Guidelines on Best Management Practices for Rainwater Harvesting and Conservation (RWH&C) for Cropland and Rangeland Productivity in Communal Semi-Arid Areas of South Africa

JJ Botha, PP van Staden, JJ Anderson, HC van der Westhuizen,
JF Theron, DJ Taljaard, IS Venter & TAB Koatla

WATER
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GUIDELINES ON BEST MANAGEMENT PRACTICES FOR RAINWATER HARVESTING AND CONSERVATION (RWH&C) FOR CROPLAND AND RANGELAND PRODUCTIVITY IN COMMUNAL SEMI-ARID AREAS OF SOUTH AFRICA

WATER RESEARCH COMMISSION

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Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Report to the
Water Research Commission

by

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LIST OF ABBREVIATIONS

AI	Aridity index
ARC	Agricultural Research Council
BMP	Best management practice
DAL	Daling plough
DM	Dry matter
Es	Evaporation from the soil surface
FSDARD	Free State Department of Agriculture and Rural Development
ha	hectare
IRWH	In-field rainwater harvesting
ISCW	Institute for Soil, Climate and Water
K	Potassium
LSU	Large stock unit
MB	Mechanized basin
MIN	Minimum tillage
N	Nitrogen
NT	No-till
P	Phosphorus
PRA	Participatory Rural Appraisal
RWH&C	Rainwater harvesting and conservation
VCS	Veld condition score
WRC	Water Research Commission

PREFACE

These guidelines provide an overview of scientifically developed and tested rainwater harvesting and conservation (RWH&C) practices that have been successfully implemented in the Eastern Cape, Limpopo and Free State Provinces. They will provide decision makers, land use planners, extension officers and farmers with the basic guidelines/principles on how to maintain/improve the productivity on croplands and rangelands in semi-arid areas where rainfall is considered to be the most limiting factor for production. It should be kept in mind that each situation is unique and that a given set of guidelines/principles should be viewed in that regard.

The guidelines presented have been developed during the research undertaken as part of WRC project K5/1775/4. Conclusions drawn from this project and general principles can be extrapolated to a range of locations and crop types.

1 RAINWATER HARVESTING AND CONSERVATION

1.1 INTRODUCTION

After the successful implementation of hand-made basins in two provinces, it was found that there was a need for up-scaling and commercialization of in-field rainwater harvesting (IRWH) for use on larger croplands. Almost half of South Africa's population can be classified as living in poverty while 25% of the population can be categorized as ultra-poor. Although the country is self-sufficient in food production, about 14 million people are reported to be vulnerable to food insecurity and 43% of households suffer from food poverty. The majority (65%) of the poor live in rural areas and 78% of those likely to be chronically poor are also found in rural areas. Agriculture is considered the best tool to address food security challenges, reduce rural poverty and create employment in rural areas. South Africa is a semi-arid country and the rainfall distribution is somewhat unreliable. The low rainfall and limited arable land make it imperative to effectively and efficiently use natural resources for food and fibre production.

Rainwater harvesting and conservation (RWH&C) practices have not only been demonstrated to increase agricultural production but also to be environmentally sustainable. Rainwater harvesting is based on the principle of depriving (naturally or artificially) part of the land of its share of rainfall (which is usually not used productively) and adding it to another part where it can be used beneficially.

A project initiated and funded by the Water Research Commission (WRC) was conducted to assess the impact of RWH&C practices and related institutional arrangements on the cropland and rangeland production in three communities in semi-arid areas of South Africa. Suitable techniques from a literature review of RWH&C techniques on croplands and rangelands were identified and discussed with the community members and other stakeholders in the target areas, whereafter selected techniques were tested and evaluated with on-station and on-farm experiments. On-station experiments were conducted at Glen, Towoomba and Fort Cox in the Free State, Limpopo and Eastern Cape Provinces, respectively. On-farm demonstration plots were laid out in the communities of Gladstone, Merino, Feloane (Free State), Krwakrwa (Eastern Cape) and Lambani (Limpopo). Results obtained from this project were used to compile these guidelines on best management practices for RWH&C for cropland and rangeland productivity in communal areas. Therefore, these guidelines form part of a series of two reports. The other report is entitled "Rainwater harvesting and conservation (RWH&C) for cropland and rangeland productivity in communal semi-arid areas of South Africa" (WRC report no. 1775/1/14).

These guidelines must be viewed as an add-on product to guidelines already developed and existing scientific literature specifically about selected RWH&C techniques. Basic principles of soil (selection, analysis, fertility), climate (determination of mid-summer drought period, first frost, etc.) and crop production (cultivar choice, plant population, fertilization, pest and disease control) are not included. The purpose of the guidelines is to give the reader basic management practices useful for RWH&C techniques on croplands and rangelands in semi-arid communal areas.

The following best management practices (BMPs) are guidelines to implement:

- RWH&C techniques on croplands of communal areas, and
- sound rangeland management principles as well as associated activities including rangeland improvements and/or land use.

The utmost importance of seeking additional technical assistance to these guidelines must be emphasized. Land managers, farmers and villagers should consult the appropriate experts for relevant information on cropland and rangeland production. The application of all BMPs should be monitored frequently to allow for flexibility and adjustment.

1.2 DEFINITIONS

Rainwater harvesting is the process of concentrating rainfall as runoff from a larger area for its productive use in a smaller target area (Oweis *et al*., 2001). The collected runoff can be applied either directly to an agricultural field for crop or rangeland production or be stored in some type of storage facility for domestic use and/or supplemental irrigation.

Conservation tillage is a tillage system that creates a suitable soil environment for growing a crop and that conserves soil, water and energy resources mainly through a reduction in the intensity of tillage and retention of plant residues.

1.3 CLASSIFICATION

Rainwater harvesting (RWH) can be classified as:

- Macro-catchment (ex-field RWH)
- Micro-catchment (in-field RWH)
- Non-field micro-catchment

For the croplands these BMPs focus on on-farm micro-catchment methods.

The micro-catchment methods and conservation techniques used in this project were:

- In-field rainwater harvesting (IRWH)
- Mechanized basins (MB)
- Daling plough (DAL)
- Minimum tillage (MIN)
- No-till (NT)

IRWH and DAL are the RWH techniques while MB, MIN and NT are the conservation techniques.

Macro-catchment (Outside the farm/field/land boundary	Micro-catchment (Inside/within the farm/field/ land boundary	Non-field micro-catchment (Artificial man-made runoff area)
	Characteristics	
• Overland flow harvested from catchment areas outside the farm/field/land boundary • Runoff stored in soil profile/ below-surface reservoir • Provision for overflow of excess water • Can be practised in arid and semi-arid areas with annual rainfall below 450 mm	• Overland flow harvested from short catchment lengths within the farm/field/land boundary • Runoff stored directly in the soil profile • No provision for overflow of excess water most of the time • Can be practised in semi-arid areas with annual rainfall be- tween 450 – 700 mm	• Generally smaller catchment area compared to ex-field • Runoff stored in reservoir above/below ground surface • Tap/outlet normally attached to reservoir to access water • Can be practised in arid and semi-arid areas with annual rainfall below 450 mm
		
	Advantages	
• Makes crop production pos- sible in arid/semi-arid areas • Reduces risk of crop failure • Harvested water can be used for supplementary irrigation • Recharges aquifers	• Increases crop production in semi-arid areas • No ex-field runoff from the field • No erosion from the field • Low maintenance • Only dependent on rainwater from own field • Can be practised on small or large areas • Low implementation cost • No high-tech structures needed	• Used to obtain water for irrigation purposes as well as domestic purposes • Has potential to supply drinking water when no water is available • Reduces risk of crop failure
	Examples	
• Jessours • Contour stone bunds • Stone dams	• Small pits • Small runoff basins • Runoff strips interrow system • In-field rainwater harvesting	• Rooftop water harvesting
		

2 RWH&C FOR CROPLANDS

2.1 CRITERIA FOR APPLICATION

- The slope should not exceed 8%.
- The effective soil depth should be at least 700 mm.
- The annual rainfall must be between 450 – 700 mm.
- Preferably marginal clay (> 10%) or duplex soils.
- Seek professional advice before using a sandy soil.

2.2 SOIL PREPARATION

New entrants of farmers/villagers who want to start with RWH&C:

- Apply for land from the Tribal Authority.
- If the land received was ploughed more than 10 years ago, contact the extension officer of your ward to assist with a soil survey and application for a plough certificate from the Department of Agriculture, Forestry and Fisheries Directorate: Land Use and Soil Management. Ensure that the soil meets the criteria mentioned in section 2.1 - Criteria for Application.
- When successful, it is recommended to get appropriate technical assistance in land use planning and/or whole farm planning.
- See Procedure below.

Existing farmers/villagers who are effectively practising crop production on their croplands, who want to change to RWH&C, can follow the following procedure:

Procedure:

- Make sure the soil meets criteria mentioned in section 2.1 - Criteria for Application.
- Take soil samples on a grid pattern of 50 x 50 m for a thorough soil analysis in order to get a clear picture of the physical and chemical status of the soil.
- Consult with appropriate consultants to develop a proper soil preparation programme.
- Any soil compaction should be addressed before implementation of the technique.
  - Soil compaction in the upper 25 cm can be addressed with a chisel plough.
  - No ripping is recommended in clay soils.
  - Ripping in duplex soils must be considered very carefully in consultation with appropriate consultants/experts.
- Any fertility problems should be addressed before implementation of the RWH&C techniques.
- Only implement the techniques at the correct moisture content to prevent clods if the soil is too dry and “smearing” when the soil is too wet.

2.3 IMPLEMENTATION OF THE RWH&C TECHNIQUES/SYSTEMS

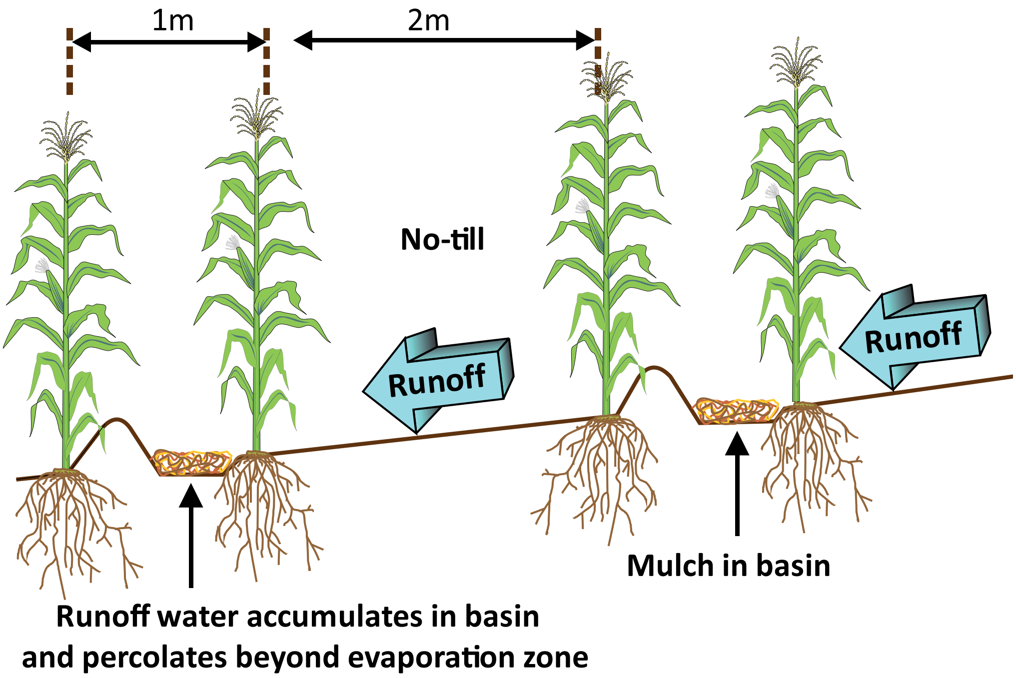
2.3.1 IN-FIELD RAINWATER HARVESTING

Manual IRWH was developed by the ARC-ISCW team at Glen and is described in detail by Hensley *et al*. (2000). The technique proved to be sustainable and outperformed conventional tillage due to the total stoppage of ex-field runoff and minimizing of evaporation from the soil surface (Botha *et al*., 2003; Botha, 2006; Anderson, 2007). Apart from increasing crop yield due to a better utilization of rainwater and increased rainwater productivity, it also stops erosion (Hensley *et al*., 2000; Botha, 2006). The successful uptake of this technique in homestead gardens is described in detail by Botha *et al*. (2003).

