

# Climate change and adaptive land management in southern Africa

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Assessments  
Changes  
Challenges  
and Solutions

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# **Biodiversity & Ecology**

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## **Climate change and adaptive land management in southern Africa**

**Assessments, changes, challenges, and solutions**

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# Initial experiments on intensified use of rangelands through enhanced water and nutrient cycling

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**Abstract:** Rangelands in southern Africa are degrading as human pressure on them increases. Better grazing management is clearly needed. Intensive management can also be applied to a few small areas, such as by harvesting rainwater to soak into the ground and support the growth of natural grasses and planted trees. Initial experiments were attempted at three sites by digging contour ditches, and in addition by constructing ponding banks at one of those sites. Earthmoving machinery was used at a 100 ha rural site, while contour ditches were manually dug with pick and spade at two small urban sites. Diverse tree species were planted below contour ditches for different functions and products, including ‘chop-and-drop’ mulching, tall protective canopies, and edible leaves, fruits, and pods. Much of the low rainfall experienced was soaked into the ground. However, the initial survival rates of tree seedlings was low, suggesting that tree planting should await some years to allow sufficient rainwater to be planted first. Useful lessons were learned from the various designs of infrastructure tried, which will be applied to further evolve appropriate regeneration methods. These must be integrated with other techniques that address the root causes of degradation, such as through the appropriate management of grazing and fires, while fitting into the heterogeneity occurring at different scales in the landscape.

**Resumo:** As pastagens do Sul de África estão a degradar-se enquanto a pressão humana aumenta. Uma melhor gestão do pastoreio é claramente necessária. A gestão intensiva pode também ser aplicada a algumas pequenas áreas, como ao colher a água da chuva para ensopear o solo e apoiar o crescimento de gramíneas naturais e árvores plantadas. Experiências iniciais foram realizadas em três locais, com a escavação de valas de contorno e a construção de *ponding banks* num destes lugares. Maquinaria de terraplanagem foi utilizada num local rural de 100 ha, enquanto que as valas de contorno foram escavadas manualmente com picareta e pá em dois pequenos locais urbanos. Diversas espécies de árvores foram plantadas abaixo das valas de contorno para diferentes funções e produtos, incluindo mulching *chop-and-drop*, copas de protecção altas, e folhas, frutos e vagens comestíveis. Grande parte da pouca chuva vivenciada infiltrou-se no solo. No entanto, as taxas iniciais de sobrevivência das plântulas de árvores foi baixa, sugerindo que a plantação deverá aguardar alguns anos para permitir primeiro a infiltração de água suficiente. Lições úteis foram retiradas dos vários projectos de infra-estruturas testados, as quais serão aplicadas para desenvolver futuros métodos de regeneração adequados. Estes devem ser integrados com outras técnicas que abordem as causas principais da degradação, como através da gestão adequada do pastoreio e dos fogos, ao mesmo tempo que se encaixam na heterogeneidade que ocorre em diferentes escalas na paisagem.

## Introduction

Rangeland is defined by Craggs (2017) as land that provides grazing and foraging for livestock and wildlife, where the nat-

ural vegetation consists of native grasses, grass-like plants, flowering plants and shrubs, and introduced plant species that are naturalised. The Namibian rangelands of this study all receive a mean annual

rainfall of approximately 350 mm, falling mostly during the single rainy season from December to April. The soil texture is mostly sandy loam with a gently sloping topography. The rangelands used to

be savanna of perennial grassland with scattered bushes and trees of diverse species, but over the past decades they have become dominated by annual grasses and been encroached on by a few species of thorn bushes of the genera *Acacia* and *Dichrostachys* (de Klerk, 2004).

Some observers, including many Namibian farmers, believe that in the past, before inadvertent damage by modern humans, rangelands used to be highly productive. They supported abundant and diverse fauna and flora, behaving as a 'stepped diffusion hydroponic system' largely through self-reinforcing barriers on contour (Andrews, 2008) and seasonal migrations of animals (Fynn & Bonyongo, 2011), made possible by the heterogeneity of the landscape (Sianga et al., 2017). The process of rangeland degradation has been described by authors such as Ludwig & Tongway (1995) for the small scale; Milton et al. (1994) generally; and Pringle & Tinley (2003), Pringle et al. (2011), and Tinley & Pringle (2013b) for the broad scale. In sloping rangelands, gully incision and lowered base levels, often initiated by animal tracks, result in a downward spiral of desiccation and lowered fertility as water, organic debris, and soil flow out of the landscape (Pringle & Tinley, 2003). The common theme, regardless of the scale at which degradation occurs, is less efficient use of raindrops because of increased runoff and evaporation, while infiltration and transpiration decline.

