed agriculture. Hydrology and Earth System Sciences, 14, pp. 627-638.

Motsi, KE., Chuma, E. and Mukamuri, B.B. 2003. Rainwater harvesting for sustainable agriculture in communal lands of Zimbabwe. Physics and Chemistry of the Earth, 29 (15-18), pp 1069-1073.

Tenge, A.J. Graaff, J. de and Hella, J.P. 2005. Financial efficiency of major soil and water conservation measures in West Usambara highlands, Tanzania. Applied Geography, 25 (4), pp. 348-366.

WOCAT. 2007. World Overview of Conservation Approaches and Technologies. [Online] Available at: http://www.fao.org/ag/agl/agll/wocat/wqtsum2.asp?questid=KEN05 [Accessed 23 March 2011].

ZFU AGRITEX. (no date). A guide for farmers on good land husbandry – Alternative soil and water conservation Ideas. [Online] Available at: http://www.uz.ac.zw/agriculture/cropscience/CD/gff/13%20More%20soil%20and%20water%20conservation.pdf [Accessed 23 March 2011].

20. Maximizing recharge with cascade check dams, Yemen

Introduction

Yemen is one of the five most water-stressed countries in the world, and within Yemen, Sana'a Basin – the seat of the country's capital – is the most precarious area. Yet Yemen is also a country with an extraordinary history of innovations in water management. One such innovation is the construction of cascades of check dams in wadis (ephemeral rivers). These check dams slow down the short-term flood flows in these dry rivers and maximize recharge. This enables the cultivation of very high-value grape farming in an area essentially dependent on only short floods.

Figure 1. High value grape farming, Wadi Qaradah Yemen (Photo credit: MetaMeta)

Cascade check dams

Wadi Qarada and Wadi Bahman are tributaries of Wadi A'ssir, located 30 km northeast of Sana'a. Like elsewhere in Sana'a Basin the climate is semi-arid. Average annual precipitation is 250 mm but evaporation is 2500 mm. Rainy days are few – 6 to 25 – spread mainly from March to August. In the dry catchment they transform into short-term floods, lasting a few hours. This is the main source of water.

The intermittent floods used to be either directly diverted to the land (so-called 'spate irrigation') or stored as surface storage in local reservoirs. Over the years agriculture has come to rely heavily on groundwater irrigation, but groundwater consumption far exceeds groundwater recharge. The difference is that Sana'a

Basin is estimated at a factor four. Due to extensive irrigation and the rapid growth of Sana'a, the drop in groundwater levels in the main Tawilah Sandstone aquifer in the last fifteen years is estimated at 141 m.

Wadi Qarada and Wadi Bahman are famous for their grape farming and the production of high-quality and high-value raisins. Given the dry nature of the area this looks like a miracle – trellis grapevines stretch from mountain to mountain on either side of relative narrow dry riverbeds.

Historically, grape fields were spate irrigated by short-term floods, with supplementary irrigation practised from shallow open wells. These open wells were located near the banks of the riverbeds. Over the years, however, the shallow dug wells went dry or became seasonal. Many were abandoned and water abstraction from deep tube wells became the main source of water – resulting in lowered water levels to 350 m and reduced well productivity to less than half.

In Yemen in several places cascade check dams were built, for instance, in Wadi Qaradha and Wadi Bahman with the support of the Sana'a Basin Water Management Project. The cascade check dams consist of a series of low-elevation barriers (1-3 m high) built up from coarse stone pitching. Twenty-nine of these small structures were built in Wadi Bahman and 75 in Wadi Qaradha. The check dams are complemented by a protection wall along the riverbed, again made of stone pitching.

The cascade check dams serve two purposes: (a) to reduce the speed of flow in the wadi; and (b) to impound excess water during flash floods. The check dams divert water to spate irrigation canals on both sides of the wadi bed and increase the recharge of shallow groundwater. In semi-arid environments recharge most effectively occurs through riverbeds, as in these areas the alluvial deposits overlay sandstone and the cascade dams optimize the recharge effect.

Cost and benefits

An assessment was made of recharge efficiency of several water harvesting systems in the area: cascade check dams and different sized surface storage dams. Using a water balance model and flow monitoring values, the assessment concluded that cascade check dams have a recharge efficiency of 94%. This is ahead of the smaller storage dams and definitely much better than medium-sized dams. The cascade check dams are a major improvement over surface storage dams, because:

- Recharge through the riverbed is most effective. With cascade check dams there is an increase in the time for recharge and the areal spread of water, as floods are slowed down.
- Unlike in storage dams, sedimentation is not an issue: sediments are flushed by every subsequent flood. In storage dams on the other hand sediments accumulate at the bottom of the reservoir and obstruct the recharge of water.
- Check dams do not destroy the traditional distribution of water. Farmers along the wadi can continue to use the water for spate irrigation.

The value of incremental recharge due to cascade dams in Wadi Bahman was three times more than the incremental recharge at Beryan masonry surface storage dam. The cost of construction was only one fifth of the cost of construction of the gravity dam. The cost of investment in water storage per unit of check dams was calculated at USD 1.26 per m3 and for recharged water it was in the order of USD 0.10 per m3 (assuming a lifespan of 20 years).

Farmers in the area observed a marked improvement in water availability in the open wells near to the riverbed and a decline in the water level of tube wells. Fadhel M. Manea, Chairman of the WUA in Qaradha pointed out that 'one of the positive effects of check dams was diversion of run-off to spate irrigate grape fields on both banks of the wadi bed.'

Box 1: Designing cascade checkdams in dry river beds

The location and the height of the check dams are governed by the gradient of the stream bed, and the depth of waterway, respectively, while the cross-sectional dimensions depend on the expected peak flow. The design should preserve a proper speed of flow which ensures that sediment is removed at the upstream check dams providing clear water to the downstream part, which infiltrates more readily. A number of design criteria were adopted for the Wadi Bahman:

- The cross section of the check dam has mild side slopes to improve access to the wadi bed and to simplify the construction.
- A foundation key is preferred to improve dam stability against sliding and improve resistance to hydraulic pressure.
- For stream training purposes, the first dam of a check dam series should be constructed at the uppermost end of the valley. The first dam serves as the reference for calculating the distance to the second dam. It is rule of thumb that the height of the lower dam should be at the base level of the upper dam.
- To take into account the dug wells around the check dam site, the elevation of the crest of the check dam, and therefore the dam height, is set equal to the top elevation of the wells so that the upstream reservoir is extended to reach the wells, thus maximizing the dam's recharging capacity.
- The size of voids between boulders in the dam structure is selected so that sediments carried by the first flood will penetrate the check dam body and be deposited inside of the body of the dam, therefore improving stability and water tightness of the structure.
- The site of the check dam should not result in flooding behind the dam or create large shallow pools. Where back flooding does take place, protective embankments should be built.
- A protection wall along the wadi is added.