IRWH combines the advantages of rainwater harvesting, no-till and basin tillage on high drought risk clay and duplex soils. During a rain event on these soils, the IRWH technique collects runoff from a 2 or 2.4 m wide no-till strip between alternate crop rows and stores the runoff water in the basins, where it can infiltrate deep into the soil beyond the surface evaporation zone. After the basins have been constructed, no-till is applied to the land. Since there is no cultivation that is done on the runoff area, a crust forms and this can enhance runoff.

This innovative RWH technique has the potential to reduce total runoff and minimize surface evaporation (Es) considerably when implemented correctly. The result is increased plant-available water and thus increased yields. The advantages of IRWH are considered to be:

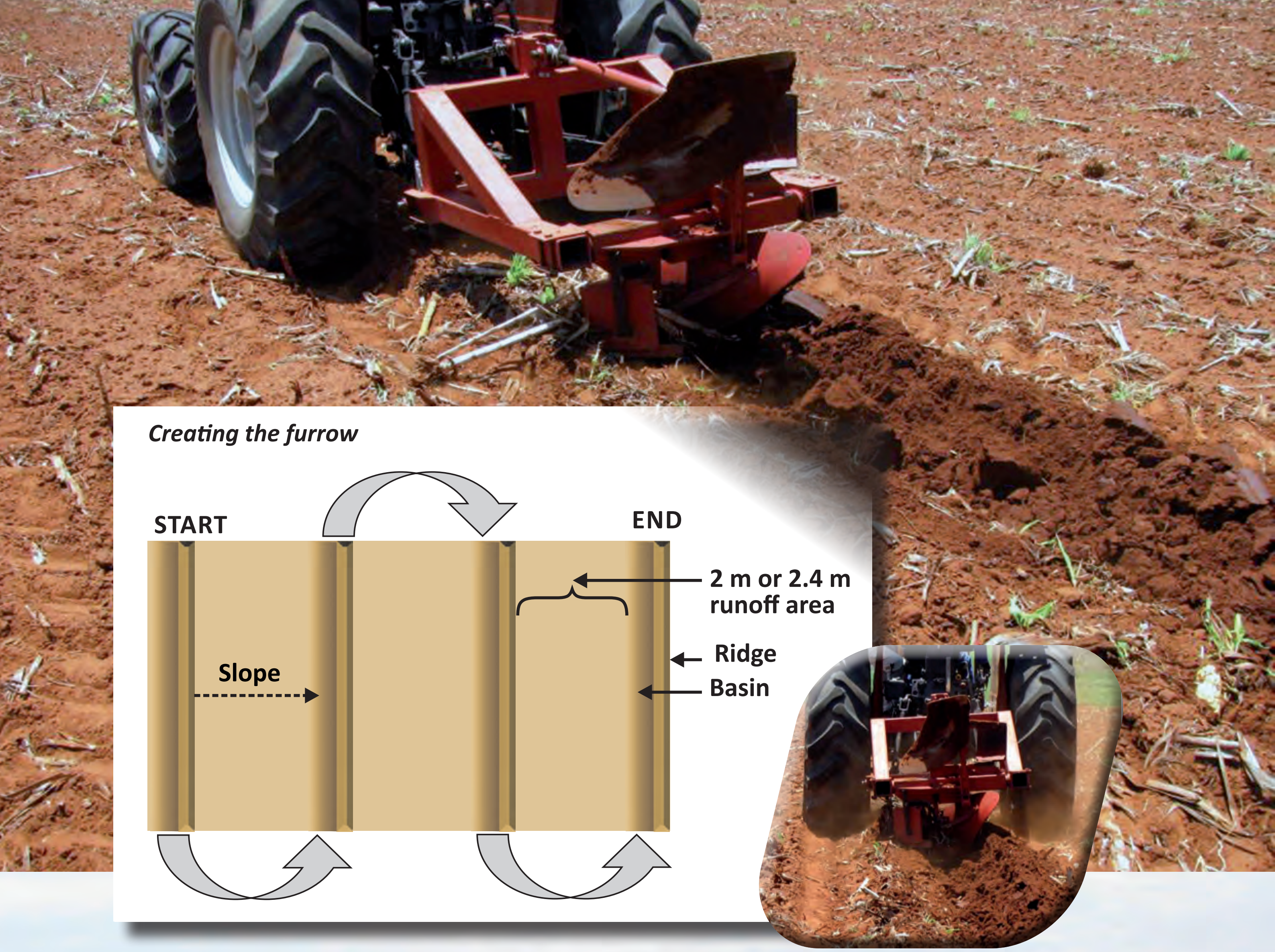
- Basin tillage minimizes runoff from the land.
- Water harvesting from the untilled, crusted soil on the 2 or 2.4 m wide intercrop row area serves to promote and concentrate runoff water in the basins. This promotes infiltration of water beyond the surface evaporation zone and therefore minimizes Es losses.
- Mulch on the runoff area contributes to minimizing Es losses and prevention of erosion or soil movement.



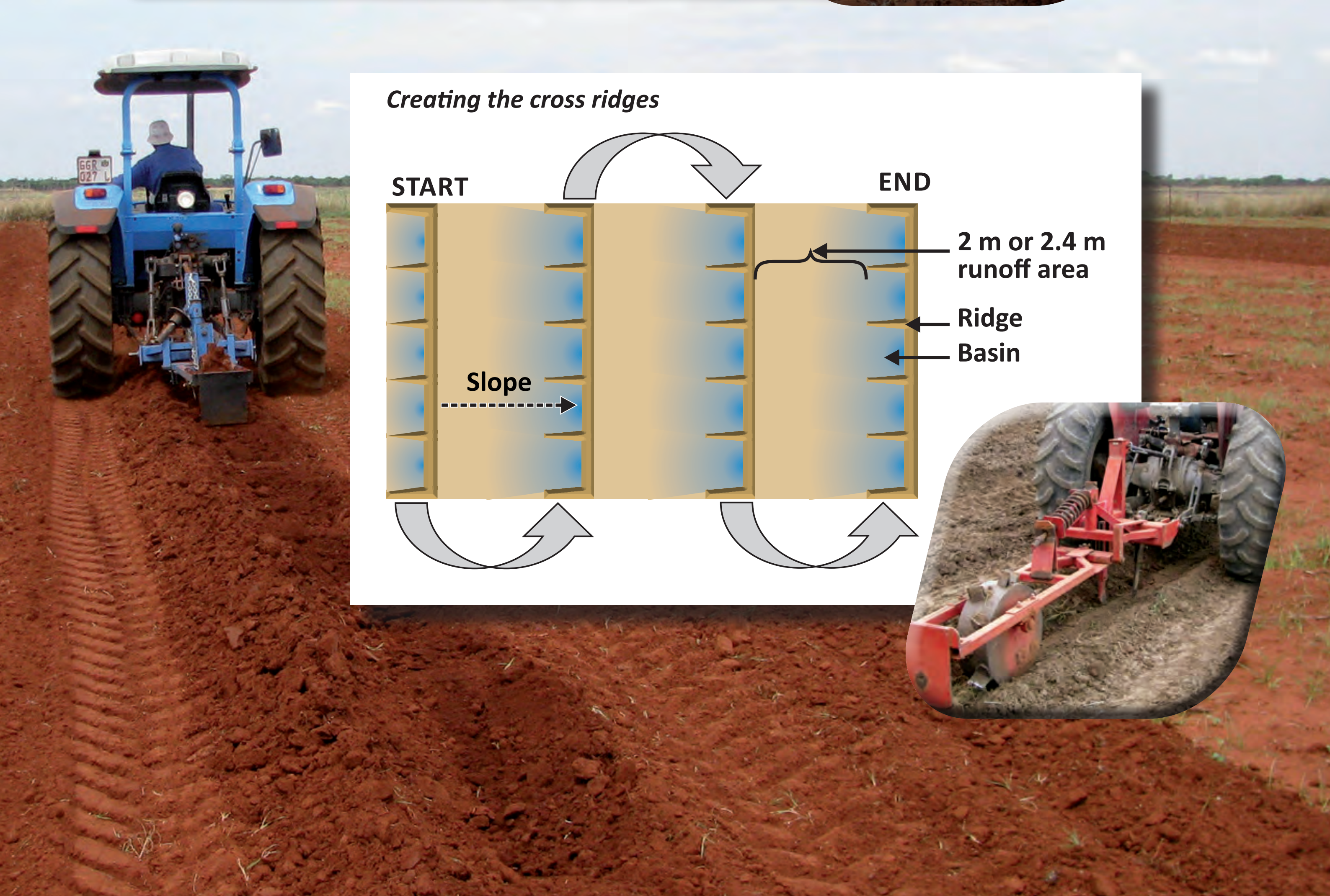
The mechanized IRWH structures are constructed with a furrow plough and basin plough. The furrow plough creates a 20 cm high contour ridge with a slope striving to be zero. The basin plough creates a 10 cm deep and 1 m wide basin every 1.5 m along the ploughed contour.

How to implement:

1. Determine the main slope.
2. Plan lay-out across main slope in such a way that maximum rainfall as runoff can be harvested. Take secondary slope also into consideration.
3. Determine whether 2.4 or 2 m runoff areas are going to be used. A 2.4 m runoff area is more practical for additional management practices during the season and fits with standard farming/agricultural equipment.
4. Demarcate the lay-out.
5. Use single row furrow plough as the first implement.
6. A 20 cm high ridge is made with a single furrow plough perpendicular to the main slope direction.
7. The distance between the furrows is 3.4 m.
8. This is followed by the second implement, the basin plough, which runs in the furrow and creates a 15 cm deep and 1 m wide basin every 1 m within the furrow. The tractor drives wide-legged over the furrow. Make sure that the basins are not implemented too deep to open the B horizon.
9. Make sure the off-centre wheel turns and does not pack.
10. Basins have to be evaluated every season to determine whether to re-use them or construct new basins.
11. If basins are to be reconstructed, the implementation should take place on the same basin line as previous seasons.



Creating the furrow
START
END
2 m or 2.4 m runoff area
Ridge
Basin
Slope



Creating the cross ridges
START
END
2 m or 2.4 m runoff area
Ridge
Basin
Slope

2.3.2 MECHANIZED BASIN PLOUGH

The mechanized basin (MB) plough was originally developed by Mr. Jurie Serfontein near Kroonstad for the creation of basins to rehabilitate degraded veld. Dagga & Macartney (1969) reported that the system of cultivation based on ripping, ridging and tie-ing proved to be an adequate alternative to ploughing and harrowing for seedbed preparation, and a much more efficient method of water conservation. The MB plough was modified to incorporate a small tine to rip the bottom of the basins to improve infiltration (Van der Merwe, 2005).

Van der Merwe (2005) tested the MB plough on a clay soil at the Springbok flats and found that it increased maize and sunflower yield as compared to conventional tillage due to its better water conservation ability. Small basins in rows conserve the rainwater that falls into the basins, where the water in the basins can infiltrate deeper into the soil, below the evaporation layer. The MB technique does not have the ability to harvest additional runoff water.

The MB plough has a basin attachment (small sharp scraper blade) which pivots on the rear of a three-point hitched ripper. The ripper tine operates directly in front of the attachment to break up compacted soil. The scraper at the rear of the attachment creates the basins. The diamond shaped wheel controls the movement of the scraper blade, resulting in a row of basins being created.

The distance between basin rows is versatile and depends on the planter and maintenance considerations. A 1 m spacing is recommended. With a tractor wheel width of 480 mm it implies that during implementation the tractor returns on its tracks when implementing a new row, but the return trip must start about 50 mm away from the initial wheel tracks.