There has been less documentation of rangeland degradation specific to Namibia. Over the past decades, most of Namibia's rangelands have degraded, as evidenced by symptoms such as lowered animal production and bush encroachment (de Klerk, 2004). Ward & Ngairorue (2000) measured the herbage standing crop on Namibian commercial farms along a rainfall gradient ranging in mean annual rainfall from 140 to 450 mm. They found that the herbage yield was approximately half that of 50 years previously, which they attribute to long-term heavy grazing. In addition, a large amount of soil and water has been lost, the fertility of the remaining soil has declined, and plant species composition has changed.

The greatest disruptions to nutrient cycling occurred through the sale of milk until the mid-1900s, and thereafter through sale of farm animals (Lau & Reiner, 1993) without farmers returning to the soil the minerals that the animals consumed by grazing year after year. In communal areas, the common practice of overnight kraaling of livestock also robs the land of minerals and organic matter, as much manure is deposited and confined to the kraals. In instances where it is recycled, the manure is not returned to the grazing land but instead to arable land and usually after much of its nitrogen and sulphur have been lost to the atmosphere as volatile gases. The few minerals returned to the rangeland through mineral licks and supplementary feed tend to focus on only a few elements such as phosphorous and sodium, thus failing to restore the balance of elements lost. The former practice of farmers supplying their animals with bonemeal has been declared illegal to comply with EU veterinary regulations (Kaurivi, 2013), and most Namibian and Botswanan bonemeal is now exported, as is most of the beef, together with all their minerals.

The degraded nutrient status of rangeland soil not only results in less nutritious grass but is also likely to contribute to bush encroachment (Mills et al., 2013). The encroached bushes are often blamed for degrading the rangeland, yet they are a symptom of the degradation and not its cause (Andrews, 2008). The increased bush growth can be viewed as nature's way of trying to regenerate a healthy soil by bringing up minerals through their deep roots (Sandhage-Hofmann et al., 2015) and increasing the soil's carbon content largely through growing roots that exude organic acids and sugars to feed beneficial soil microorganisms in return for minerals and organic nutrients (Bais et al., 2006). Large-scale clearing of bushes disrupts both water and nutrient cycles, leading to soil capping, increased runoff and evaporation, reduced organic matter, and lowered production from perennial vegetation.

Numerous approaches have been applied elsewhere using locally available materials to restore water and nutrient cycling. Critchley (1991) describes two pro-

jects in Burkina Faso. In the Agroforestry Project of Yatenga Province, farmers had built stone bunds at a slight gradient to divert runoff away from their fields. During successive years of drought, however, the project helped them shift these stone bunds to follow the contour to maximize infiltration and soil moisture availability for crops while building up organic matter from debris deposited upslope from the rocks. Where there were insufficient stones to adequately raise the bund height, a perennial grass, *Andropogon guyanus*, was planted on the upslope side of the stone line to serve the same filtering purpose. In the conservation and land development project known as Patecore in Kongoussi, many long, low permeable rock dams were constructed from loose stones and stretched across valley floors, thereby spreading floodwater and healing gullies. In Zimbabwe, the innovative water harvester Zephaniah Phiri developed ways to slow, spread, and sink runoff water in an integrated system of stone walls, pits, and ditches (Witoshynsky, 2000). Nevertheless, it took more than 15 years for these methods to be adopted by others, largely resulting from the negative attitude of extension workers who lacked faith in the locally developed technology (Murirwa et al., 2001). In Kenya, a high density of farmers allowed the intensive application of terracing, planting, and management of grazing to support their high population (Tiffen et al., 1994). The abundance of stone wall terraces of the Bakoni ruins in South Africa provide 'evidence of advanced technological and agricultural innovation, long before the colonial era' (Whitlock, 2015).