Box 2: Check dams

Check dams in Wadi Qaradha

Number of check dams: 75 Length : varying from 40 m to 100 m Height of cascade check dam: varying from 1 m to 1.5 m Crest width: 2 m Upstream slope : 1V: 1H Downstream slope: 1V : 3H Total contract cost: USD 648,000

Check dams in Wadi Bahman

Number of cascade check dams: 29 Length : varying from 7 m to 57 m Height of cascade check dam: varying from 1 m to 3 m Crest width: 2 m Upstream slope : 1V: 3H Downstream slope: 1V : 5H Total contract cost: USD 182,000

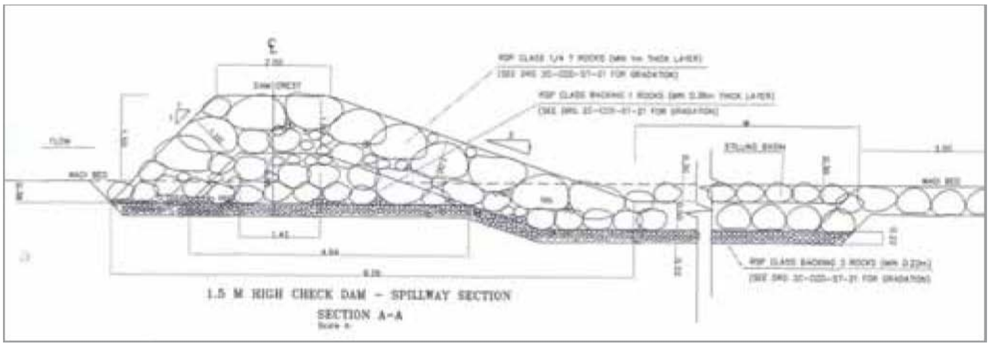


Figure 2. Features of a cross section of a 1.5 m high check dam at wadi Qaradha, Yemen

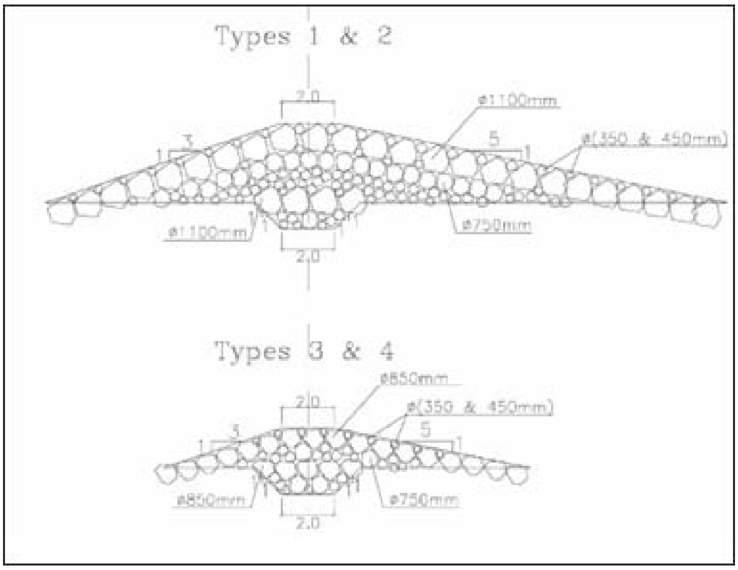


Figure 3. Typical cross sections of 3 m and 1.5 m high check dams at wadi Bahman , Yemen

References

Alderwish, A. M. and Alderwish, W. I. 2009. Integrated Water Management for Small Catchments in Arid Mountainous Region-Yemen. Sana'a: Sana'a Basin Water Management Project. [Online] Available at: http://gscp.gov.ye/BS/Sumary_report_dams_recharge_final.pdf [Accessed 14 August 2011].

Japan International Cooperation Agency (JICA). 2007. The Study for the Water Resources Management and Rural Water Supply Improvement in the Republic of Yemen, Water Resources Management Action Plan for Sana'a Basin, Final Report. [Online] Available at: http://gscp.gov.ye/BS/ JICA_summary_report.pdf [Accessed 14 August 2011].

Practical Action. 2005. Water Harvesting in Sudan. Warwickshire: The Schumacher Centre for Technology and Development.

Sana'a Basin Water Management Project. 2010. Assessment of Water Resources Potential of the Sana'a Basin, Strategic Options for the Sustainable Development and Management of the Basin's Water Resources, Final Report. Sana'a: Sana'a Basin Water Management Project.

Sana'a Basin Water Management Project. 2010. Sana'a Basin Integrated Water Resources, Management Action Oriented Policy Paper, Assessment of Phase I. Sana'a: Sana'a Basin Water Management Project. [Online] Available at: http://gscp.gov.ye/BS/AOPP_Final_Report.pdf [Accessed 14 August 2011].

Sana'a Basin Water Management Project. 2006. Bahman Check Dams Design Report. Muscatine: Stanley Consultants, Inc.

21. Groundwater retention weirs, Maharashtra, India

Introduction

Groundwater retention weirs, so called 'Kolhapur Type Weirs' (KTW), have been constructed by the Rural Development and Water Conservation Department of the Government of Maharashtra (India) under the Minor Irrigation Programme, Maharashtra (MIP-M). As far as irrigation structures go they are unique: the weirs do not divert water but rather they retain and head up the subsurface flow in the rivers, so as to replenish the wells upstream of the weir. The benefits are enormous: they create assured groundwater supply from the wells and improve soil moisture – contributing to substantially higher yields and making it possible to utilize a wider range of crops and benefit from higher crop intensities. They do not suffer from the operational problems of other irrigation systems as there are no channels to maintain. There are a recorded 131 medium-size KTWs in Maharastra, managed by the Rural Development and Water Conservation Department. A typical KTW has a command area of 100-250 ha. In addition there are thousands of smaller groundwater retention weirs under the authority of the local government.

Bolegaon KTW

A KTW is built across a river in order to store water in the riverbed within the banks upstream of the weir and the adjacent aquifer. For this purpose, a number of piers are constructed on top of the weir. Between these piers shutters are placed – known as 'needles'. This is done at the end of the monsoon season so as to store water flowing in the river. These shutters are then removed at the start of the monsoon season in June, so that the monsoon flows in the river can pass the KTW freely. It is common to build a bridge on top of the piers for the placement and removal of the shutters and also allow traffic to cross the river.

Figure 1. Downstream side of Bolegaon KTW (Photo credit: Olaf Verheijen)

An example of a KTW is the Bolegaon Weir located in Gangapur Taluka in Aurangabad District. The climate in Bolegaon is typical for southern India: dry and dominated by an intense southwest monsoon from June to October. Average annual rainfall is 710 mm – but most of this is in this monsoon period. Dry spells in the middle of the rainy season lasting up to a fortnight are experienced in August and they can play havoc with the rainfed crops. A farming population of approximately 2700 people depends on the KTW, mostly farmers owning less than 2 ha. In 2004-2005 the Bolegaon KTW was constructed across the Shivna River, which is a tributary of the Godavari River. Its length is 92 m and reaches a maximum height of 4.5 m. It counts 31 piers constructed on top of the weir. The metal shutters are placed in the openings between the piers towards the end of August in order to catch the receding monsoon flow. With a discharge of at least 6.0 m^3/s, it takes no more than two days to fill up the area upstream of the weir. The storage capacity is 1.04 Mm^3.

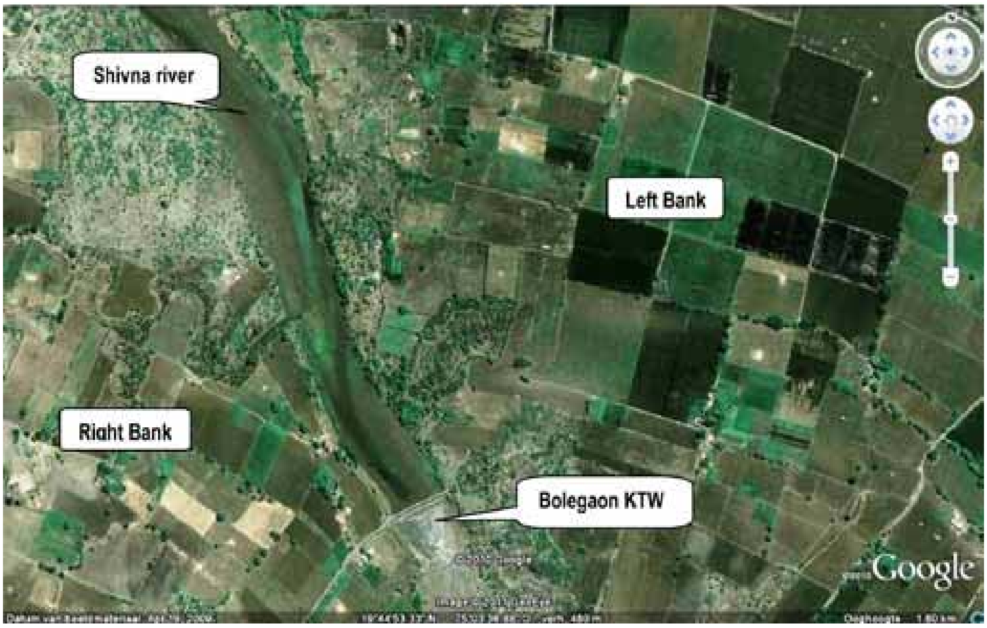
Costs

The total construction cost of the KTW was USD 425,000. With a command area of 159 ha, this works out to USD 2,660 per ha. A main advantage of the KTW is that no land acquisition is required for water storage as the existing riverbed and adjacent aquifer is used for this purpose. Initially it was proposed in Boleagon to install 3 or 4 lift irrigation systems to pump stored water to the fields on the left bank of the Shivna River. Farmers insisted that there was no need for this as the seepage from the stored water would sufficiently recharge the existing wells.