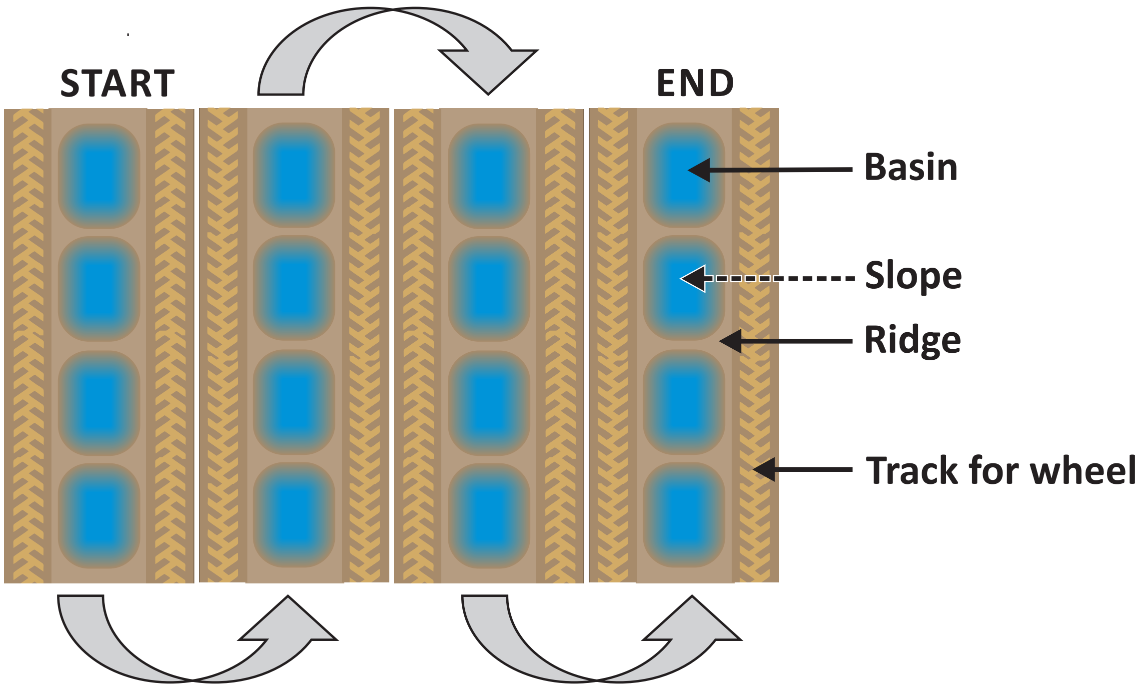
How to implement:

1. Determine the main slope.
2. Plan lay-out of basins on the field.
3. Determine planter and other equipment ability to adapt the row width.
4. The distance between basin rows is versatile and depends on the farmer's planter and maintenance considerations.
5. A 1 m spacing is recommended.
6. With a tractor wheel width of 480 mm it implies that during implementation, the tractor returns next to its tracks when implementing a new row, with the return trip about 50 mm away from the initial tracks.
7. Make sure the wheel turns and does not drag.
8. Evaluate condition of basins to conserve rainwater before each new season; whether they should be re-implemented or not.
9. If basins need to be reconstructed, implement the new basins on the same basin line as previous seasons.

Mechanized basin plough

Construction of basins

Description of tractor movement during implementation



2.3.3 DALING PLOUGH

The Daling plough (DAL) was developed by a farmer, Mr. Dirk Daling, near Settlers in Limpopo Province. The DAL creates a 1.8 m runoff area with a relatively wide and shallow basin. The DAL consists of a chisel plough in front followed by a large V-shaped scraper blade with an off-centre wheel. The chisel plough is connected directly to the three-point linkage of the tractor. The large V-shaped scraper blade follows directly behind the chisel plough. The chisel plough first loosens the soil before long V-shaped or chevron-shaped basins are constructed. The off-centre rotating wheel lifts the scraper over the soil in front of the scraper so that it is left as a ridge (Anderson & Botha, 2009).

The DAL was built on the same principles as IRWH with the exception that no sunken basins are created. The DAL works on the principle of scraping the top layer of the soil without changing the natural slope and applying large ridges on both sides of the large (wide) scraper blade. V-shaped or chevron-shaped basins are created. The chisel plough prepares a fine seedbed, while the scraper blade enhances runoff towards the lower point of the basin.

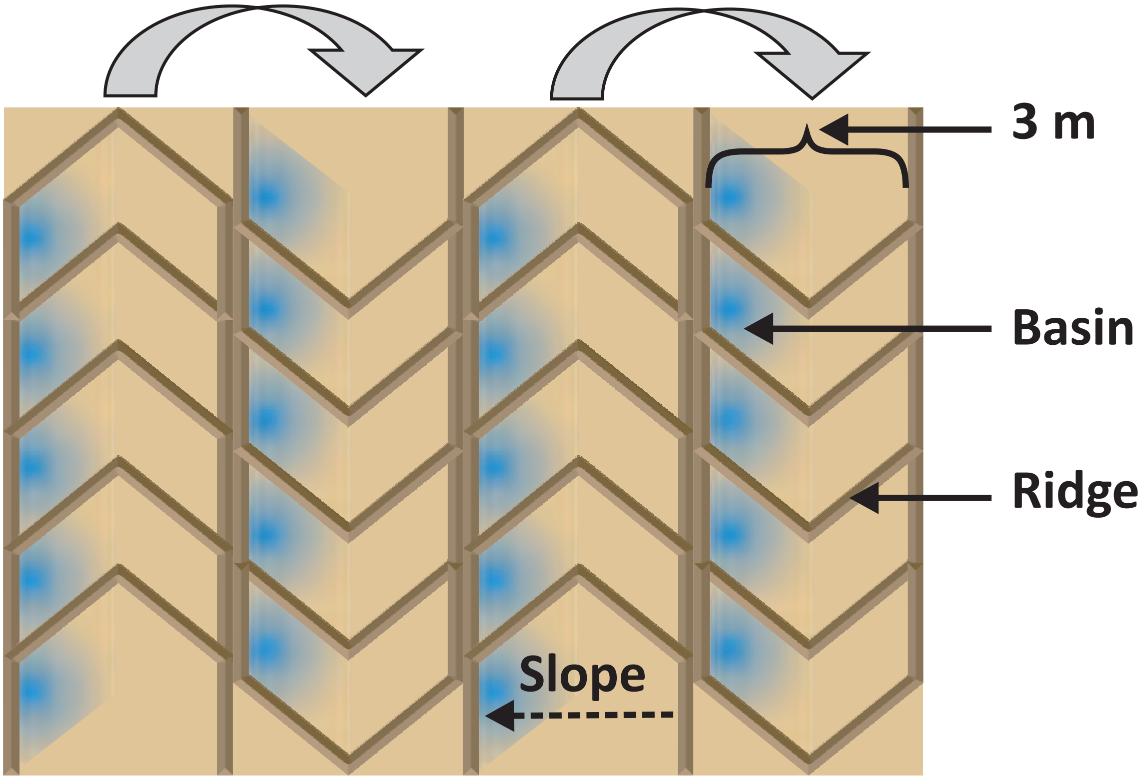
How to implement:

1. Determine the main and secondary slopes of the land.
2. Plan the lay-out in such a way that the large basins will be implemented perpendicular to the main slope but also taking the secondary slope into consideration for maximum rainwater harvesting potential.
3. A larger tractor is required to implement the DAL technique (58 kW).
4. Implement first row of large V-shaped basins.
5. Return next to the first row in such a way that the ridges applied by the scraper blade of the previous and current row touch to create a good strong ridge. This will ensure that all the basins are the same size.
6. See section 2.4 - Planting. Correct planting is critical; this determines the correct position of smaller basins between crop rows.

Daling plough during implementation

Land after implementation with Daling plough

Implementation process with Daling plough



2.3.4 MINIMUM TILLAGE AND NO-TILL

These conservation techniques are a system approach, using commercial implements available on the market. They thus differ from the rainwater harvesting techniques. Minimum tillage (MIN) and no-till (NT) are conservation techniques that reduce the negative impact of rainfall on the soil *via* the organic matter at the soil surface. The consequence is less runoff and improved infiltration of rainwater, and thus also seen as a form of rainwater harvesting.

Only basic principles are included because NT is currently not recommended for the semi-arid areas by scientists in South Africa. The extent of basic principles involved in no-till is beyond the scope of these guidelines and therefore included only for an overview.

Minimum or reduced tillage (MIN)

WHAT?

- Conservation tillage practice that minimizes mechanical soil disturbance.
- Leaves crop residues on the soil surface that act as mulch.

HOW?

- MIN can vary from rip on the row with controlled traffic to only one primary tillage/ cultivation followed by chemical weed and disease control. Row spacing can vary from 0.9 - 2.4 m depending on the farmer's tractor, implements and system used or recommended. For example, in this project it was practised in the Free State as rip on the row with controlled traffic and in the Eastern Cape as one primary tillage/cultivation followed by chemical weed and disease control.
- The principles of MIN used in the Free State (rip on row – 1.5 m rows with controlled traffic) were:
  - infiltration on the rows was improved and stimulated, while
  - compaction occurred on the areas for tyre tracks between crop rows, and
  - therefore water will be conserved in the rows between the tracks.
- As a general recommendation: Rip on the row with controlled traffic on sandy soils and reduced tillage with no rip on clay soils.

WHY?

- MIN conserves water in the soil profile due to reduced soil tillage.
- Increases organic material.
- Improves soil structure.
- Increases infiltration.
- Increases soil carbon sequestration.
- Reduces capital investment in infrastructure and annual input costs.

How to implement:

Sandy soils:

1. Identify main slope.
2. Rows must be implemented perpendicular to the main slope.
3. Use one tine ripper that is centred between the two tractor wheels and a chain dragging behind just to close the little furrow.
4. Try to rip deeper and deeper over a period of time so that the ripping can go down to 450 mm depth.

5. Controlled traffic is critical and all activities should be conducted in such a manner that tracks are exactly on the same line.
6. Rip actions should be seasonally repeated on exactly the same row where crops were planted.

Clay soils:

1. Identify main slope.
2. Implement whatever primary tillage entails only once, before planting.

No-till (NT)

WHAT?

- Croplands are not tilled at all.
- Row spacing can vary from 0.9 – 2.4 m depending on the farming system used.

HOW?

- Herbicides and pesticides are used in management.
- Planting is done with a NT planter.

WHY?

- Conserves water in the soil profile.
- Promotes recycling of nutrients.
- Increases organic material.
- Improves soil structure.

2.4 PLANTING

The principle of rainwater harvesting is to plant as close as possible to the basins where the harvested rainwater is stored in the soil profile. Therefore the IRWH, MB and DAL techniques are tailor-made for planting alongside the basins in tramlines which is an acceptable practice amongst farmers. The distance between the tramlines alongside the basin can vary between 0.9 – 1.1 m. This will be to protect the basins and ridges for more water storage and will be determined by the farmer's planter and system used. The wider option (1.0 – 1.1 m) is recommended in order to cater for human error.