## Methods

A few attempts were initiated to regenerate healthy water and mineral cycles on three small portions of Namibian rangeland (Fig. 1) by establishing contour ditches (Lancaster, 2013) for planting trees below them and by constructing ponding banks (Bastin et al., 2001) and bush filters aligned on contour to invigorate natural grasses at one of the sites. This was done on an experimental basis to learn from such action research

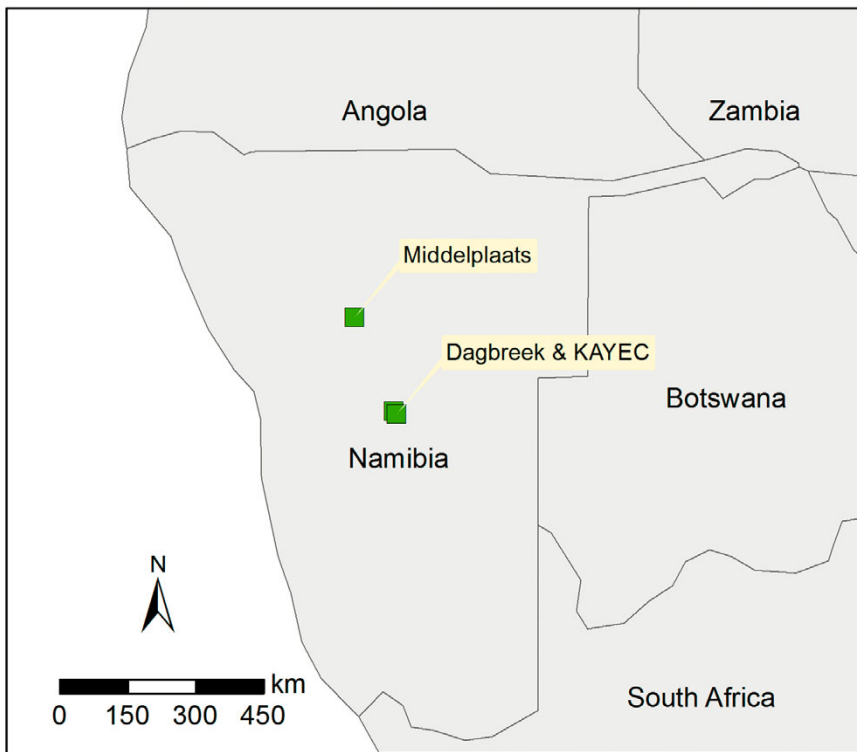


Figure 1: Location of the three sites where intensified use of rangelands was piloted.

for further application of successes and modification of partial failures.

### Fruitful landscape at Farm Middelplaats

At Farm Middelplaats, approximately 40 km south-west of Otjiwarongo, evidence remains of rangeland degradation that has been taking place over past decades. Aligned patches of dark soil in slight depressions testify to former interconnected ephemeral wetlands. Dominance by annual grasses, with only a few remnant perennial grasses often on raised pedestals, bear testimony to the loss of water and soil in sheet flow, exacerbated by deep channelling of nearby ephemeral rivers. Overbrowsing by high densities of game animals that often visit the farm, such as oryx and red hartebeest, is evident on palatable woody species kept in a low coppiced state, except for a few mature individuals that previously escaped beyond browsing height.

On a 30 ha portion of the farm, 12 contour lines were marked out by laser or dumpy level in 2014 at 0.5 m height intervals. Two strips were bulldozed along the contour lines while avoiding large trees to leave them in place (Fig. 2), and a line was ripped (Fig. 3) for later key-

ing in of soil heaped over it to form a bund (Stanton & Waterson, 2007). A grader was then used to dig a ditch along each contour line while heaping the dug soil on the downslope side over the rip line to form the bund. The combined depth of ditch and height of bund could hold water approximately 0.5 m deep to slowly infiltrate and moisten the soil below (Fig. 4). At each end of the ditch, the grader made an upward turn to hook the ditch and bund upwards by approximately 2 m to prevent water from spilling around the ends of the bund. The hook connected with a hump across the road (Fig. 5) in cases where it was considered worthwhile to divert water flowing down the road into the ditch, or from a ditch outside of the fruitful landscape to bring water across the road and into the ditch. Initially, spillways of 10 m width were made by removing soil from the top of the bund (Fig. 5), with the positions of spillways staggered between successive ditches, aimed at getting spilled water to zigzag its way down the landscape and increase infiltration time. In 2017, it was decided to install a second spilling ditch below each contour ditch, which would spread excess flow from spillways along the contour and then release it widely

(Fig. 6), rather than as a concentrated release that then ‘hit’ the next contour ditch and bund downslope. We did this because it was felt the system was not accommodating major storm events effectively and that such events may increase in magnitude and frequency.