Figure 2 and 3. Piers with installed shutters and bridge (upper) Reservoir area upstream of KTW (below) (Photo credit: Olaf Verheijen)

One of the basic concepts was the effective participation of the concerned farmers in the planning, design, construction and management of their irrigation scheme. Once completed, the responsibility for the operation and maintenance of the newly-constructed KTW was formally transferred to the farmers. For this purpose, a water users association (WUA) was formed and registered, taking over responsibility for the KTW in 2005.

To finance the operation and maintenance of the KTW, the WUA collects an annual irrigation service fee from all landholders irrigating their fields within the command area. For the 2009-2010 season, the WUA set the fee at INR 1,000 (USD 22) per ha for sugar cane and INR 750 per ha for all other crops. For the 2010/2011 financial year (FY), the WUA proposed to increase the service fee to INR 3,500 (USD 77) per ha in order to finance the replacement of the rubber seals of the shutters. An additional source of income is the lease of the fishing rights at a rate of INR 15,000 (USD 330) per year.



So far, the actual maintenance expenditures were modest: INR 63,000 (USD 1386) during the FY 2008/2009 and INR 53,000 during the FY 2009/2010, mainly for the replacement of bolts of shutters. One important advantage is that – contrary to conventional diversion irrigation systems – siltation upstream of the KTW is not a problem. When the shutters are removed from the KTW prior to the onset of the monsoon season, the first floods wash away any silt that has been deposited during the storage of water.

Box 1: The Water Balance at Boleagon

The catchment area upstream of the KTW site is 2,035 km^2. The total annual yield of the catchment area upstream of the KTW site is approximately 208 Mm^3. 162 Mm3 is already allocated to 40 existing and proposed irrigation schemes upstream of the KTW site, so a net volume of 46 Mm^3 is available at the KTW site. As the Bolegaon KTW has a storage capacity of 1.04 Mm^3, downstream water users are not adversely affected as more than 40 Mm^3 continues to be available for utilization downstream.

There are three alluvial aquifers within a depth of 20 m at Boleagon. The thickness of each aquifer ranges from 1.5-7.0 m. These shallow aquifers are largely filled at the end of the monsoon season from natural recharge. Based on this natural recharge 4,000 m^3 water per ha can be abstracted for rabi (dry season) cultivation. This represents about 80% of the average irrigation requirement at 65% distribution efficiency. The remaining 20% of the irrigation requirement comes from the additional retention of water by the KTW.

Although the KTW itself is built on rock strata, the upstream riverbed and banks are comprised of sandy soils which are permeable. At full storage capacity, the daily seepage rate to the aquifers is estimated to be over 6,000 m^3, decreasing to zero when the KTW is empty and the ponded area decreases (Table 1). It is estimated that approximately 20% of the total storage of about 1 Mm^3 recharges the aquifers through seepage from mid-September to mid-February. This is sufficient to allow the irrigation of 109 ha of rabi crop from groundwater as it will make up the 20% deficit that is not available in the aquifers from natural recharge. In addition, stored water is lifted by seven wells located in the riverbed itself with the capacity to irrigate about 50 ha. The water balance is lost to evaporation, leakage and deep percolation.

Depth of water at KTW site (m)	Storage (m3)	Surface area (m^2)	Pond length (m)	Seepage area (m^2)	Seepage rate (m^3/day)
0.5	38,000	76,000	50	25	1
1.0	111,300	111,300	444	444	39
1.5	184,600	123,067	888	1,331	175
2.0	257,900	128,950	1,331	2,663	466
2.5	331,200	132,480	1,775	4,438	971
3.0	508,925	169,642	2,219	6,656	1,747
3.5	686,650	196,186	2,663	9,319	2,854
4.0	864,375	216,094	3,106	12,425	4,349
4.5	1,042,100	231,578	3,600	16,200	6,379

Benefits

The command area of the Bolegaon KTW is situated on both banks (although mainly on the left bank) of the Shivna River over a total length extending 2.5 km upstream and 1.0 km downstream of the KTW site, with a width of about 300 m. It is estimated that approximately 20% of the total storage of about 1 Mm3 recharges the aquifers through seepage between mid-September and mid-February. This is sufficient to safeguard irrigated agriculture of 109 ha of rabi crop from groundwater as it will make up the 20% deficit that is not available in the aquifers from natural recharge. In addition, water is lifted by seven wells newly installed inside the riverbed with the capacity to irrigate about 50 ha. These are operated as soon as the river bed falls dry. The balance water is lost to evaporation, leakage and deep percolation. A total of 152 households own land in these areas. According to an inventory, a total of 45 dug wells and 9 tube wells were installed in the command area prior to the construction of the KTW. The wells are clustered along the banks of the river and in a defined 'strip' of land away from the river with a recharge connection from the river. Most farmers use 5.0 to 6.0 HP (electric) pumps to lift groundwater from the wells.

Before the KTW was constructed, the wells had water for about 9 months per year until February/March – missing out on the large and vital part of the growth season. Following the construction of the KTW, all wells except three on the right bank have water throughout the entire year. The main limitation for the operation of the wells is the availability of electricity for only 8 hours per day.

The WUA has adopted a policy that forbids the installation of new wells within the command areas in order to avoid that the aquifers are overdrawn and the existing wells become dry. Further to improving water use efficiency, a total of 20 farmers have installed sprinklers on 50 ha and drip systems on 10 ha in the ICA.

Figure 5 and 6. Dug-well (upper) and tube-well (below) in ICA on left bank, India (Photo credit: Olaf Verheijen)

Transforming lives

The agro- and socio-economic impact of the construction of the Bolegaon KTW together with the development of the WUA and the implementation of the agriculture development programme has been very significant. The main achievements are briefly described below (Table 2.).

First and foremost, the cropping pattern has changed considerably with the larger groundwater security and assured soil moisture. The range of crops has increased, the cropping intensity has gone up and so have the yields..

Table 2. Impact of the construction of the Bolegaon KTW , the development of the WUA, and the implementation of the agriculture development programme

Crops	Pre-Project Cropping Pattern		Post-Project Cropping Pattern			
	2002/03		2009/10		2010/11	
	Area (ha)	% ICA	Area (ha)	% ICA	Area (ha)	% ICA
Kharif						
Millet	68	43%	41	26%	10	6%
Maize	16	10%	7	4%	20	13%
Pulses	-	-	26	16%	-	-
Vegetables	-	-	-	-	2	1%
Rabi						
Wheat	-	-	24	15%	20	13%
Sorghum	24	15%	12	8%	6	4%
Gram	33	21%	27	17%	1	1%
Sunflower	10	6%	-	-	-	
Maize	-	-	6	4%	-	
Vegetables	-	-	12	8%	2	1%
Two Seasonal						
Cotton	48	30%	48	30%	98	62%
Chilli	-	-	13	8%	2	1%
Sugarcane	-	-	11	7%	27	17%
Horticulture	-	-	6	4%	-	-
Ginger	-	-	-	-	2	1%
Total	199	125%	233	147%	188	120%

Kharif

Prior to the construction of the KTW, the farmers cultivated primarily dry staple crops. Five years after the completion of the KTW, a larger range of crops are being grown. This includes new cash crops: vegetables, chilli, sugar cane and fruit. During the 2010/11 rabi season, a number of farmers also started the cultivation of ginger, and the area under cotton increased from 48 ha to 98 ha.