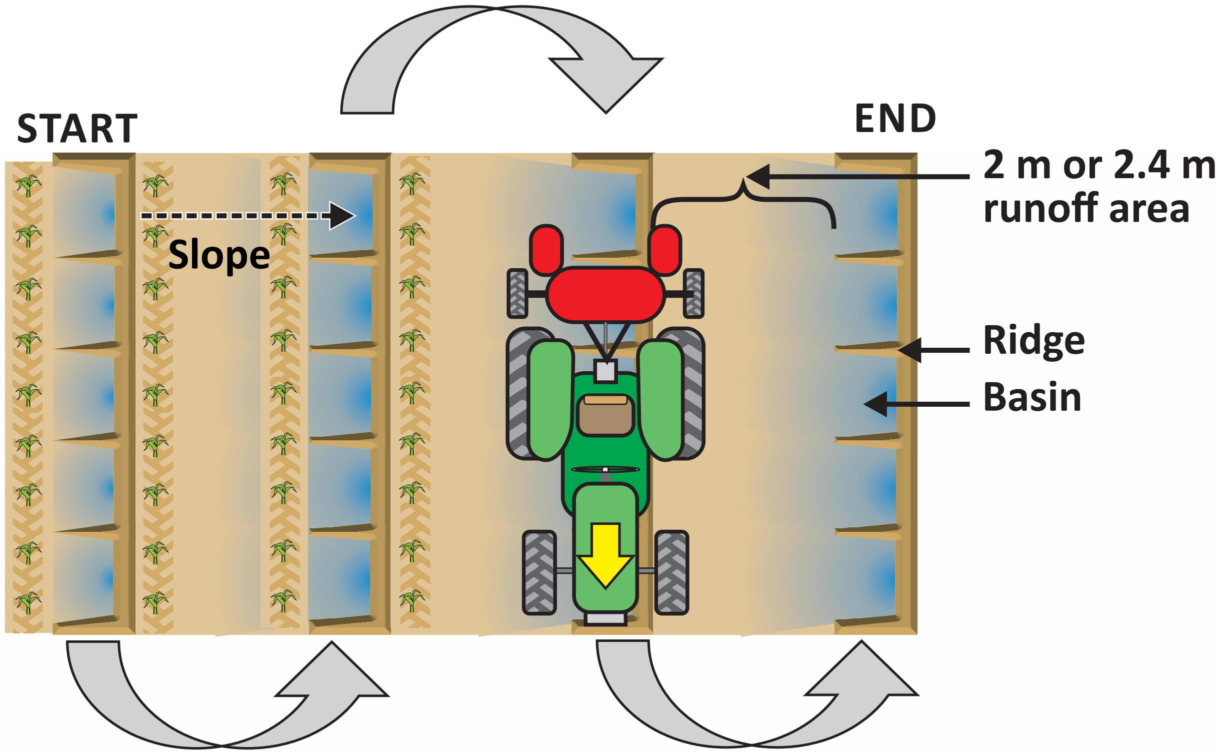
Planter requirements:

- The minimum requirement is a planter with two planting units which can be adjusted to plant alongside the basin.
- Planter must be equipped with proper fertilizer and seeding mechanisms that can be calibrated.
- Planter must be equipped with NT technology.

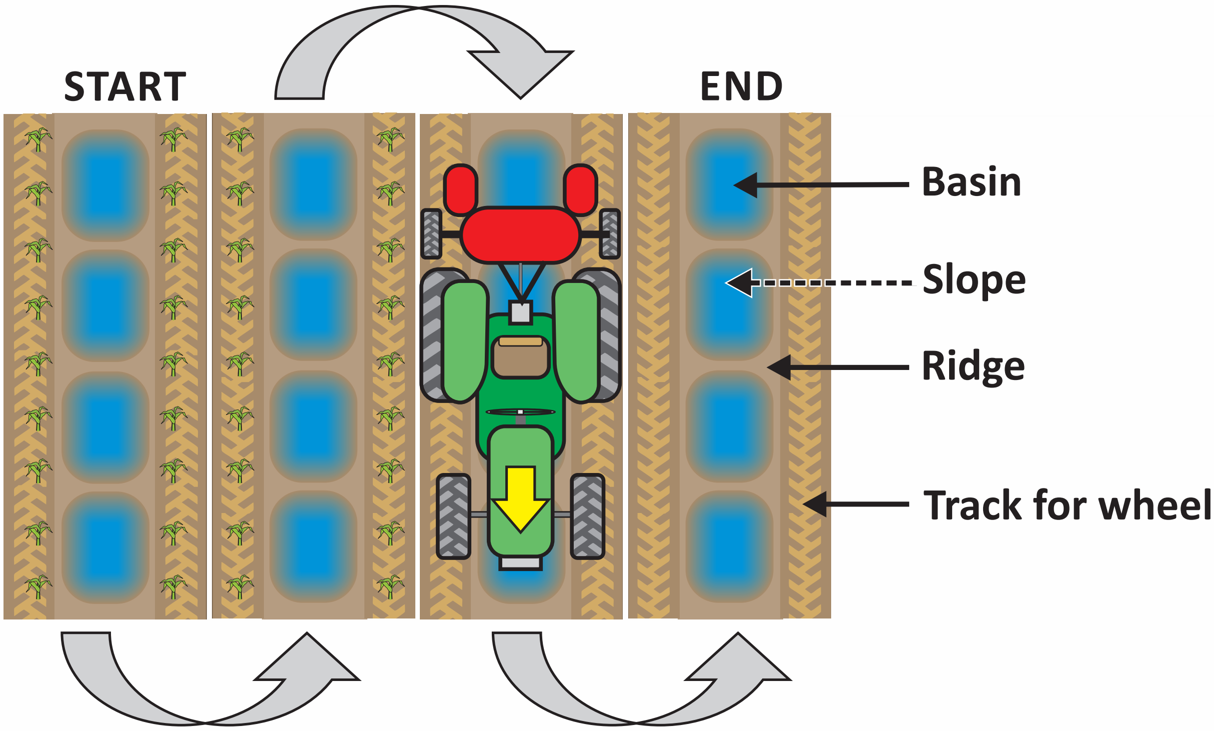
Procedure:

- Ensure equipment is serviced and in a good working condition before planting. Adjust planter units to correct row spacing.
- Decide on crop, cultivar, plant density and planting time.
- Get proper fertilization recommendation.
- Buy certified seeds and fertilizer.
- Calibrate planter for correct seeding rate:
    - Determine the number of rows in 100 m (100 / row distance).
    - Determine the number of plants in a 100 m row (plant density / number of rows).
    - Determine the distance between seeds (number of plants in 100 m / 100).
    - Select the applicable gears on the planter according to the planter instructions.
- Calibrate the fertilizer application as follows (based on the assumption that the circumference of the planter wheel is 2 m):
    - Determine the quantity of fertilizer to be applied in 20 m (quantity of fertilizer / number of rows / 100 x 20).
    - Make a mark on the planter drive wheel.
    - Fill the planter with fertilizer.
    - Put bags underneath the fertilizer delivery units and turn the drive wheel ten times.
    - Weigh the quantity of fertilizer.
    - Open or close the fertilizer delivery unit until the quantity of fertilizer captured in the bags is equal to the above-mentioned determined value.
- Take enough seed and fertilizer for filling the planter in the field.
- **IRWH & MB:** Plant with tractor moving astride the basins of IRWH and MB. Driver must take care not to damage the basins. This is where an inter-plant row spacing of 1.0 – 1.1 m is an advantage.
- **DAL:** Identify slope direction. Plant astride the ridge. Tractor wheel set below the slope of the ridge should be as close as possible to the ridge. Tractor wheel set above the slope of the ridge should be as far as possible from the ridge. This will create sets of smaller basins similar to that of IRWH. If the planting is done incorrectly the basins will face the wrong direction.
- Tractor must have a good and stable lift, be in proper working condition with depth control.

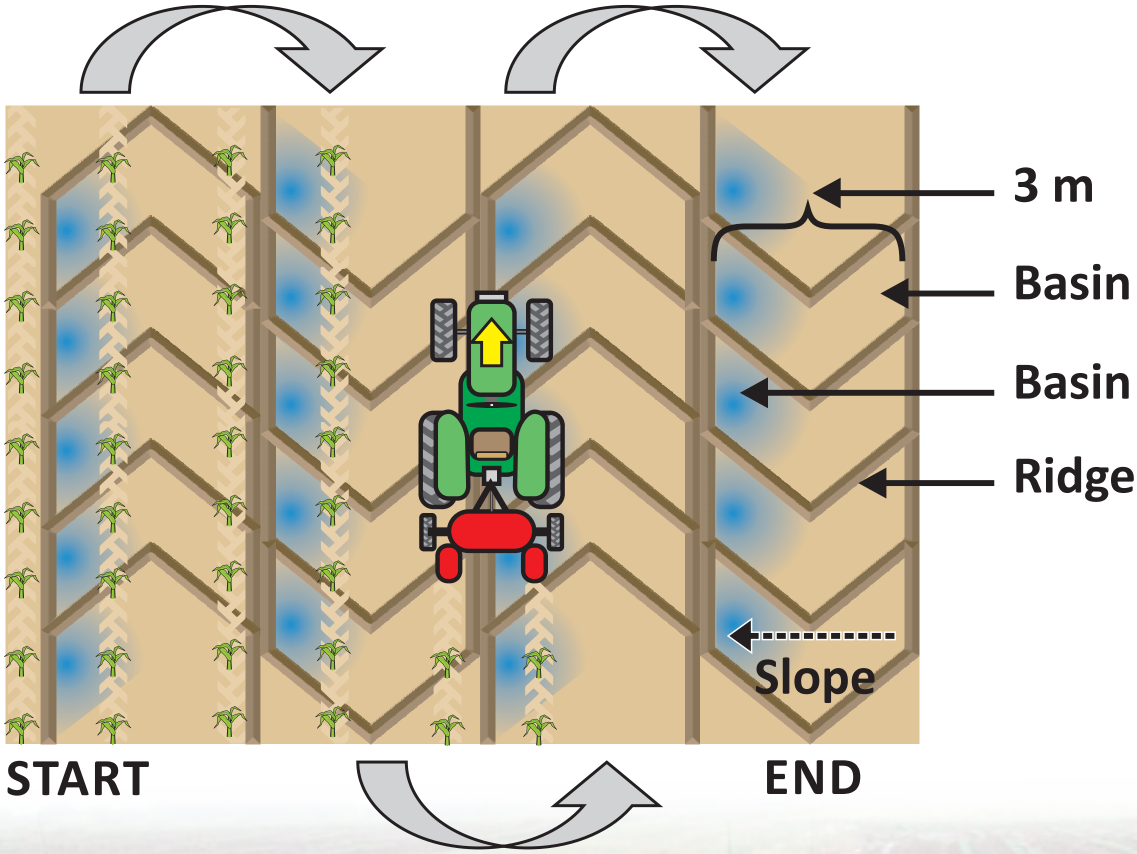
IRWH planting procedure



MB planting procedure



DAL planting procedure



2.5 WEED CONTROL

Proper weed and disease control is critical especially with minimum tillage. In this particular case all the techniques (IRWH, DAL, MB, MIN and NT) are in some way or another a type of minimum tillage. Therefore, consult professional experts.

Methods of control:

1. Prevention.
2. Mechanical/manual weed control.
3. Chemical weed control.
4. Integrated weed control.

Prevention:

- Proper weed control already starts before planting.
- Avoid crop seed contamination by buying certified seed.
- Avoid spreading weed plant parts that propagate vegetatively.
- Do not use contaminated manure.
- Kill weeds before the flowering stage.
- Use of mulches suppresses weed germination.
- Modify plant spacing between and in the rows.

Mechanical weed control:

- Use secondary cultivation implements as determined by choice of crop.
- Ensure that the tractor and implements are in a good working condition for effective weed control.
- Take precautions to prevent spreading weeds to other sites.

Chemical weed control:

- Herbicides are made up of chemical compounds, known as active ingredients, which affect the life processes within the plant, eventually leading to damage or death.
- Herbicide formulations are a combination of active ingredients and other chemicals. A formulation can be a liquid or a solid consisting of particles of different sizes.
- Formulations also contain solvents to disperse the active ingredients and other chemicals with solvents to disperse them, stabilizers for prevention of interaction with other chemicals and prolonging shelf life, and emulsifiers to enable mixing of active ingredients with water and oil.
- Adjuvants improve their entry into the plant and dyes are added to show where the herbicides have been applied.

Procedure:

Step 1: Identify the weeds in your field for selection of effective control.

Step 2: Consult specialists to select the correct chemical registered for the specific crop for the control of weeds identified in step 1.

Step 3: Ensure proper care and maintenance of the boom sprayer.

Step 4: Pre-inspection

- Check nozzle performance by running the sprayer with clean water.
- Open any blockages and replace broken nozzles.
- Check all pipe connections for leakages.
- Follow maintenance instructions of pump.

Step 5: Fill the tank of the boom sprayer with water.

Step 6: Calibrate your sprayer

- While sprayer is running at working pressure, measure the quantity of water at one of the nozzles.
- Record the time for completion of a 100 m distance in the field.
- Calculate the application rate.
- Make necessary adjustments by either changing tractor speed or pressure.
- Repeat until the application rate is according to prescription on the herbicide label.

Step 7: Read and follow instructions on label carefully. Only apply the recommended dosages.

Step 8: While the power take-off is running, mix the chemical with water.

Step 9: Spray the field taking all precautions into consideration. Operators MUST always wear protective clothing (rubber boots, protective aprons or suits, rubber gloves and safety glasses or goggles) and a face mask.