A variety of tree seedlings were planted below the ditches to provide different products and perform different functions (Leakey, 2014). These included large protective canopy trees with edible pods and deep roots, such as *Faidherbia albida* and *Acacia erioloba*; shorter thornless trees for ‘chop-and-drop’ mulching (Thurston, 1997), such as *Peltophorum africanum* and *Bolusanthus speciosus*; and trees that produce fruits, such as *Sclerocarya birrea* and *Berchemia discolor*, or edible leaves, such as *Moringa oleifera*. In 2017 two wires were added to the bottom of the fence around the 30 ha fruitful landscape to exclude large game animals.

### Ponding banks at Farm Middelplaats

On another portion of Farm Middelplaats of approximately 50 ha, where bushes had previously been cleared and soil was therefore likely to be less fertile, locations were identified where water appeared to have been held back in the past, such as where the soil was darker in colour. Here contour lines were marked out for the bases of ponding banks, with gradients of approximately 1:200 to hook the bank upwards into an arm at each end to pond 10 to 20 cm of water. Care was taken to spill the water widely and slowly at one or both ends. Starting in 2015, but mostly in 2016, a bulldozer was used to construct the banks using two approaches. For banks receiving strong flows, soil was scraped from above the bank (Fig. 7), while for others it was scraped from below, which was further applied in 2017 (Fig. 8). For most banks, a powerful grader would have been far more cost effective than a bulldozer.

To construct several neighbouring ponding banks along the same contour, the contour line was marked out for approximately 80 m and then taken upwards by approximately 15 cm height over 30 m before being lowered again



Figure 2: Contour strips are cleared, except for large trees that are left in place.



Figure 3: A line is ripped where soil dug from the ditch will be heaped to key in the bund to better secure it with the ground below.



Figure 4: Water infiltrates in a contour ditch after a rain shower of 11 mm.

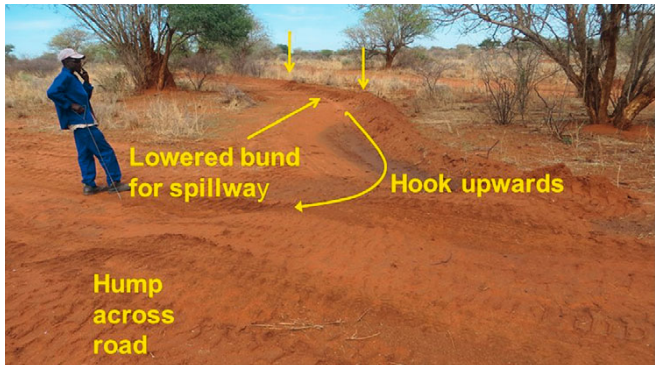


Figure 5: Upward hook to avoid spillage at end of ditch, and hump to divert water from road.



Figure 6: When grading a new ditch below the old contour ditch, the dug soil is heaped upslope so that water spilled from the upper ditch will first spread out to fill the lower ditch before spilling as wide sheet flow over the lower edge at ground level.



Figure 7: A ponding bank is built in September 2016 by scraping soil from above the bank.



Figure 8: A ponding bank is built in September 2017 by scraping soil from below the bank.



Figure 9: The bank is pushed down at its highest positions to allow spillover from ponding banks on each side to first fill the ditch below before excess water spills as wide sheet flow over the lower edge of the contour ditch.