Figure 7 and 8: Cultivation of cotton and sugarcane (left) and ginger (right) in ICA (Photo credit: Olaf Verheijen)

The cropping intensity increased from 125% in 2002/03 to 147% in 2009/10, but it decreased to 120% in 2010/11 as a result of the cultivation of two additional seasonal crops – mainly because of the cultivation of two long duration crops, sugar cane and cotton.

Due to the larger groundwater security, better soil moisture and the agricultural development programme, yields have improved significantly. For instance, maize production increased from 3.0 t/ ha in 2003-2004 to 5.8 t/ha in 2009-2010. During the same period, the yield of cotton improved from 0.5-1.0 t/ha to 2.5 t/ha.

According to data collected during the agro-economic impact assessment in 2010, the net return increased from INR 6,921 (USD 157) per ha in 2003-2004 to INR 36,401 (USD 824) per ha in 200920101. In other words, the farmers' incomes improved by 425% and the payback to investment period is less than five years. The improved availability of soil moisture irrigation water in the wells throughout the growth season due to the construction of the KTW is the most important factor for this significant increase in farmers' income as it allows farmers to cultivate more irrigated land, to grow more high value crops and to achieve higher yields for the planted crops.

In addition to the benefits in crop production, the following positive impacts were highlighted by the Water Users Association:

- 50 to 60 landless households are employed as daily labourers throughout the year and wage rates for female labourers have increased from INR 30 to INR 150 per day.
- Access to better education as 15 students attend an English Medium School.
- Improved access to health care as more households go to the hospitals in the town of Aurangabad instead of the local health clinic in Gangapur, whereas all pregnancies are now supervised by medical staff.
- More families can afford the consumption of wheat in their daily meals.
- 25 to 30 households have replaced their mud houses by premises made of brick and concrete.
- About 100 households use LPG for cooking instead of kerosene burners, whereas most households have purchased a colour television and satellite dishes.
- Almost all households with land use rights in the ICA have purchased a motorcycle during the last 5 years.
- 15 new tractors were bought by households having irrigated land in the ICA.
- Dowry for marriages has increased and weddings take place in wedding halls in urban centres instead of the village itself.
- Many households have been able to buy extra cows and buffaloes in order to increase the production of dairy products.

22. Controlled intensive grazing, Savannah Grasslands, Africa

Introduction

Cattle grazing is often singled out as the main cause of the loss of savannah grasslands. Overgrazing, it is said, causes degradation and makes savannah areas susceptible to desertification. To reverse this trend reduced livestock herds and area closures are recommended to restore grasslands. Some experts – such as Allan Savory – are of a diametrically different opinion, namely that at least in xeric savannah areas land degradation would accelerate should cattle or wild grazers disappear. Perennial grasses die out when they are not being grazed or occasionally trampled. Instead planned grazing by bunched animals can restore grasslands and add to their productivity as well as biodiversity and capacity to sequester carbon. There are a now many experiences with this 'holistic management' approach that illustrate its merits.

When savannah terrain is grazed by large, tightly-bunched livestock herds, their trampling breaks the soil crust. This ensures that air can enter and more water infiltrate when it rains. The trampling also knocks down ungrazed leaves to provide a soil-covering mulch, while compacting soil to provide good seed-to-soil contact. Dung and urine provide fertilizer to feed the new grass plants that establish in the improved microenvironment.

Box 1: From an interview with Jody Butterfield, author of 'Holistic Management Handbook - Healthy Land, Healthy Profits.'

"We actively discourage fire – because of the pollutants it puts into the atmosphere (which in turn exacerbate climate change), and while overgrazing is a problem, the bigger problem in most of the savannah grasslands is 'overrest' – too much soil remains undisturbed, too many plants are left ungrazed. As a result plant spacing gets wider, bare ground increases and so does soil surface evaporation and rainfall runoff and 'droughts'. What we promote is holistic planned grazing, which bases herd moves on plant recovery times – so that animals don't remain for too long in one place, nor return to it too soon (before plants have regrown leaf and re-established the root sacrificed following the first grazing). We try to maximize the herd size and density so that more soil is loosened, so it can breathe and water can penetrate; and so that uneaten plants get trampled down to cover the soil and to expose growth points to sunlight in the following growing season (overrested perennial grasses – neither eaten nor trampled) will turn grey and remain standing for years in seasonally humid environments, and gradually choke out new growth altogether."

Figure 1. Dimbangombe herd of cattle and goats being tightly herded on the river banks. Note herding mostly from front controlling speed of move as they graze and trample. (Photo credit: CJ Hadley, RANGE magazine.)

More cattle, more grass, more water

There are generally four recommended ways to keep perennial grass plants healthy: mowing, burning, resting or grazing them. The first option 'mowing' is impractical in most places as it is too laborious. Economics militate against this and even the resources to do this may simply not be there. Neither is fire recommended. It is now used on a large scale to manage African grasslands, basically due to the lack of animals. More than 800 million ha of grasslands are burned each year on the African continent alone, adding huge quantities of carbon to the atmosphere and drying out the soil.

'Resting' (or non-disturbance by livestock or fire) is conventionally proposed to restore perennial grasslands. This may result in an initial burst of growth in vegetation that was being overgrazed and can now grow freely. But within a few years, rested perennial grasses grow rank and start to oxidize, as indicted by their grey colour. The oxidizing mass of leaves prevents sunlight from reaching the growth points at the base of the plant, and it gradually chokes to death. When the soil surface is rested from 'hoof impact' it seals with the first rainfall and stays sealed so that very little water can infiltrate, and what does soak in quickly evaporates on flat land or, on slopes, runs off. Though resting soils and forage is perennially humid environments, it is damaging in semi-arid seasonally humid or 'brittle' environments.

By far the best option is to re-appreciate the role of livestock in grassland management. Root systems of perennial grasses react to above ground disturbances (grazing and trampling) of the grass. If perennial grasses are grazed by cattle (or for that matter by the bison, buffalo and other wild grazers that co-evolved with grasslands and their soils), the root system reacts with a survival mechanism: roots die back to provide energy for growing new leaf. However, if the animal that grazed the plant remains, it is likely to bite the tender new growth well before roots have had time to grow back and the plant will then be 'overgrazed'. On the other hand, perennial grasses properly grazed – i.e., given time to recover and regrow – can live several hundred years. In the process soil is built up and carbon is sequestered.

When properly grazed and impacted, grasslands act like sponges, storing humus and carbon, while the roots perforate the soil and open it up, which increase porosity and infiltration capacity. This is further aided by the trampling of the sealed soil surface, or soil crust, as well as the ungrazed vegetation. This then allows water to soak in where it can be used by plants, or eventually trickle down to feed springs, rivers, and boreholes or wells, thus increasing the residence time of the rainfall in the catchment and prolonging the hydrological cycle – or in 3R terms it 'extends the chain of uses'. The beneficial impact in semi-arid but seasonally humid environments is that a wetter ecosystem is created, capable of supporting more life and more economy. The wetter ecosystem is better for herbivores, because the native long life perennial bunch grasses green up sooner and stay green longer. This in turn feeds the grazing animals longer. It is also generally a much better bet than introducing exotic annual grasses. These annuals need to grow up, flower, set seed and die all in one season. In the next season they may not germinate at all if conditions aren't exactly right. Annual grasses are also shallow rooted and hence do not sequester carbon in the soil.

From a buffer management perspective, a main task for pastoralists and rangers is to reclaim the perennial grass component of their rangelands. This will help retain water, provide much better forage and mitigate erosion and soil loss. Holistic planned grazing works toward this end by timing recovery periods to the needs of perennial grasses, which then allows them to germinate and grow. Resilient, healthy grasslands are animal-maintained, rather than fire-maintained or rest-maintained grasslands. Although pastoralists may be seen as cattle farmers, it would be better to view them as grass-farmers working to harvest sunlight through green, growing plants that cover soil, feed animals and people, and, through well planned grazing also sequester water and carbon. The priority is to invest in developing animal-maintained grasslands in which perennials dominate.