Step 10: Carefully clean application equipment after use.

2.6 HARVESTING

The crop can be harvested with a single row or combine harvester. See Existing Infrastructure under section 2.7.

2.7 WHAT TECHNIQUE/SYSTEM TO SELECT

When choosing a RWH&C technique it is important to not only consider the physical aspects, but also the socio-economic and institutional requirements of the farmers/villagers it is to serve. The most important factors to consider when implementing RWH&C techniques are: the technique should be accepted by the local population, be sustainable in the local environment, and all stakeholders should be involved from the beginning.

Factors to consider in selection of any technique/system by a farmer are the following:

- **Soil type:**
  - DAL and MIN with rip on the row are not recommended for soils with a vertic A horizon, or duplex soils with a shallow A horizon (< 300 mm).
  - Application of various RWH&C techniques is influenced by clay content of the topsoil (A horizon):
    - < 18% clay: DAL, MIN (rip on row with controlled traffic)
    - 18 – 30% clay: IRWH, DAL, MB, MIN, NT
    - > 30% clay: IRWH, MB, NT, MIN

- **Crop:**
  - All techniques/systems are suitable for production of maize, sunflower and other summer row crops.
  - For winter cash crops and annual pastures, DAL is recommended on sandy and loam soils for maximum summer rainfall harvesting, while IRWH is recommended on clay soils. The crops can then be planted in winter and success will depend on early summer rain.
  - To reduce input costs the basins of IRWH and MB can only be reconstructed after two or three years. Thus it induces a mono-culture or rotation system as long as the crop is planted on the exact row position of the previous crop. Rotation with a legume is recommended to improve soil nitrogen status and sustainability of the technique used. Planters must be able to handle the stubble of the previous crop.

- **Existing infrastructure:**
  - A 35 kW tractor can be used for IRWH and MB with a double row planter.
  - A 58 kW tractor is necessary for DAL.
  - For MIN and NT the tractor size depends on the planter size.
  - Two-row or four-row planters will influence tractor size.
  - Preferably a NT planter should be used if IRWH, MB, NT or MIN is applied; otherwise a conventional planter equipped with NT technology can be used.
  - The row distance of existing conventional planters can be easily adjusted to fit MIN with rip on the row.
  - Row crops produced with the DAL technique can be harvested with a Slatery harvester. A combine harvester can easily be used with the MB and IRWH technique without damaging the basins. For IRWH a small adjustment of the cutting unit is needed if the farmer does not want the basins to be damaged. MIN and NT are also suitable for any harvester depending on the row distance.

- **Farmer preference:**
  - Farmers must choose the RWH&C technique that will best fit their system, taking tractor capacity and available implements into consideration.

Results from the project conducted on ten different ecotopes over two to four growing seasons indicated that IRWH performed the best, followed by DAL, MB and NT. Therefore the following techniques are strongly recommended for higher yields:

- Clay soils (> 30% clay): IRWH and MB
- Loam soils (15 – 30% clay): DAL, IRWH and MIN (rip on row with controlled traffic)
- Sandy soils (< 15% clay): DAL and MIN (rip on row with controlled traffic)

For more information on the availability or building of water harvesting ploughs, contact the
ARC-ISCW (Glen office) • bothac@arc.agric.za • 072 036 9080

3 RWH&C FOR RANGELANDS

3.1 INTRODUCTION

Literature indicates the ancient history of water harvesting in Southern Mesopotamia, the Negev Desert, Arizona, northwest New Mexico, Australia and West Africa. A summary of the existing knowledge is as follows:

- Water harvesting on rangeland is used in the arid zones with no functional rangelands.
- The mean annual rainfall is from 200 – 350 mm. Rainfall less than 200 mm during the growing season would not produce enough runoff to justify a water spreader system. Forage production occurs only on sites that receive a minimum of at least one flooding event per year. Therefore it is a 10 - 12 year investment.
- Clay, silt-clay or silt-loam soils are suitable for water ponding dykes/berms/semi-circular bunds. These structures promote sediment deposition in the ponding area, with an effective lifetime of 3 years. Thus their success depends on maintenance.
- With regard to water requirements of fodder and rangeland, the focus is to improve performance within economic constraints, and to ensure survival of the plants from season to season rather than fully satisfying water requirements.
- Structures used are water spreaders, dykes, stone bunds and semi-circular bunds.
- Research results indicate increased production quantity but not necessarily quality.
- The small research areas used are a drawback in extrapolation to large areas.
- Controlled rotational grazing is essential to maintain good quality rangeland, and the bunded area must be rested periodically.
- The basic goal of water harvesting on rangeland is to intercept the flow of surface runoff water to increase soil water content and forage growth by constructing shallow water ponding dykes across known overland flow paths.
- In these arid areas water harvesting creates conflict of interest between rangeland improvement and livestock watering.
- When stock ponds are considered to be constructed, it must be kept in mind that the number of ponds depends upon the type of livestock because the distance that specific breeds of cattle typically graze away from a water resource varies. Mexican breeds, for example, can travel longer distances (5.8 vs 2.2 km) from water compared to British breeds (Angus) when forage availability is limited.
- Water harvesting in rangeland and fodder production will mainly be applied in areas where the majority of inhabitants or users are agro-pastoralists. The concept of improving communal rangeland is usually alien and adoption of such an approach is not easy. An integrated management programme is critical to avoid over-grazing and subsequent degradation.

Rangelands occupy over 70% of the land surface of South Africa making it the largest single land use approach (Snyman, 1999). According to Schulze (1979), approximately 65% of South Africa's rangeland is in the arid and semi-arid areas, with a mean annual rainfall of 500 mm or less. These areas are characterized by annual or shorter seasonal droughts. Rangeland deterioration is initially inconspicuous and farmers only realize that the land is deteriorating when drastic changes like bare patches occur. An estimated 66% of the rangelands of South Africa are in a moderate to severe stage of degradation. Degraded vegetation, bush and shrub encroachment and erosion are generally visible symptoms of disturbed rangelands.

Restoration/reclamation of rangelands

In certain rangeland areas of South Africa, natural vegetation has degraded to such an extent that the application of management practices or even total withdrawal of grazing will not have the desired effect on recovery. More drastic restoration measures must be applied and should strive, among others, towards increased water infiltration, improved vegetation composition, cover and density, decreased runoff, a better microclimate, and soil erosion control.

Numerous studies in South Africa revealed that restoration of rangelands is determined by soil type, climatic conditions, the causes and degree of rangeland deterioration and especially the degree of degradation. Rangeland restoration is an expensive and time-consuming process requiring pre-planning. Methods vary from shallow working with a light-toothed harrow to deep working tined implements, or by making hollows or pits. These methods are to shatter the crust on compacted areas. Results indicated that plant establishment and survival were better overall when a hollow cultivation technique with a ripper action (400 mm depth) was applied in one operation. It is recommended that the depth of cultivation should be 200 mm or more and the cultivation width not less than 2 m in semi-arid areas.

Great success was achieved by using different types of dyker ploughs for creation of small shallow pits scattered across the soil surface. The dyker plough is similar to the MB plough used for IRWH under croplands. The results indicated that cultivation with the dyker plough was the most effective in clay soils and that the ripper cultivation techniques were the most suitable on sandy soils.

Why are water harvesting and restoration/reclamation not widely used in South Africa?

- **Soil water management in rangelands**

Identification of rangeland management practices ensuring optimal rainfall utilization and effective soil water management is one of the most important requirements of sustainable rangeland production in arid and semi-arid areas.

After a rain event the largest percentage of soil water is lost by evaporation from the soil surface. It increases with aridity and ranges from 20 - 70% of the infiltrated rain. It can be decreased by managing grazing to maintain an optimal cover of the plant community, which can only be obtained when the rangeland ecosystem is in equilibrium (normally the climax vegetation). Under climax range conditions, there is not only a significant relationship between seasonal plant production and evapotranspiration in semi-arid areas, but the rangeland also produces significantly more per unit volume water used than when in a poor condition.

Surface runoff varies with rainfall, soil type, slope, plant cover and soil conservation practices. Bare areas that have opened between tufts mean more runoff, increased evaporation and higher soil temperatures. Runoff and soil losses are thus controlled by man as manipulator of the rangeland ecosystem. An increase in surface runoff and sediment loss with veld degradation results in increased drought risk and facilitates so-called man-made droughts.

A decrease in infiltration rate in the soil with an increase in stocking density is common in rangelands and can be ascribed to compaction of the soil by hoof action of animals. A lack of knowledge on the actual time needed for reversing soil compaction after different levels of grazing pressure, limits optimization of rangeland production.

- **Water-use efficiency**

The significant decrease in production as range condition deteriorates is a function of water-use efficiency (WUE) and stability of the different species within a plant community. An increase in WUE occurs as range condition improves. This results not only from the influence of veld condition on infiltration rates but also from the more effective use of available water by climax compared with pioneer species. Moderate levels of defoliation can further increase the rain-use efficiency of *Themeda triandra* swards. In arid and semi-arid rangeland areas of southern Africa, dry matter (DM) productivity is higher and more constant on soils deeper than 0.75 m which are able to store limited rainfall, and between 2 - 6 kg DM ha^{-1} can be produced from rangeland in good condition for every mm rainfall used. Actual rain-use efficiency figures throughout the arid zones of the world may vary from less than 0.5 in depleted sub-deserted ecosystems to over 10.0 kg DM ha^{-1} mm^{-1} in highly productive and well managed steppes, prairies or savannas. WUE, which decreases with an increase in aridity, can be considered a good indicator of an ecosystem's productivity and resultant grazing capacity.

Sustainable animal production and maximum income per unit water used are only attainable from rangeland in a productive and stable condition. Farm size does not necessarily determine whether it is an economically sustainable stock farming unit, but the condition of the rangeland directly influences the grazing capacity and risk management.

- **Rangeland dynamics**

Biological complexity and diversity, essential components for sustainable production of a rangeland ecosystem, require the maintenance of a wide range of vegetation and various habitats within a production system. A plant community is never static but always improving or deteriorating. The condition of the vegetation of a rangeland ecosystem over time indicates the very ability of the plant community to remain relatively stable in a specific area. The condition of the plant community is further related to ecological status (succession stage, botanical composition and cover) and also its productivity, nutritive value and palatability.

The significant decrease in production due to deterioration of rangeland condition is a function of WUE and stability of the different species within a plant community. Sustainable animal production and maximum income per unit water used are only attainable from rangeland in a productive and stable condition. Theoretically, no drought should occur if the stocking rate applied is managed according to the long-term grazing capacity of a plant community.

Conclusion

Water harvesting on rangeland was mainly used in the arid zones. It is considered the last resort to restore severely degraded arid zones. On functional degraded rangelands, conservation, by restoring proper management practices, is recommended.

The approach of RWH&C techniques on rangeland differs from that on cropland. Rangelands are a dynamic system that developed over the long term and is therefore adapted to the local climate, including floods and droughts as well as soil differences. Mechanical disturbance with rainwater harvesting techniques will disturb this ecological system which usually leads to a decline in the ecological status, increased drought risk, decline in quality, and results in a loss of the functioning of the grazing system. Therefore mechanical disturbance in rangeland that is still functioning is not recommended, while it could be used in areas where cover loss has already occurred and bare patches are dominant.

RWH&C techniques in rangeland with moderate to excellent condition will have a negative effect on the rangeland ecosystem, animal production and drought risk. Soil tillage techniques, like IRWH, MB or DAL (discussed in section 2.3 under croplands) are NOT recommended on these rangeland condition classes.

On rangelands, the approach is to quantify the veld condition on farm or district scale and obtain advice in developing a proper camp system. In the process bare patches, eroded and degraded patches, as well as old cultivated fields are identified for development of proper renovation or reclamation strategies. In the case of an existing camp system, quantify the veld condition and adjust the stocking rate and/or grazing plan.

3.2 BASIC PRINCIPLES OF VELD MANAGEMENT

The best conservation technique recommended is proper veld management with the correct stocking rate according to the veld condition.

WHAT is grazing capacity?
For the purpose of macro planning, the figures on a national grazing capacity map should reflect the long-term grazing capacity for animals for a specific area, based on a good veld condition under the long-term rainfall and that would ensure sustainability over the long term. Therefore, the grazing capacity is the result of the interaction between: rainfall, available soil water (depends on soil type), soil depth, evaporation, veld condition, topography, animal type and management factors.