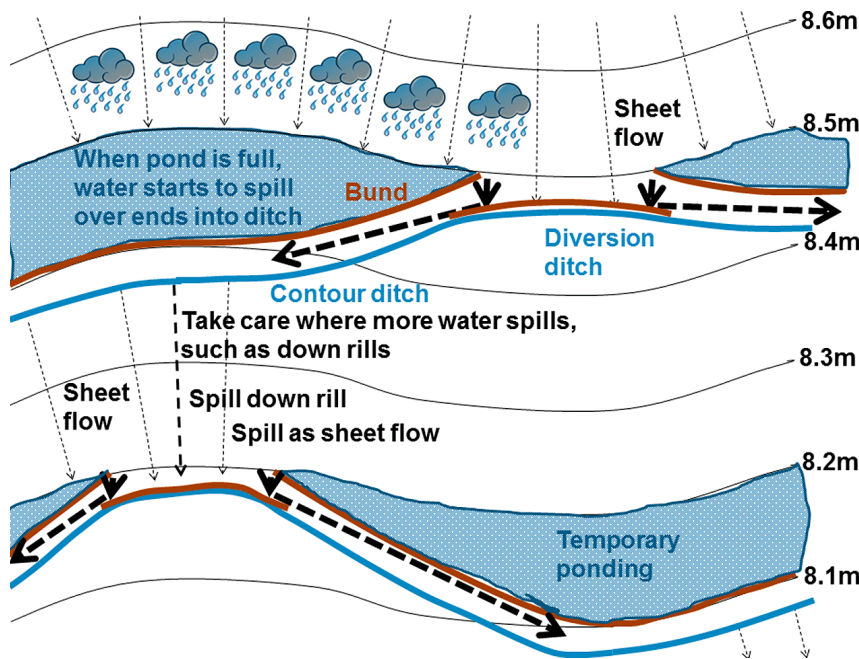


Figure 10: Sketch map to illustrate functioning of neighbouring ponding banks after rain.

over the next 30 m to rejoin the contour for another 80 m. After soil was bulldozed upwards along this wavy line, thereby digging a ditch below, the resulting bank was broken through from above (Fig. 9) and heaped below the ditch for water to spill from banks into the diversion ditch to flow into the contour sections of the ditches and later spill as sheet flow over the lower edge (Fig. 10). Deep ripping above and below the bank created a calming 'sponge' and prevented any tunnelling, respectively. Some wetland grass species were brought onto the farm and transplanted into the homestead garden for multiplication and eventual transplanting of propagules into the ponded areas above the banks.

### Bush filter lines at Farm Middelplaats

On yet another portion of Farm Middelplaats of approximately 20 ha, two contour lines of several hundred metres each were marked out in 2016 and a longer one in 2017. Old grass seed was scattered along the lines and lightly raked in (Fig. 11) before being covered with branches cut from nearby thorn bushes with the cut stem facing downslope (Fig. 12). Different sections of these bush filters were experimentally constructed at two levels of intensity. The light filter comprised a single layer of

medium-sized branches, while the dense filter had tightly packed small branches below medium-sized branches, followed by larger branches on top.

### Urban fruitful landscapes in Windhoek

On a 2 ha portion of the campus of the Katutura Youth Enterprise Centre (KAYEC), four successive contour ditches were marked out and dug by NUST students using pick and spade between 2014 and 2016. Where each of the two lower ditches crossed a gully, a leaky weir was constructed with old tyres (Fig. 13) to divert most of the initial water flowing down the gully to the ditches on either side. A bund was heaped on the downslope side of three of the ditches, while soil from the other ditch was heaped to create a large diversion bund where water from the tar road outside the campus flowed in. This left the lower edge of the whole ditch of approximately 60 m length serving as the spillway.

In 2017 at the campus of Dagbreek School, the soil dug from a contour ditch of approximately 40 m was heaped to form a large bund across a shallow gully to divert its water into the ditch. At the other end, a pit was dug 1.5 m deep for organic material to be thrown in (Fig. 14) for improving fertility of spilled water.

## Results

### Fruitful landscape at Farm Middelplaats

Although the intention had been to let the seedlings depend entirely on rainwater and care for themselves with minimal input (Shepard, 2013), the 2014/2015 rainy season was very poor. This caused many of the planted tree seedlings to die, with only 17 seedlings surviving out of the 152 seedlings planted that season. Therefore, it was decided to irrigate surviving or newly planted seedlings with 1 L of water every 10 days unless sufficient rain had fallen. Another challenge was that many of the seedlings were browsed upon, especially in the dry season, by either wild or domestic animals. It took three years for sufficient soil moisture to accumulate below the contour ditches, as a result of which tree survival is expected to greatly improve.

By the end of the 2017 dry season, 315 planted tree saplings survived in the 30 ha fruitful landscape, mostly of *Moringa oleifera* (Fig. 15). More will be planted now that the surrounding fence has been strengthened by adding two wires and replacing some worn droppers and posts to keep out oryx and hartebeest, while horses are no longer allowed to graze there.