Examples

On Dimbangombe Ranch in Zimbabwe, which is managed by the Africa Centre for Holistic Management, livestock (cattle, goats and sheep) is herded by day and placed in lion-proof enclosures at night, according to a holistic grazing plan. In the growing or rainy season the herd does not graze an area for more than three days and doesn't return to it for at least three months. Because the animals are herded, rather than controlled by fencing, they remain in a group throughout the day, providing good impact on soils and plants. In the long dry season, the timing is similar, but because plants are not growing- or growing very slowly – this can sometimes be a longer process. In the nighttime enclosure, remaining in one place from 3-7 days, the herd creates very high impact, which results in stunning growth in the months afterward (or when it rains). In agro-pastoral areas the nighttime enclosure is used to prepare crop fields for planting and results in maize yield increases of 3-7 times higher than those on adjacent conventionally prepared fields (Savory and Butterfield, 2010).

The improved forage on Dimbangombe, following almost a decade of holistic planned grazing and fire prevention, has enabled the ranch to increase livestock numbers substantially – currently 400 per cent higher than when they began, and they say they could double the figure immediately if the funds and the livestock were available. The land has improved too. Once dominated by bare ground, fire-prone grasses and intermittent river flow, it is now difficult to find bare ground in the low-lying areas. In fact remnant patches are being preserved for wildlife. Grasses are becoming less fibrous and leafier resulting in an enormous reduction in fires, and the Dimbangombe River, though not yet perennial year round, has increased its length by 1.5 km higher up its catchment where it now has perennial pools with fish, ducks and other wildlife year round. The whole upper catchment area has become an ever-expanding wetland with new springs emerging as well as reed thickets. Furthermore, by keeping the livestock in lion-proof kraals, predators – lion, cheetah, leopard and hyena – are able to roam freely and help keep the wild grazing herbivores moving. In the absence of predators the wild grazers, like livestock, become static and damage soils and plants through overgrazing and overtrampling, especially in riparian areas.

Figure 2 and 3.These pictures are taken at fixed points at one of the sites on Dimbangombe. The top picture is taken in 2006 and the bottom picture in 2009 after treatment once with very high animal impact. The top picture a shows the situation of this land as it had been for over thirty years. No matter whether the rainy season was good or bad - it used to be permanently bare and eroding for many years. (Photo credit: Savory Institute)

Flexibility is a big part of the new grazing concepts. In another area in Zimbabwe, commercial farmer Johan Zietsman used cheap portable electric fences and strip grazing to create ultra-high densities – which had since been impossible to achieve other than by herding. During the dry season these densities – up to 3,000 cattle per ha – were used to trample the old growth and cover the soil. Over a ten-hour period the animals were moved ten times. Being so close to each other the hoof action of the animals is different, less gentle and able to disturb the area in a regenerative way – much as the tightly-bunched herd at Dimbangombe achieves. At night the animals were left to ruminate over a larger portion of the lane being strip grazed. The ultra-high density and good planning – still based on recovery time - achieved higher productivity of both cattle and forage. The large 'herd effect' resulted in a very effective impact on the land compared to herds that graze at low density. No trailing occurred and all animals grazed at the same time. They were still able to select their diets although the 'paddock' appeared to be more uniformly grazed. Zietsman was been able to double his stocking rate with this innovative fencing layout and good planned grazing against a minimal capital layout – i.e. the small costs of the movable live fencing. The results after one year were already significant: mature capping of the soil decreased from 43% to 1%; over-rested grass plants disappeared from 42%; palatable broad-leaved grass increased from 11% to 52% of the area, whereas unpalatable narrow-leafed grass decreased from 86% to 46% (Howell, 2008).

Holistic planned grazing is also practised in other semi-arid parts of the world with intense rainfall periods. On the large La Inmaculada Ranch, managed by the Aguirre family, in the Sonaran Desert of northern Mexico, planned grazing has resulted in a vigorous return of perennial grasses as well as ironwood and mesquite, the latter providing high-protein forage in the dry season. Rainfall averages 330 mm – most of it falling in the summer but this varies widely in time and space. During the summer growing season each paddock or grazing area is grazed only once, generally because growth is slow and recovery time for perennial grasses can be very long. They generally don't stay longer than two or three days when growth is fast, but can stay more than a week when growth is slow. Cattle never make a large dent into the new season's growth and sufficient forage is left to be rationed out through the long dry or winter season. Since beginning to plan their grazing, the Aguirres have increased soil litter cover 23% to 63% and the density of perennial grasses more than fourfold (Howell, 2008), again bringing together productivity and sustainability.

References

Howell, J. 2008. For the love of the land: global case studies of grazing in nature's image. Charleston: BookSurge.

Savory, A and Butterfield, J. 2010. The Holistic Management Framework: Social, Economic, and Environmentally Sound Development. In: Ukaga, O., Maser, C. and Reichenbach, M. eds. Sustainable Development: Principles, Frameworks and Cases. Boca Raton FL: CRC Press, pp 149-175.

23. Shallow tubewells in flood plains, Africa

Introduction

There is no precise estimate of the area under flood based farming systems in Africa – but a reasonable estimate is that it is upwards of 10 million ha. Flood recession farming occurs in the areas along the Niger, Zambezi, Senegal, Tana, Rufelji and Lufira rivers and their tributaries, around lakes, minor rivers and in natural depressions, such as dambo, as well as on the vast plains of South Sudan. So far flood recession agriculture has received as good as no attention, but there is large scope for applying a broad-based approach to improving the productivity of these systems and the livelihoods of the people depending on them.

Flood plains in Africa are excellent natural wet buffers. Groundwater is usually available at shallow depth and is replenished annually. Moreover any water that is diverted and not used ends up inside the 'wet water buffer' – from which it can be easily retrieved. The inundation also carries sediment that revives the land annually. However, compared to Asia the density of population, livestock and agriculture in African flood plains is still very low.

Techniques

There are several opportunities to explore the potential of the flood plains:

1. Better water management – use of dikes, inundation canals and drains to better guide and control water Flood based farming systems occur in different parts of the world and can sustain large populations. A prime example is Bangladesh, where over centuries a sophisticated system of bunds, dikes, canals and drains has developed, spreading the inundation over a large area, avoiding standing water and generally retaining the water for a longer time. Elsewhere raised beds are made to start cultivation earlier and use the inundation water (Mexico), or in the dry season crops are transplanted to chase the falling moisture table (India).

2. Transformation to flood-rise agriculture Crops can be grown in the residual moisture after the flood plains have fallen dry, but in some areas the rising flood water can also be used, particularly for the cultivation of fast-growing rice species which keep apace with the rise in inundation levels. The recent transformation from flood recession to flood rise culture around Lake Tana in Ethiopia has permitted double cropping: growing rice on the rising flood and, subsequently, other crops, such as chickpeas, on the residual moisture. Such transformations are possible for other areas too depending on the pattern of flood rise. In such areas the introduction of floating rice varieties may be considered – very fast growing varieties that keep up with the speed of the rising flood and can reach 3-5 m in height. Floating rice varieties grow in areas as varied as Mali and Cambodia.

3. Use shallow groundwater Most flood plain areas are areas with ample shallow groundwater resources. As they are continuously recharged from the floods and the river flow, they constitute a highly dependable resource that is relatively easy to exploit. It requires the use of shallow tube wells – that can be sealed during the flood season – rather than dug wells that will inevitably be damaged when inundated. Irrigation from shallow tube wells will allow starting supplementary irrigation soon after the floods have receded. There are several techniques (Box 1) that are low cost and can be mastered artisanally. Unlike Asia the skills in manual drilling of shallow wells is not yet as widespread in Africa.

4. Diversification - fishery, livestock Flood based farming system provide the basis for diversified livelihood systems – not just farming, but also fishery and livestock keeping. Fish for instance can be promoted by finger-ponds. Also the wetlands in and around flood based systems often offer opportunities for non-timber products, medicines and other products. Market chains are however not well developed.