- Grazing capacity is the number of animals that can be kept on a unit area over the long term, without deterioration of the natural resources (rangeland).
- The determination of grazing capacity is necessary as it is the basis for sustainable rangeland utilization.
- Grazing capacity is expressed as ha LSU^{-1} (LSU = large stock unit).
- A LSU is defined as the equivalent of a head of cattle with a mass of 450 kg which gains 500 g day^{-1} in mass on a grass pasture with a mean digestibility of 55% (Meissner *et al.,* 1983).

HOW do you determine grazing capacity?
There are several techniques developed to determine grazing capacity with each differing in accuracy and reliability for different rangeland types and regions. These methods can be classified into three basic groups:

1. The complex and time consuming determination of biomass of the rangeland, through e.g. line intersect and wheel point method.
2. The estimation of grazing capacity by expertise.
3. Calculation according to the veld condition.

The best technique to determine grazing capacity is by assessing veld condition.

3.2.1 PROCEDURE FOR RANGELAND ASSESSMENT

Following the procedure below without the technical assistance of professional rangeland experts is not recommended.

- Planning a veld survey for each camp:
  - Get a farm map of the area.
  - Decide on method and site selection.
  - Determine logistics for 200 point sampling on a fixed line transect.
  - Determine the soil information from the map and make provision for a soil survey to evaluate the soil potential.
- Execution of survey:
  - Use the nearest point technique to determine the species composition.
  - Identify and record bare patches if further than 0.5 m from fixed point.
  - Calculate veld condition. If the veld condition is lower than 25%, restoration can be considered. If it is higher than 25% it will be increased by good veld management practices and will be more economically viable and sustainable.

- Interpretation of data:
  - The grazing capacity is calculated from the veld condition. Refer to Van der Westhuizen *et al.* (1999) and Van der Westhuizen (2003) for more details.
  - Strategic planning follows and includes consideration of:
    - Selection of grazing plan (see section 3.3 - Basic Principles of a Grazing Plan).
    - Development of an animal production system.
    - Setting up an animal health programme.
    - Conservation measures to regenerate eroded areas with withdrawal of animals or additional measures (stone packs, brush packing, etc.).
    - Conservation of poorly vegetated areas like soil loosening with ripper or creation of basins with basin plough and over-seeding with adapted or drought tolerant species.
    - Veld restoration measures on old cultivated fields (see section 3.4 - Restoration of Old Arable Land). The latter are defined as areas which were ploughed and used for crop production less than 10 years ago. If used for crop production longer than 10 years ago, a ploughing certificate is needed under the regulations of the Conservation and Rehabilitation Act of 1983.
    - Cultivated/planted pastures on cultivated fields earmarked for animal production (see section 3.5 - Cultivated Pastures).
    - Management skills of the land user(s) as well as the communal rules and regulations.
- Implementation of strategic plans.
- Veld surveys should be repeated every 2 - 3 years, and changes in grazing capacity should be used to update/change management strategies.

3.3 BASIC PRINCIPLES OF A GRAZING PLAN

- It is critically important to implement the correct stocking rate to ensure sustainability of the natural resources.
- The application of licks must be considered very carefully, because it can influence the veld condition negatively in the long term.
- Livestock must be adapted to the natural resources on the farm.
- Ensure that the grazing system has a long rest period for the grasses to regain their vigour.
- Ensure that the camps are grouped representing all the different veld types on the farm and can carry the same number of LSUs.
- Grazing systems are veld type specific and therefore professional advice is recommended.

Examples:
In each of the systems below, the camps are grouped into three groups (A, B, C), representing all the different veld types on the farm and carrying the same number of LSUs. One of the camp groups is then grazed in rotation within the months specified. If the grazing material is consumed before the end of the period, the animal numbers must be reduced. For both sweet and mixed *Themeda* veld types in the Free State the following systems are recommended:

Cattle grazing system

Year	Jun, Jul, Aug, Sep, Oct, Nov, Dec	Jan	Feb, Mar, Apr, May
1	A	B	C
2	B	C	A
3	C	A	B

Sheep grazing system

Year	Aug, Sep, Oct, Nov, Dec	Jan, Feb, Mar	Apr, May, Jun, Jul
1	A	B	C
2	B	C	A
3	C	A	B

If the cattle numbers exceed those of the sheep in a communal area while using the same camp, the cattle grazing system must be followed.

In the Molopo area the MARA veld management system for sweetveld is recommended (see section 3.6.3. - Management of Rangeland in Limpopo with Specific Reference to Lambani).

3.4 RESTORATION OF OLD ARABLE LAND

The following recommendations are based on the results of a research trial done on the experimental farm of the Glen Agricultural Institute (Taljaard, 2008).

- Before any action takes place, the ecological status of the arable land needs to be evaluated with the help of experts (see section 3.2.1 - Procedure for Rangeland Assessment).
- Simultaneously with the evaluation of the ecological status of the arable land, a soil survey is necessary to identify soil indicators that can hamper the normal vegetation succession.

3.4.1 FACTORS TO BE CONSIDERED BEFORE ANY RESTORATION ACTIONS ARE IMPLEMENTED

- Seed aspects:
  - Only buy certified seed as the success of re-seeded restoration technology depends on the quality of the seed used in restoration, influencing the cost-effectiveness (Boateng, 2002; Van den Berg, 2002; Van der Merwe, 1997).
  - The availability of different grass species will play a role in choosing species for the re-seeding application.
  - If non-certified seed is bought, or if the seed of natural occurring species such as *Themeda triandra* is harvested in the nearby rangeland, seed viability and germination tests should be carried out to establish the quality of the seed in order to determine the seeding ratio.
  - Use seed that was harvested during the previous summer as fresh seed germinates poorly.
  - Uncertified seed may contain lots of stones, soil, and other plant material such as weed seed.
  - If a natural existing highly palatable perennial grass species such as *Themeda triandra* is to be used in a re-seeding application, the seed should be harvested in the rangeland near the site where the old cultivated land is to be restored, to ensure that the correct ecotype of the same species is used. The specific ecotype (ecotypes are the product of genetic responses of a population of the same species to a specific habitat (Barbour *et al*., 1987)) is adapted to the specific habitat it occurs in, and it may not necessarily survive in any other habitat.
  - Ensure that the cost involved to test non-certified seed does not exceed the price of certified seed.
- The history of the arable land will play an important role in deciding which restoration technology to apply. If the specific land was ploughed recently then it could be planted with cultivated pastures, on condition that the land is still fairly clean of weeds. If it was lying fallow for a long period (5 - 10 years) then a rip and re-seeding restoration technology must be applied depending on the veld condition. If it has been ploughed more than 10 years ago, follow the procedure as described in section 3.2.1 - Procedure for Rangeland Assessment.
- The identification of the existing species composition is very important and determines the type of restoration technology to be applied. If the grass community consists mainly of pioneer grasses, then a rip and re-seeding (in narrow rows) restoration technology must be applied. Where the succession of the grass community has already progressed to a point where climax species are present, then a rip action in wide rows will be recommended.
- If the plant community of an old cultivated land is characterized by a high species abundance of annual low-valued grass species and weeds, then the application of herbicide

is advised to eliminate the competition factor of the existing vegetation against the newly established seedlings of the re-seeded species.

- Input costs can be reduced by using only a single species. Choose the species suitable for the specific environment, e.g. *Digitaria eriantha* for the central (including Thaba Nchu) and *Eragrostis curvula* for the eastern Free State.
- If the species composition is to be increased and the old cultivated land managed as a natural rangeland, then a more expensive option should be considered, such as rip and re-seeding with a seed mixture (the three recommended species for the Free State region are *Digitaria eriantha, Themeda triandra* and *Eragrostis curvula*).
- Development of a partial budget is necessary to consider the most economical restoration technology to be applied. The ratio between the input costs and the possible increase in income should be sufficient to absorb the input costs of restoration.

3.4.2 PRINCIPLES TO CONSIDER WITH SOIL PREPARATION

- Soil sampling and analysis of nutrients, before and during the restoration of old cultivated lands, will facilitate the process.
- A rip action will prepare a good seedbed, improve the water infiltration and uplift compacted soil layers. It also stimulates the germination and establishment of dormant seed in the soil seed bank.
- The rip furrows must be made perpendicular to the slope of the old cultivated land, in order to maximize water infiltration and minimize runoff water.
- The row width will depend on the existing plant composition. A 0.75 m row spacing is recommended for re-seeding the grass species mixture and a 1.5 m row spacing for naturally occurring grass species such as *Themeda triandra*.
- The soil must be ripped, preferably not less than 30 cm deep.
- Any sufficient source of organic material, such as composted manure, closely available, can be beneficial for the establishment of the re-seeded species.

3.4.3 RE-SEEDING

Time

Rip and re-seeding is done in one action. Factors to consider with regard to timing of the action, are:

- Start the action about 2 - 3 weeks after a rain event of at least 20 mm.
- The recommended time frame is from mid-January to mid-March.
- Planting must be stopped approximately 8 weeks before the first heavy frost is expected.

Sowing density

In the rip furrows:	*Digitaria eriantha* & *Eragrostis curvula*	5 kg seed ha^{-1}
	Themeda triandra	2 kg seed ha^{-1}

Seed of *Themeda triandra* is not commercially available. Specialist advice on harvesting seed vs putting out *Themeda triandra* bales, as well as the density, is recommended.

3.4.4 RESTORATION TECHNOLOGY

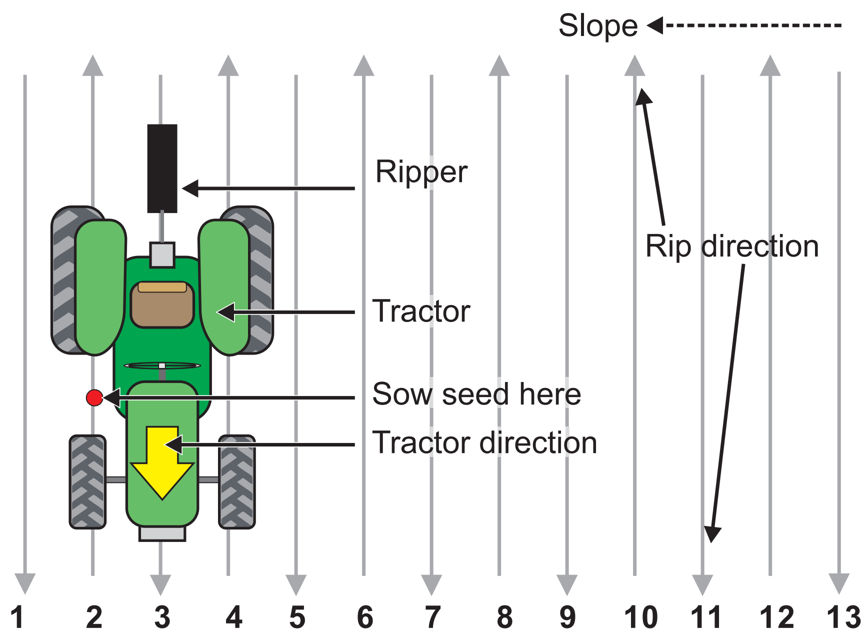
Recommendation:

The restoration technologies recommended for the Thaba Nchu area (Free State) are:

- Rip and re-seeding with a seed mixture and/or
- Rip and re-seeding with a single grass species.

Procedure:

- A one tine ripper is used to rip the soil.
- The first rip furrow is made without re-seeding.
- When returning with the second rip furrow, the driver must drive with the wheels on the first furrow and the seed must be sown between the front and the back wheels, in the rip furrow (see figure below).
- The seed can be sown with a 2 litre cool drink bottle, with a hole in the cap that allows the seed to flow out evenly.



3.4.5 GRAZING OF THE RESTORED CULTIVATED FIELD

- The restored field should be left for at least one year, through one growing season, but preferably for two years before any animals are allowed to graze it. The purpose is to let the grass tuffs establish well and develop a good root system.
- If the veld condition is to be determined for the calculation of the grazing capacity, the vegetation surveys should be carried out over the total area that is restored and not only on the rip-furrows, as this may lead to an overestimation of the veld condition.