Spillage from contour ditches tended to occur as concentrated flow, either at designed spillways or at breaches through weak points in the bund. This required some maintenance work to repair bunds after intense rain and led to spreader ditches being dug in 2017 (Fig. 6).

### Ponding banks at Farm Middelplaats

The 2017 rainy season resulted in a good vegetation response above the ponding banks (Fig. 16), where a dense cover of creeping legumes had established itself (Fig. 17). It was interesting to observe that the abundant wild melon plants were fruiting only where creeping legumes covered the soil underneath them. This was attributed (Hugh Lovel, Quantum Agriculture Consultancy, pers. comm.) to the organic acids exuded by legume roots releasing the tightly bound calcium-complexed minerals in the soil for uptake by both legumes and melons, to



Figure 11: Grass seed is scattered and lightly raked in along a contour line before being covered with thorn branches.



Figure 12: Branches are stacked to form a filter along the contour.



Figure 13: Old tyres are secured by steel posts to create a leaky weir.



Figure 14: Organic material is thrown into a pit at the end of a contour ditch to improve fertility of infiltrating water.



Figure 15: *Moringa oleifera* trees grow below a contour ditch.



Figure 16: View in April 2017 of the same ponding banks as in Figure 7.



Figure 17: Creeping legumes densely cover the ponded area above a bank.



Figure 18: Herbaceous plants establish under a bush filter line on contour.



Figure 19: Rainwater spills over a slightly lower edge of a contour ditch.



Figure 20: Denser grass grows where water spilled previously, thus trapping more sediment and puffing up soil underneath to achieve self-reinforcement.

later facilitate the establishment of more perennial grasses. At the end of the 2017 dry season, while most of the rangeland was dry, the perennial plants in and below the ponding banks were sprouting green growth, indicating the improved moisture stored in the soil.

### Bush filter lines at Farm Middelplaats

Herbaceous plants established better under the dense filters (Fig. 18) than under the light filters, although forbs tended to dominate grasses. Termites started to consume many of the branches and animal paths crossed some of the light filters, as this portion of the farm was still exposed to high pressure from both wild animals and cattle.

### Urban fruitful landscapes in Windhoek

Trees planted below the contour ditches initially established well, as the rocky soil allowed water to infiltrate deeply, and the lateral flow of water seems to have occurred rapidly, with good response from trees within one year of being planted.

However, the planted trees then faced the enormous challenge of vandalism by a minority of the hundreds of community members making use of the campus, mostly from the neighbouring school that had access to the soccer field on the KAYEC campus. Uprooted tree saplings were often found lying along the ditches.

The contour ditches with bunds on the lower side resulted in concentrated spill-

age that required some maintenance after intense rain. The contour ditch without a bund often filled with extra water from the tar road outside. The initial spillage took place over the slightly lower sections of the lower edge of this ditch (Fig. 19), resulting in denser grass growing in that moister soil (Fig. 20). This initiates self-reinforcement as used to occur in nature when the denser grass traps more sediment and puffs up the soil underneath because of the greater activity of soil organisms until water starts spilling more elsewhere, leading to a 'wind-screen wiper' effect over the long term.

The fruitful landscape at Dagbreek was only started in 2017, but from the few rain showers that fell thereafter, it appeared that this setup was working well.

## Discussion

Each of the different methods used for infiltrating more rainwater had its advantages and disadvantages, yet all appeared to be producing improved landscape functioning. They are addressing degradation processes of many decades, so none was expected to be a 'silver bullet'. All need to be integrated into a wider ecosystem management approach (Tinley & Pringle, 2013a). Therefore, despite setbacks, the true value of the works is not yet realised and the positive results are inspiring.

The ditches with bunds excavated from above could hold more water per

volume of soil dug from them. However, the spilled water concentrating at their spillways or breached bunds tended to cause some erosion that required maintenance. The ditches without bunds started to show signs of self-reinforcement that would minimise maintenance requirements and lead to a more naturally stepped landscape. It is expected that the many contour ditches dug from below on Middelplaats in 2017 will allow wide spillage as sheet flow with such self-reinforcement properties.

Less earthmoving would be required for construction of a micro-catchment for each tree (Jo & Park, 2017). Although this may improve survival and growth rate of trees, it is unlikely to adequately control loss of rainwater as sheet flow. It may alternatively be possible to improve the establishment of trees by raising and planting them as long-stem tube-stock (Australian Plants Society, 2010), with their roots planted approximately 1 m deep to escape the harsh conditions experienced in shallow soil of fluctuating extremes of temperature and moisture.