Figure 1. Developing high value horticulture on the Lake Koka floodplain, Ethiopia (Photo credit: MetaMeta)

Table 1. Manual drilling techniques

Technique	Description	Advantages/ disadvantages
HAND AUGER	Consists of extendable steel rods, rotated by a handle. A number of different steel augers (drill bits) can be attached at the end of the drill rods. The augers are rotated into the ground until they are filled, then lifted out of the borehole to be emptied. Specialized augers can be used for different formations (soil types). Above the water table, the borehole generally stays open without the need for support. Below the water table a temporary casing may be used to prevent the borehole collapsing. Drilling continues inside the temporary casing using a bailer until the desired depth is reached. The permanent well casing is then installed and the temporary casing must be removed. Augers can be used up to a depth of about 15-25 m, depending on the geology.	Advantage: Easy to use above groundwater table; Cheap equipment. Disadvantage: It may be difficult to remove the temporary casing. Geological application: Sand, silt & soft clay.
SLUDGING	Uses water circulation to bring the drilled soil up to the surface. The drill pipes are moved up and down. On the down stroke, the impact of the drill bit loosens the soil and on the up stroke, the top of the pipe is closed by hand (or valve), drawing up the water through the pipe and transporting the cuttings to the surface. On the next down stroke, the hand (valve) opens the top of the pipe and the water squirts into a pit, in front of the well. In this pit, the cuttings separate from the water and settle out, while the water overflows from the pit back into the well. The borehole stays open by water pressure. Thickeners (additives) can be added to the water to prevent hole collapse and reduce loss of working water (drill fluid). Water mixed with cow dung is often used for this matter. Sludging can be used up to depths of about 35 m.	Advantage: Easy to use and temporary casing is not needed. Disadvantage: Working water has to be maintained during the drilling process; The level of the water table is not known during drilling. Geological application: Sand, silt, clay, stiff clay and soft consolidated rock formations, e.g. weathered laterite.
JETTING	Based on water circulation and water pressure. As opposed to sludging, water is pumped down the drilling pipes. The large volume of water has an erosive effect at the bottom and the 'slurry' (water and cuttings) are transported up between the drill pipe and the borehole wall. A motor pump is used to achieve an adequate water flow. The drill pipe may simply have an open end, or a drill bit can be added and partial or full rotation of the drill pipe can be used. Thickeners (additives) can be added to the water in order to prevent hole collapse and reduce loss of working water (drill fluid). Jetting (with rotation) is generally used up to depths of 35- 45 m.	Advantage: Rapid in sand. Disadvantage: A lot of working is needed at once; The level of the water table is not known during drilling. Geological application: Limited to sand and thin layers of soft clay.
MANUAL PERCUSSION	Uses a heavy cutting or hammering bit attached to a rope or cable and is lowered in the open borehole or inside a temporary casing. Usually a tripod is used to support the tools. By moving the rope or cable up and down, the cutting or hammering bit loosens the soil or consolidated rock in the borehole, which is then extracted by using a bailer. Just as with hand augering, a temporary casing of steel or plastic may be used to prevent the hole from collapsing. When the permanent well screen and casing are installed, this temporary casing has to be removed. Manual percussion drilling is generally used up to depths	Advantage: Drills hard formations and alluvial formation with large stones. Disadvantage: Equipment can be heavy and expensive; Slow, compared to other methods. Geological application: Sand, silt, stiff clays, sandstone, laterite, gravel and small stones.

	of 25 m.	

The fadama are the extensive flood plains and low-lying areas underlined by shallow aquifers, found along Nigeria's river systems. The alluvial aquifers are formed by the deposition of suspended material over the low gradient plans and its poorly defined canals. Silt and other materials are suspended in stagnant ponds. Over time, these accretions form layers of silt, clay, sand and silty loam overlying the original sandy material – in no obvious order. The low water transmissivity and storage properties of the heavy alluvial material and its uneven distribution result in pockets of aquifers throughout the floodplain. Through experience and trial and error, water users excavated wells where local aquifers occurred. Hence, traditional shallow dug wells – with depths of less than 5 m - are often clustered in groups along the fadama. Areas of local occurrence of clay are revealed by failed wells and become preferred sites for brickmaking. The climate is semi-arid with rainfall in the order of 700 mm, with a peak in August. In the past irrigation started in November, after the plains were sufficiently dried to allow the re-excavation of the dug wells (Tarhule and Woo, 1997).

Since 1992 the World Bank has supported the development of agriculture in these areas. An important component has been the construction of over 40,000 shallow tube wells, equipped with small engine-driven water pumps, a new technology at the time. This made irrigation more reliable, covering a longer period and allowed for the cultivation of vegetables for instance. This was part of

a larger package – increased supplies of farming inputs and extensive infrastructure improvements – from local storages to roads. To sustainably increase the incomes of different groups (farmers, fishermen, hunters, pastoralists, gatherers) grants were provided for small-scale productive and/or economic infrastructural sub-projects, such as fishponds, cold stores, feed mills, harvesting equipment and feeder roads, small bridges, culverts, rural markets, rural electrification as well as training and skills development. The accelerated development also created tensions between different users groups, particular farmers and sometimes militant outside pastoralist groups, concerning access to land caused by the degradation of grazing land elsewhere. Another issue is that, as wells are used intensively for irrigation in the morning, they are sometimes not yet recharged in the afternoon when they are used for livestock watering. The Fadama Development Project takes a community-driven development approach, which places beneficiaries in the driver's seat. Local community members, under the umbrella of Fadama Community Associations and Fadama User Groups, oversee the development of local development programmes and are empowered through skills and capacity-building to improve their livelihoods by increasing income generating activities.

Figure 2. Dugwells in flood plains: prone to collapse and vulnerable to lowered water tables (Photo credit: MetaMeta)

References

Barrow, C.J. 1999. Alternative irrigation: the promise of runoff agriculture. London: Earthscan. Siebert, S., Burke, J. Faures, J.M.,Frenken, K., Hoogeveen, J., Doëll, P. and Portmann, F. T. 2010. Groundwater use for irrigation – a global inventory. In: Hydrology and Earth System Sciences, 14, pp. 1863–1880.

Tarhule, A. and Woo, M. 1997. Characteristics and use of shallow wells in a stream fadama: a case study in northern Nigeria. Applied Geogmorpolgy, 17 (I), pp. 29-42.

Practica Foundation. (2009). How to Professionalize the Manual Drilling Sector in Africa, Practica Foundation [online video] Available at: http://www.thewaterchannel.tv/index.php?option=com_hw dvideoshare&task=viewvideo&Itemid=4&video_id=889 [Accesed at 23 August 2011].

van der Wal, A. 2010. Understanding Groundwater and Wells In Manual Drilling. Papendrecht: Practica Foundation.

24. Plastic mulches, biodegradeable alternatives, China and US

Introduction

In the last twenty years plastic mulching has made a meteoric rise – very much so in China, where in some areas entire valleys glisten as they are partly wrapped up in plastic mulch. In 1999 already the area under plastic mulch was estimated at 9.5 million hectares (Brown 2004). This area has by now at least doubled. Especially in drought prone provinces in North West and South West China, such as Xinjiang and Yunan, the technique is very common. Plastic mulching is popular because it creates a microclimate allowing better control of water, temperature and nutrients. It allows earlier cultivation and requires substantially less weeding. The plastic mulch prevents unproductive evapotranspiration of water. Instead water is kept within the reach of the crop roots. Besides its effective internal water circulation in the top soil, the plastic cover increases nutrient uptake (through prevention of nutrient leakage during occasional showers), and increases or decreases soil temperature (allowing earlier germination).