3.5 CULTIVATED PASTURES

Most of the following information was sourced from Dickinson *et al*. (1990) as well as GVA (1993). There are three different grass species recommended for cultivated pastures in the Thaba Nchu area (Free State), some of which are also suited to the Eastern Cape and Limpopo Provinces.

3.5.1 WEEPING LOVE GRASS (*Eragrostis curvula*)

Establishment:

Planting time

- *Eragrostis curvula* can be successfully planted from October until the beginning of December, providing that the seedbeds are relatively free from weeds. Where weeds occur, the early planting of Teff together with *Eragrostis curvula* is recommended.
- In areas where the rainfall is below 600 – 650 mm, or where weeds are a problem, or where the grass has to be planted with legumes, it is best to plant in late summer or autumn, i.e. late January or early March.

Sowing density

- It varies to some extent with rainfall, spacing and soil type (2 - 6 kg seed ha^{-1}).

Row spacing

- Depending on the rainfall, a width of 0.3 - 0.75 m between rows is recommended.

Planting

- Plant when the topsoil is moist.
- If the aim is to provide grazing, then planting in rows is recommended.
- If the aim is hay production, then broadcasting is preferred. A roller must be applied before and after planting.

Requirements and use of plants:

- *Eragrostis* grows in many soil types, but prefers sandy soils.
- Under dryland conditions, a minimum of 500 mm water is required. Best results are obtained in areas where the rainfall is > 650 mm per annum.
- *Eragrostis curvula* is mainly recommended for hay production.
- The quality of the grazing or hay depends on soil fertility. Low fertility soils produce a product of low quality.

- *Eragrostis* is, however, the best grass to plant in low-potential acidic and humus-exhausted soils, as it is one of the few grazing types that does not need liming to be productive and that will, with proper management, restore the soil fertility.

Production potential:

The production potential is directly dependent on rainfall and the nature of the soil, especially with regard to clay content and soil depth. It is important to note that 70% of the total dry material yield is produced during November to January. The following table shows the expected dry matter production (t ha^{-1}) of *Eragrostis curvula* at various levels of nitrogen and rainfall.

Nitrogen application rate (kg N ha^{-1})	Annual rainfall (mm $year^{-1}$) 500
75	2
125	3

Carrying capacity:

500 - 600 mm rainfall: 1.022 ha LSU^{-1} $year^{-1}$
(In calculating the carrying capacity, allowance is made for 25% wastage.)

Fertilization:

Phosphorus (P)

- Phosphorus plays an important role in making the grazing productive and palatable.
- This is especially the case where nitrogen interacts with phosphorus. A guideline is to use 1 kg P per 10 kg N applied.
- If the P-content on low potential soil is 15 mg P kg^{-1} (Bray 1), and 20 mg P kg^{-1} on high potential soil, then P-fertilization is not recommended.

Nitrogen (N)

- Nitrogen is the key to obtaining a high yield of top quality fodder with *Eragrostis*. A 5% increase in crude protein content of hay can be expected after application of 100 kg N ha^{-1}.
- Top-dressing of N on *Eragrostis* must be considered financially.
- Two basic aspects of top-dressing need consideration: the quantity and the time of application. Depending on the rainfall, application of N before the end of December is recommended. This will produce the best dry matter yields. A later top-dressing will result in higher quality forage via increased protein content.

Potassium (K)

- Supplementation of potassium is very important, especially for hay production (10 - 30 kg K t^{-1} of DM).
- A hay yield of 10 t ha^{-1} equals the removal of 150 kg K ha^{-1}. Provision must be made for the replacement of this loss of K.

Utilization/management:

Utilization as hay

- Do not cut more than can be cut, harrowed and baled in one day with available implements.
- The best method of making hay is to cut the grass early in the morning (at sunrise).

- After 4 - 6 hours it can be harrowed into wind rows and proceed with baling.
- In order to retain high protein content it should be cut before flowering.
- To obtain a higher yield it could be harvested later, but not later than the early flowering stage.
- It is important to consider the nutritional needs of the various kinds of livestock when a decision is made on the time of harvesting. The protein content of *Eragrostis* cut at an early stage is 40% higher compared to cutting during stem elongation and 50% higher compared to cutting after flowering.

General:

- *Eragrostis* is not generally cultivated under irrigation.
- It must also not be subjected to heavy grazing in the year of planting.

3.5.2 TEFF (Eragrostis teff)

Establishment:

Planting time
Cultivars differ in length of the growing period, and can be planted from 15 October until 15 December. Consult an expert.

Sowing density
- Sandy soils: 7 - 10 kg seed ha^{-1}
- Clay soils: 12 - 15 kg seed ha^{-1}

Planting
- Soil preparation starts after the first rain in spring by establishing a level and firm seedbed.
- Use a roller on the seedbed before and after sowing.
- The seed can be broadcast using a teff seeder or a cyclone hand seeder.

Requirements and use of plants:

- Teff is regarded as an easy and excellent grass hay crop and very popular for horses.
- It is often used as a cover crop to help prevent flooding and erosion.
- Teff is widely adaptable and can grow in different soils (from sandy to turf soil), but cannot tolerate waterlogging.
- Normal cultivation is on dryland in areas with rainfall as low as 400 mm per annum.

Production potential:

- Teff can yield up to three cuttings if planted in time with good distribution of rainfall.
- The total dry matter production is determined by the rainfall and the soil fertility. It can vary between 2 - 8 t DM ha^{-1}.

Rainfall:	**Targeted yield**
500 – 600 mm	4 t ha^{-1}
600 – 675 mm	5 t ha^{-1}

Carrying capacity:

- Teff is not used for grazing.

Fertilization:

- Ensure the P content of the soil is at least 15 mg kg^{-1} (Bray 1).
- Ensure the K content of the soil is at least 100 mg kg^{-1}.
- Where two to three cuttings are required, 50 kg N ha^{-1} can be applied twice. The first dressing can be done shortly after the first sprouts, and the second dressing applied after the first cutting.

Utilization/management:

- Teff can be cut every 65 - 75 days.
- Cutting must be done at the start of reproductive development before seed formation.

3.5.3 SMUTS FINGER GRASS (*Digitaria eriantha*)

Establishment:

Planting time

- Seed can be sown at any time during the summer, with November and January to March as the best months to plant.
- Planting in December is not recommended due to midsummer drought conditions typical of January.

- Hot and dry conditions during autumn can also result in poor growth with January and February planting.
- To reduce the risk of total failure, sowing times can be spread from November to March.
- Planting later than eight weeks before the first frost is expected is not recommended.
- On new fields where no weed problems are encountered, planting can also be done during September/October.

Sowing density

- 1 m rows: 2 kg seed ha^{-1}
- Broadcasting: 3 - 6 kg seed ha^{-1}

(These quantities must be increased on heavy clay soils.)

Planting

- Favourable soil moisture conditions are required during planting.
- Rolling after sowing is recommended.
- Planting in rows:
  - The best method to plant *Digitaria eriantha* in rows is to mix the seed with fertilizer (superphosphate) and plant it with a maize planter.
  - Another method for planting in rows is to mount 20 ℓ containers between the front and rear wheels of a tractor.
- Broadcasting:
  - Mix the *Digitaria eriantha* seed with lime, fertilizer or sand.
  - Use a rear mounted disc or pendulum spreader for broadcasting the mixture.
  - Broadcasting is recommended in high rainfall areas where weeds and grasses such as *Eragrostis plana* and *Eragrostis curvula* are creating problems. With *Eragrostis* spp. encroachment, an undesirable mixture of sweet and sour grass develops. The following is important:
    - Never plant *Digitaria eriantha* grass in soil in which *Eragrostis* was cultivated previously. It contains too much *Eragrostis* seed. Rather plant such a field with row crops for a year or two before planting *Digitaria eriantha* grass.
    - *Eragrostis* tends to encroach from adjacent fields. It is therefore advisable to sow a 20 - 40 m wide strip on the side of the *Digitaria eriantha* grassland at double the normal sowing density.

General:

- *Eragrostis* is not generally cultivated under irrigation.
- It must also not be subjected to heavy grazing in the year of planting.

Requirements and use of plants:

- *Digitaria eriantha* grass requires an annual average rainfall of at least 450 mm and produces best in conditions of annual rainfall > 500 mm.
- It grows in a variety of conditions and soils (sandy to clay) including shallow rocky soils. Very sandy soils should be avoided.
- It has a life-span of 8 years and longer under good management.
- The grass does not survive waterlogging for prolonged periods.

Production potential:

- The production and yield potential is directly dependent on the soil potential (especially clay content and soil depth).
- High clay content and shallow soil are associated with low dry matter production.
- The following table shows the expected DM production (t ha^{-1}) of *Digitaria eriantha* at various levels of nitrogen and rainfall.

Rainfall (mm)	N level (kg N ha^{-1} yr^{-1})		
	30	60	90
400	1.1	1.4	1.7
500	1.6	1.9	2.3
600	2.0	2.5	2.9

Carrying capacity:

- 450 - 500 mm rainfall: 2 t DM ha^{-1} = 2.5 ha LSU^{-1} $year^{-1}$
- 500 - 600 mm rainfall: 3 t DM ha^{-1} = 1.62 ha LSU^{-1} $year^{-1}$
- > 600 mm rainfall: 4 t DM ha^{-1} = 1.22 ha LSU^{-1} $year^{-1}$

  (Wastage of 25% is taken into account.)

Fertilization:

Four strategies/approaches can be followed:

1. **Minimum-cost grazing:** No fertilizer is applied and the grass is managed as rangeland.
2. **Maintenance fertilization:** In areas of > 500 mm rainfall per annum, 10 kg N and 1 kg P per ton of expected DM for a season are fertilized every third year. It is recommended that the area be divided into three and that one third is fertilized each year. Maintenance fertilization is recommended for medium to low potential soils.
3. **Production fertilization:** Must only be considered for rainfall areas > 500 mm per annum and according to the expected yield. Production fertilization is only for medium to high potential soils.
4. **Fertilization for foggage (standing hay):** If the DM is saved for foggage it is important to fertilize it directly after withdrawal from grazing towards the end of January. In the drier semi-arid areas 70 kg N ha^{-1} is recommended. The quantity of grass that can be stored for the winter is the result of the interaction between fertilization level, heat and rainfall. Approximately 60% of available foggage can be utilized by animals.

Utilization/management:

- It is recommended that the camp size should be 10 - 20 ha.
- Grazing should be allowed for a maximum of two weeks during the active growing period and four weeks in the dormant period.
- Grazing pressure of three times the annual grazing capacity is recommended.
- Although hay can be cut, it should be noted that the material does not dry easily.

3.6 MANAGEMENT OF VELD (RANGELAND) IN COMMUNAL AREAS

Management of communal rangeland areas is a real challenge because of the dynamics, diversity of stakeholders and socio-economic conditions involved in this farming system (Everson & Hatch, 1999). A multidisciplinary task team is of the utmost importance to set up a sustainable management strategy.

Everson & Hatch (1999) defined communal rangelands as "those areas where agriculture is largely subsistence-based and where rangelands are generally communally-owned and managed, as opposed to private or individual ownership".

3.6.1 PROCEDURE FOR DEVELOPMENT OF BEST MANAGEMENT PRACTICES

Due to the numerous factors involved, a proper management plan for communal areas can only be developed, implemented and managed by a local or area team/body where all relevant stakeholders, socio-economists and rangeland consultants are represented. The following procedure is recommended:

- Follow the Participatory Rural Appraisal (PRA) approach to identify/define the historical and existing management strategy for the area.
- Define the communal rangeland. Define the difference for individual communities and the municipal area.
- Identify the historical rangeland management strategies and how they changed over time due to political, social and economic development in the area as well as the South African context.
- Identify the land tenure system and how it changed from the historic until the existing model.
- Identify the degradation of natural resources due to the above identified factors.
- Identify the community/tribal authority/villagers/farmers' definition of degradation of the natural resources.
- Identify the rules and regulations used by community or tribal authorities to control stocking numbers and how they changed over time.
- Identify the definition of land users on soil and rangeland, i.e. do they see it as a productive resource or as a cultural asset?
- Identify how many farmers/villagers are sustained from animal production on the rangeland and/or croplands and how many are actually financially sustained by income from grants or income earned outside the communal area.
- Identify the reason for keeping animals, e.g. milk, draught power, expression of wealth.
- Identify the farmers/villagers' perception of factors limiting animal production.
- Launch a soil and rangeland survey as described in section 3.2.1 - Procedure for Rangeland Assessment.
- Identify the change in management system due to rainfall.
- Follow the PRA approach to develop a management strategy for the area. For more details on the procedure consult Chambers (1993) and Flintan & Cullis (2010).