The ponding banks built from soil scraped below them had a lower capacity to pond water before spillage, but the undisturbed soil in their ponded areas grew better ground cover and the water from a small rain shower ponded over a larger area above the bank, thus irrigating more grass. Scraping soil from above the bank is warranted only where a sponge is required for calming the flow of water before it hits the bank. The challenge is to

choose carefully where to spill the excess water from these ‘buffer’ check banks and do so calmly over as wide an extent as possible. The bunds should be only as wide as needed to ‘take the hit’, and the pacified flow should be intercepted and spread as close below as possible before the flow can accelerate (particularly on steeper slopes).

The bush filter lines are much cheaper than earthmoving, especially when labour is essentially free (students) or low cost (farm labourers) to the farmer, and they serve the dual purpose of filtering and reducing bush encroachment. However, they are likely to take much longer before effectively infiltrating rainwater to anywhere near the levels achieved by ditches and banks. Whether or not they are capable of self-reinforcement will depend on whether grass can establish fast enough to replace the filtering function of the decomposing branches, which largely depends on the grazing pressure being exerted by wild animals and livestock. Some maintenance and augmentation may be required, and this will depend on both grazing pressure and the quality of seasons.

It is too early to observe the micro-habitat benefits expected from planted trees as they grow. Over the years, they are likely to improve soil conditions, not only through better nutrient cycling (Sandhage-Hofmann et al., 2015) but also through improved water cycling (Joffre & Rambal, 1988). The high death rate of tree seedlings initially planted below contour ditches could have been avoided by following the advice of Zimbabwean water harvester Zephaniah Phiri (Witoszynsky, 2000) to plant the water before planting the trees.

Since there is enormous variation in climatic conditions from year to year, monitoring should rely on contrast between treated and untreated sites rather than before and after measurements. Indicators related to soil moisture that can be measured easily are the depth to which rainwater percolated at the start of the rainy season in relation to water harvesting infrastructure (Zimmermann et al., 2015) and the extent of sprouting perennial plants in spring, at the end of the dry season.

## Conclusion

No single technique for infiltrating more rainwater can be singled out as being better than others. Each has its own advantages and disadvantages that may better serve the particular circumstances experienced at any site and the objectives desired by the farmers. To recoup the high cost of earthmoving, the value of the resulting increase in production must be sufficiently large within an acceptable time frame. This requires a high survival rate and fast growth of valuable trees planted below contour ditches, and fast establishment of productive and nutritious grass above ponding banks. These challenges are being addressed by applying the lessons learned so far in this action research.

All of these innovative approaches should be viewed as tools in a diverse toolbox that allows intensified rangeland food production to be extended from traditional small family gardens to community gardens of tens of hectares or more. We have made a start and do not contend that we have a final product. It is probable that the combined efforts of families will extend and improve food production and production per human input and hectare. The potential rewards of localising the security and quality of key food needs have driven us to try many approaches in different environments, and we hope to develop a framework for wider adoption in different situations. The challenge now is to select tools and techniques in harmony with landscape patterns and processes to maximise the depth, breadth, and duration of positive soil moisture balance. We will then utilise that for a diversity of fruitful outcomes that suit local community needs.

It is also important that no single technique be viewed as a stand-alone entity. Since techniques that infiltrate more rainwater tend to treat only the symptoms of rangeland degradation, it will be necessary to integrate them with other techniques that address the root causes, such as through the appropriate management of grazing and fires.

The ditches, banks, and filters have started to regenerate water cycling, and the planted trees will eventually contribute to

regenerating nutrient cycling. To replace the whole spectrum of minerals lost from the system over past decades, however, some inputs will be required (Zimmermann et al., 2017).

In cases where communities have access to the enhanced land, a concerted effort is needed to gain community ownership and leadership (governance) to ensure longevity and minimise theft and vandalism, preferably before projects commence.

Intensive management of relatively small areas fitting natural patterns and processes can not only reverse existing degradation processes but also improve productivity beyond good grazing condition. In the face of challenges such as climate change and increasing population pressure, localising diverse food security offers rural communities many benefits, including participation in the commercial economy.

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