Figure 1. Plastic mulch mulch is very popular in China (photo credit: MetaMeta)

Different colors of mulch are used: transparent (clear), white, black, each having different impact on crop growth factors. Transparent sheets support early season plant growth and cropping, as sunlight shines through the sheets. Black sheets are used to control weed growth, as sunlight is unable to pass, blocking photosynthesis. White (or silver or aluminum) sheets are used to re-direct sunlight that has passed the leaf canopy, to the leaves again, allowing higher yields. Simultaneously white sheets cool the soil allowing crop cultivation during high temperatures. The sheets also differ in thickness and porosity – with different impacts on water circulation, nutrient uptake and longevity. The plastic sheets are placed manually or mechanically and holes are punched in the sheets to allow the growth of plants.

Application and removal of plastic mulch requires additional labour and costs, but this is outweighed by the increase in crop production – that under normal circumstances is 50%, but in exceptional cases can be even a factor 4 or 5 (Sanders, D.C., 2001; Osiru and Hahn, 1994; Ashrafuzzaman, M. et al. 2011). The increased cost for the mulch is partly compensated by savings on labour and energy costs for removal of weeds, fertilizer application and irrigation. For instance drip irrigation system widely used in combination with plastic mulch uses “much less energy and water than do methods such as furrow irrigation or overhead sprinklers” (Kovach et al. 1999).

Challenges in the plastic mulch are financial and environmental. The price of plastic mulch is high – at approximately 0.14 USD per square meter or USD 700 per hectare (not the entire area all is covered). Environmental challenges concern the disposal of the plastic after its life cycle is over – typically between one to ten years – depending on thickness and use.

Biodegradable alternatives

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The concern regarding plastic mulch residuals in the soil and the costs of plastic mulch usage have resulted in a search for biodegradable alternatives. Costs of mulch removal and disposal in the US were estimated at USD 250 per hectare in 2004, a costly disadvantage (Schonbeck, 1995; Olsen and Gounder, 2001). Biodegradable plastics were introduced to agriculture in the 1980’s. However, they did not degrade sufficiently (undergo a significant change in chemical structure resulting in a decrease of physical and mechanical properties, [per ASTM D883-11, 2011]) and instead fragmented into small pieces (Riggle, 1998). By the 1990’s, inaccurate claims for these products caused confusion about the term ‘biodegradable’ (Yabannavar and Bartha, 1994), and nearly twenty years later, grower skepticism remains. Further, biodegradable products that are commercially available for agriculture are generally two to three times more expensive than standard black plastic mulches.

To be considered biodegradable, products should decompose into carbon dioxide, methane, water, inorganic compounds, or microbial biomass (Song et al., 2009). Biodegradation is generally initiated by abiotic degradation followed by microbial degradation (enzymatic hydrolysis of polymers), first to low molecular weight oligomers and finally to carbon dioxide and water. The American Society for Testing and Materials (ASTM) and other agencies worldwide have outlined protocols for assessing the biodegradability of plastics – e.g. ASTM D6400 (2004) which specifies that in compost

at 58oC, 60% of a plastic’s organic carbon molecules must be converted to carbon dioxide within 180 days. However, these methods fall short of definitively quantifying the degradation of polymers at the molecular level (Krzan et al., 2006; Roy et al., 2011; Yabannavar and Bartha, 1994).

For a biodegradable mulch to be considered successful, it should perform equal to black plastic mulch in regards to weed control, moisture conservation and temperature modification, and crop growth and yield. Additionally, it should be sufficiently degraded near final harvest to allow for burial and further biodegradation in the soil without increasing labor costs (or other inputs). Mulches that are labeled as ‘biodegradable’ are commercially available (Table 1). Paper mulch made of cellulose is 100% biodegradable in the field, while other mulches that contain polymers derived from non-renewable petroleum have been shown to be biodegradable, but under composting rather than field conditions. Biobased (derived from renewable biological starting materials such as starch) and biodegradable polymers, such as polylactic acid (PLA) and polyhydroxyalkanoate (PHA) are also available commercially, and have good potential as agricultural mulches (Vroman and Tighzert, 2009). PLA is derived from microbial transformation of corn starch, and has numerous applications in biodegradable or compostable materials. Production of PLA mulch is increasing, and costs are more competitive with polyethylene mulch (currently only approximately 15% higher) (http://www.cupdepot.com). PHA is produced by bacteria, and is significantly (three times) more expensive than PLA. Both PLA and PHA biopolymers can be brittle and PHA is susceptible to thermal degradation.

The overall effects on soil health and microbial ecology of incorporating biodegradable mulch into agricultural soils are unknown. One concern is that conventional plastics can form microplastics (particles smaller than 5 mm in diameter) that adsorb toxins present in the environment, thus concentrating them (e.g. Zarfl and Matthies, 2010; Teuten et al., 2007; Mato et al, 2001). It is not known whether biodegradable mulch fragments will also adsorb and concentrate toxins (e.g.

Figure 2. Black plastic mulch used in pineapple plantation, Kenya (Photo credit: MetaMeta)

pesticide residues) sometimes found in agricultural soils and what effect this process could have in an agroecosystem. Also unknown is the rate at which soils will promote biodegradable mulch breakdown – rates will likely differ by region and cropping system. For example, in an ongoing field study, selected commercially available biodegradable mulches (two starch-based and one cellulose-based) and an experimental spunbond PLA mulch were tested for tomato production in three diverse geographic locations of the United States (northwestern Washington which is cool and humid, northeastern Tennessee which is hot and humid, and northwestern Texas which is hot, dry and windy). At the end of the first year, all commercially available biodegradable mulches showed evidence of increased degradation (compared to polyethylene mulch) in all climates, and degradation was greatest in the hot, dry windy climate. The cellulos-based mulch degraded the most at all three sites while the spunbond PLA mulch showed no evidence of physical breakdown.

Small squares of the biodegradable mulches were subsequently buried over the winter at each site, and during the following spring, native soil bacteria and fungi that were capable of growing with only the biodegradable mulches as a carbon source, were isolated in the laboratory. Additionally, the area of each mulch piece was measured after six months of soil burial, and compared to the original size. For the starch-based biodegradable mulches, post-burial surface area ranged from 100% to 71% of the original, while for paper mulch, post-burial surface area ranged from 95% to 0% (none detectable). Overall, soil microbial biomass, and carbon and nitrogen mineralization potential were highest in soil around the paper mulch. At all sites, the PLA-based mulch showed very little visible degradation. The possible relationships among climate, soil microbiology, soil biochemical processes, and biodegradable mulch breakdown is currently studied.

Agricultural mulches can influence soil physical properties, including soil temperature and moisture, which also greatly affect crop growth and yield, and soil ecology. In the same field study, maximum temperature at the soil surface under starch-based mulches was 3-4 oC higher than under black plastic mulch. This trend continued to the 15 cm soil depth. Soil moisture content at 15 cm and 46 cm depths did not differ under the biodegradable mulches as compared to black plastic mulch, however. In the Washington part of the study (cool climate), tomato fruit yield was greater with mulch as compared to bare soil, whereas in the relatively hot climates of Tennessee and Texas, there was no difference. These results suggest that in a cool climate, soil warming from mulch use can increase tomato yields. At all three locations, tomato yield with biodegradable mulches was comparable to that of black plastic mulch. The effects of black plastic versus biodegradable mulches on tomato root diseases are still under study.

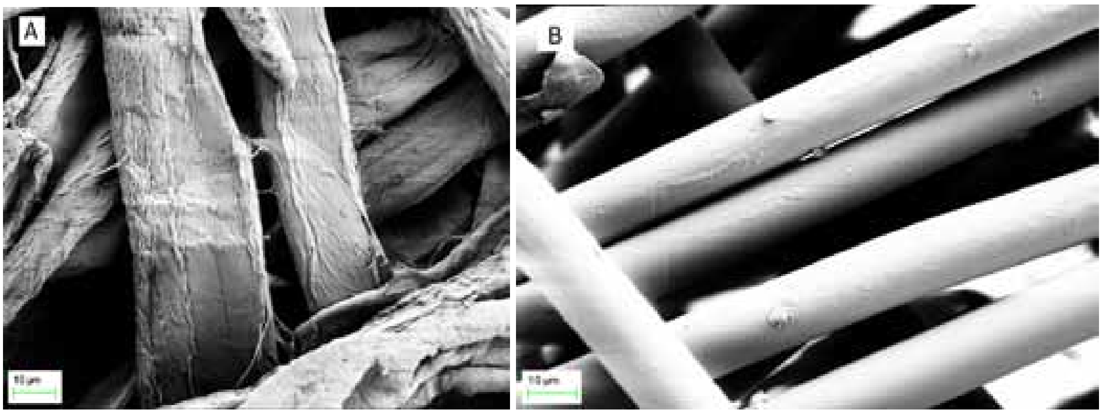

Figure 3. SEM photomicrographs of cellulosic (a), SB PLA (b) and MB PLA (c) specimens initially at 1000X

Prior to the field study to understand the current status of grower knowledge of plastic and biodegradable mulches, a key informant survey was conducted targeting leading and innovative farmers in Washington, Tennessee and Texas (Miles et al., 2009). Three quarters of those surveyed (n=34) had used plastic mulch, and were satisfied with the results. However, plastic mulch removal and disposal were the primary concerns, especially since recycling was not available in most areas. Almost 25% of farmers had tried biodegradable mulches. Of that number, 28% felt biodegradable mulches provided adequate weed control and water/moisture conservation, but 60% were dissatisfied due to unpredictable and incomplete mulch biodegradation and added cost of removal of un-degraded fragments. These survey results and our field study research results indicate that today’s biodegradable mulches are still not satisfactorily biodegradable. While one third of the farmers believed biodegradable mulches are suitable to the crops they grow, barriers to adoption include high cost, lack of availability, and general lack of knowledge about biodegradable mulches, especially with efficacy and potential impacts on soil health and quality. Continued work on biodegradable mulches should provide answers to some of these concerns.

Table 1. Commercially available agricultural mulches labeled as biodegradable.

Mulch Product Name	Constituents	Manufacturer
Ecoflex	PBAT[1] is major component	BASF, Germany
Bicosafe	fully biodegradable copolymers such as PBAT[1] and PBSA[2]	Xinfu Pharmaceutical Co., Ltd., Zhejiang, China
Biobag Agri	Starch, vegetable oil derivatives, and undisclosed biodegradable synthetic polymers	Novamont, Novara, Italy
Bio-Flex	Blend of PLA[3] and co-polyester	FKuR, Willich, Germany
BioTelo Agri	Starch, vegetable oil derivatives, and undisclosed biodegradable synthetic polymers	Dubois Agrinovation, Waterford, Ontario, Canada
WeedGuard Plus	Cellulosic	Sunshine Paper Co. LLC, Aurora, CO

[1] PBAT = poly(butylene adipate-*co*-terephthalate)
[2] PBSA = poly(butylene succinate-co-adipate)
[3] PLA = Polylactic Acid

References

Ashrafuzzman, M. et al. (2011). Effect of plastic mulch on growth and yield of chill (Capsicum annuum L.). Brazilian Archives of biology and technology, Volume 52, Issue 2, pp. 321-330

ASTM D5338. 2003. Standard test method for determining aerobic biodegradation of plastic materials under controlled composting conditions. ASTM International, West Conshohocken, PA. www.astm.org.

ASTM D6400. 2004. Standard specification for compostable plastics. ASTM International, West Conshohocken, PA. DOI: 10.1520/D6400-04, www.astm.org.

ASTM D6954. 2004. Standard guide for exposing and testing plastics that degrade in the environment by a combination of oxidation and biodegradation. ASTM International, West Conshohocken, PA. DOI: 10.1520/D6954-04, www.astm.org.

ASTM D883-11. 2011. Standard terminology relating to plastics. ASTM International, West Conshohocken, PA. www.astm.org.

Bergholtz, P. 2006. President, Ken-Bar Company. Personal communication, 5 November 2006.

Brown, R.P. (2004). Polymers in agriculture and horticulture. RAPRA review reports.

Hill, D.E., L. Hankin, and G.R. Stephens. 1982. Mulches: Their effects on fruit set, timing and yields of vegetables. Bulletin 805, CT Agr. Expt. Sta., New Haven, 15 pp.

Kijchavengkul, T., Auras, R., Rubino, M., Ngouajio, M., and Fernandez, R.T. 2008. Assessment of aliphatic-aromatic copolyester biodegradable mulch films. Part II: laboratory simulated conditions. Chemosphere 71:1607-1616.

Krzan, A., Hemjinda, S., Miertus, S., Corti, A., and E. Chiellini. 2006. Standardization and certification in the area of environmentally degradable plastics. Polymer Degradation and Stability 91: 2819-2833.

Kovach, S.P., Curtis, L.M. and Hemelrick, D.G., 1999. Plastic mulch culture for vegetables. Alabama AG irrigation info network, [online] Available at:< http://www.aces.edu/anr/irrigation/ANR-654.php> [Accessed on 30 August 2011]

Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., Kaminuma, T., 2001. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. Environmental Science and Technology 35, 318–324.

Miles, C., C. Beus, A. Corbin, R. Wallace, A. Wszelaki, H. Saez, T. Walters, K. Leonas, M. Brodhagen, D. Hayes and D. Inglis. 2009. Research and extension priorities to ensure adaptation of high tunnels and biodegradable plastic mulch in the United States. Agricultural Plastics Congress, July 13-16, College Station, Pennsylvania.

Olsen, J.K., and R.K. Gounder. 2001. Alternatives to polyethylene mulch film – a field assessment of transported materials in capsicum (Capsicum annuum L.). Austral. J. Experimental Agr. 41:93-103.

Osiru, D.S.O. and Hahn, S.K. (1994). Effects of mulching materials on the growth, development and yield of white yam. African Crop Science Journal, Volume 2, Issue 2, pp. 153-160

Riggle, D. 1998. Moving toward consensus on degradable plastic. Biocycle: 39:64.

Roy, P.K., Hakkarainen, M., Varma, I.K., and A.C. Albertsson. 2011. Degradable polyethylene: fantasy or reality. Environ. Sci. Technol. 45: 4217-4227.

Saponaro, S., Sezenna, E., Innocenti, F.D., Mezzanotte, V., and Bonomo, L., 2008. A screening model for fate and transport of BDM polyesters in soil. Journal of Environmental Management 88:1078-1087.

Sanders, D.C. (2001). Using plastic mulches and drip irrigation from vegetable production. [online] Available at:< http://www.ces.ncsu.edu/depts/hort/hil/hil-33.html> [Accessed on 30 August 2011]

Schonbeck, M.W. 1995. Mulching practices and innovations for warm season vegetables in Virginia and neighboring states. 1. An informal survey of growers. VA Assoc. Biol. Farming, Blackburn, VA, 24 p.

Shogren, R.L. 2000. Biodegradable mulches from renewable resources. J. Sustainable Agr. 16:33-47.

Song, J.H, R.J. Murphy, R. Narayan, and G.B.H. Davies. 2009. Biodegradable and compostable alternatives to comventional plastics, Phil. Trans. R. Soc. B 364:2127-2139.

Takakura, T., and W. Fang. 2001. Climate under cover. Kluwer Academic Publishers, p. 1-10. <TUhttp:// ecaaser3.ecaa.ntu.edu.tw/weifang/Bio-ctrl/cuc-chap1.pdf>.

Teuten, E.L., Rowland, S.J., Galloway, T.S., and R.C. Thompson. 2007. Potential for Plastics to Transport Hydrophobic Contaminants. Environ. Sci. Technol. 41: 7759-7764.

Vroman, I., and L. Tighzert, 2009, Biodegradable Polymers, Materials 2, 307-344

Yabannavar, A.V. and R. Bartha. 1994. Methods for assessment of biodegradability of plastic films in soil. Appl. Environ. Micriobiol. 60: 3608-3614.

Zarfl, Christiane and Michael Matthies. 2010. Are marine plastic particles transport vectors for organic pollutants to the Arctic? Marine Pollution Bulletin 60 (2010) 1810–1814.