3.6.2 MANAGEMENT OF RANGELAND IN THE EASTERN CAPE WITH SPECIFIC REFERENCE TO KRWAKRWA

A very versatile system that can be used in most of the sour and mixed veld areas in the Eastern Cape is the following:

3 Block grazing system			
Year	Aug, Sep, Oct, Nov, Dec	Jan, Feb, Mar	Apr, May, Jun, Jul
1	A	B	C
2	B	C	A
3	C	A	B

3.6.3 MANAGEMENT OF RANGELAND IN LIMPOPO WITH SPECIFIC REFERENCE TO LAMBANI

A grazing system for sweet and mixed veld called the “MARA veld management system” is recommended.

Principles of the system:

- The growing season is practically only 4 months long (November - February) and should provide for 12 months of grazing.
- The production of veld varies from year to year and stocking rate should be adapted accordingly.
- At Towoomba Research Station it was proven that grazing of veld during one growing season, followed by two growing seasons of rest, will lead to veld improvement.
- Moderate grazing during the dormant season will have minimum negative effect on the veld condition.

How the system should be managed:

- A full growing season’s rest is essential on part of the farm (at least a third) to provide grazing for the dormant season. Therefore the farm should be divided into three basic units of the same potential or veld preference communities.
- It is optional to divide each unit into more camps (secondary fences).
- Animal numbers should be adapted regularly during the year not to overgraze the veld. A flexible stock flow programme is essential.

Unit	Year 1			Year 2			Year 3		
	Grow	Dormant		Grow	Dormant		Grow	Dormant	
	Nov to Feb	Mar to Jun	Jul to Oct	Nov to Feb	Mar to Jun	Jul to Oct	Nov to Feb	Mar to Jun	Jul to Oct
1	Graze			Rest		Graze	Rest	Graze	
2	Rest	Graze		Graze			Rest		Graze
3	Rest		Graze	Rest	Graze		Graze		

3.6.4 MANAGEMENT OF RANGELAND IN THE CENTRAL FREE STATE WITH SPECIFIC REFERENCE TO THE THABA NCHU AREA

Because of the difference between cattle and sheep in terms of grazing and the impact on rangeland, two systems are suggested. A three block rotational system that aims at a controlled- or non-selective grazing regime, with a full season's rest every 3 years, is recommended. For example: Camp A is grazed from June – December and then rested until end of January in the second year.

3 Block *Themeda* Cattle grazing system			
Year	**Jun, Jul, Aug, Sep, Oct, Nov, Dec**	**Jan**	**Feb, Mar, Apr, May**
1	**A**	**B**	**C**
2	**B**	**C**	**A**
3	**C**	**A**	**B**

3 Block *Themeda* Sheep grazing system			
Year	**Aug, Sep, Oct, Nov, Dec**	**Jan, Feb, Mar**	**Apr, May, Jun, Jul**
1	**A**	**B**	**C**
2	**B**	**C**	**A**
3	**C**	**A**	**B**

If the cattle numbers exceed those of the sheep in a communal area while using the same camp, the cattle grazing system must be followed.

The overall aim of the above-mentioned systems is to apply a long seasonal rest immediately after non-selective grazing followed by a controlled selective grazing, followed by a light controlled selective grazing, after which the system repeats itself.

Due to the fact that it is more difficult to reach the stage of non-selective grazing with sheep, the grazing period for this stage is 2 months shorter than for cattle to minimize the negative effect on palatable species. The seasonal rest is also longer for sheep and includes one spring and two summer periods.

Within the above-mentioned grazing systems the following were considered: growth of *Themeda triandra*, palatability and utilization by both stock types, as well as the physiology of animals which require good quality veld during the breeding season.

4 CASE STUDIES

4.1 EASTERN CAPE: KRWAKRWA

A. Croplands

Outcome of environmental and soil analyses:

The mean long-term annual precipitation for Krwakrwa is 604 mm. The highest average rainfall occurs in March (79 mm) and the lowest (18 mm) in June. February is the warmest month and June the coldest month with average temperatures of 21.4°C and 14.1°C respectively. The aridity index (AI) varies between 0.69 in March to 0.18 in August, with an annual average of 0.42.

The area comprising the village of Krwakrwa ranges from steep slopes to very flat areas. The main croplands are situated on the eastern side of the village with old croplands situated towards the southern and western borders. The soils on the cropland sites are primarily sandy loam (Hutton soils followed by the Avalon and Westleigh soil forms) and to a lesser extent clay and duplex soils (Shortland, Bonheim, Valsrivier and Swartland).

Prior to 1994 the government had a programme to prepare their fields, providing seeds and fertilizers at highly subsidized costs. If the farmer or villager could not pay immediately, they were given a chance to pay after harvesting the crops, or sell the crops to the government. Initially animal traction was used because it was much cheaper. Tractors were available later for those who wanted to plough and plant individually at a minimum affordable levy. Consequently almost all farmers utilized their croplands successfully.

Since 1994 all the old homeland systems and policies were disbanded and integrated into South Africa. All support structures collapsed and the villagers burnt all their tractors and implements. With limited funds, no infrastructure and no assistance from government, very few farming activities took place after 1994.

The size of the croplands ranges from 0.5 - 3.5 ha and they were acquired through the Chief of the village. Chief Mabandhla also made his tractor and implements available to the community. In 2005, a village association was formed and members had to pay a R100 joining fee. This money was used to repair the tractor and pay the driver. The tractor was available for anyone in the village to utilize in their croplands. Non-members had to pay about R150 per hour in advance to hire a tractor, disk, tiller and planter. It took up to two weeks to get the necessary implements after making the payments due to the number of users. Some villagers stopped hiring the tractor due to financial problems. In 2010, it was found that the village tractor was broken for more than a year with no funds available to fix it.

Soil cultivation has decreased which in turn increased the grazing area, but did not directly increase forage production. From the total area of old cultivated croplands, 13.5% was dominated by bush encroachment, 25% was left uncultivated for grasses to establish and 6.7% was cultivated 2 – 5 years ago. Many lands were abandoned due to poor production and erosion problems. Dwindling cultivation practices and bush encroachment resulted in reduced forage production and consequently livestock production.

The croplands are well fenced on the outside but not individual plots inside. Even though most households own cropland in Krwakrwa, less than 1% of it is utilized for crop production. Inputs are bought from a local co-operative in Alice. Very little of the crops is sold due to lack of knowledge, low yield, own consumption, lack of implements and a shortage of labour to utilize the croplands. From 2007 until 2013, most of the croplands that were ploughed belonged to the Chief and were mainly used for maize production. None of the croplands are leased, due to the fact that farmers and or villagers cannot afford to rent any croplands and implements. Many of the farmers and villagers have witnessed the IRWH techniques being used to successfully produce a variety of vegetable crops in some of the neighbouring villages (Sompondo, Khayalethu, Gilton, Guquka and Mpundu).

Recommendations:

- Farmers and villagers have to get advice and/or training on tillage, use of fertilizers and/or kraal manure, basic crop production principles and management aspects.
- Fencing of croplands to prevent crops being destroyed by stray animals.
- The adoption of IRWH techniques can be used to facilitate a continual food supply when combined with other forms of rainwater harvesting, such as roof water harvesting. Regular inspection visits by extension officers can help identify problems and mistakes to help villagers with quick solutions.

B. Rangelands

Outcome of rangeland survey:

The natural rangeland in Krwakrwa is Dohne Sourveld and contains only two camps while the rest of the grazing is in the form of old lands. The latter is Eastern Province Thornveld and therefore the veld is classified as mixed veld.

The species composition showed the rangeland is dominated by good grasses, like *Themeda triandra*, with an average of 38.5%. Pioneer and sub-climax species constitute 39% of the species composition. This species composition is well balanced, indicating rangeland in good condition with an average veld condition score of 78% despite constant heavy defoliation and improper veld management practices. The average carrying capacity for the rangeland is 3.5 ha LSU^{-1}.

The disturbed rangelands are in a transition phase and therefore in poor condition. As result it is classed as Eastern Province Thornveld. This vegetation type is mainly dominated by the Increaser grasses; i.e. Increaser I in the form of *Hyparenia anomesa* (35%) and Increaser II dominated by *Cynodon dactylon* (19%) and *Eragrostis plana* (15%). The average veld condition score of the disturbed rangelands is 38%, therefore rated as poor. The grass species composition was dominated by low forage grasses and the carrying capacity is 8 ha LSU^{-1}.

Problems identified:

- The grass sward lacks a highly important rest for seeding of the grasses and the creation of a fodder bank, mainly due to lack of fencing and high stock numbers.
- Overgrazing is also seen as a problem due to the non-existent camp system. Animals are not controlled and allowed to graze at their own free will.
- These areas are infested by *Acacia karroo* which provides good forage for goats.
- The stocking rate is not considered important by these farmers. Stocking rates for the communal farming systems cannot be determined similarly to that for commercial farmers, because growth rate and calving or lambing percentages are not considered important by these farmers.
- The implementation of any veld management practice requires fencing but this should not be used as an excuse for bad veld management, as some farmers do.
- Bush encroachment is a major problem in the village.
- Many of the disturbed rangelands are suffering from erosion in various stages.

Rangelands are situated between 300 - 600 m from the residential areas. The village utilizes the communal land for livestock grazing. Each household is responsible for its own herd of livestock (sheep, goats, cattle and horses) and most of the shepherds are citizens from Lesotho. The cows and calves are moved to the kraals at sunset and released for grazing close to the village at dawn. Disease control is carried out on farmers' request, when the State Veterinarian or the extension officer who deals with animals comes to the village for vaccination. Government does not charge any fee for the vaccination of livestock. The management of communal rangelands in the village is poorly controlled. In winter, animals are allowed to graze in someone else's croplands and rangelands, provided that both owners have reached an agreement.

Before 1994, Krwakrwa used to have a very successful rotational grazing system and everyone in the village used to adhere to its rules or institutional arrangements. Once the Traditional Council lost their power, no one took responsibility for the village fences and they were stolen. The rotational grazing system totally collapsed with no more limit on the number of animals an individual can own. Animals were allowed to graze anywhere and usually did not move far from the village. This has caused the areas close to the village to become overgrazed, with the rangelands further away still in a good condition. Many of the dams have silted up. Accidental rangeland fires outside the agreed burning times are also problematic.

Recommendations:

- Rangeland specialists within the Department of Agriculture need to do a rangeland assessment and calculate the maximum number of large and small livestock units that can be carried on the communal rangeland.
- Bare open patches can be covered by branches or re-seeded with a restoration technology. This will also contribute to controlling erosion in the rangelands. Further degradation can be prevented by filling up the dongas with stones and allowing grasses to establish in them.
- The condition of the rangelands can be improved by using a rotational grazing system through the reintroduction of camping systems and controlling of animal numbers.
- Fences and proper watering points in the rangelands should be developed.
- Bush encroachment needs to be addressed by proper assessment and recommendation.
- Cultivated pastures on recently ploughed croplands can also be considered if farmers have access to tractors, implements, seed and fertilizer.

- On the disturbed rangelands the alternatives are re-seeding and/or cultivated pastures. In areas with less than 650 mm rainfall per annum, the grass species recommended for use in the restoration technology are: *Digitaria eriantha*, *Themeda triandra* and *Eragrostis curvula*. In areas with annual rainfall above 700 mm, it is recommended to introduce a low-cost perennial legume on the disturbed rangelands or croplands with a minimum or no-till approach (Jordaan, 2013). For the cooler high altitude areas, the following mixtures are recommended: *Biserrula pelecinus* (Biserrula) and *Lespedeza cunneata* (Lespedeza) or *Trifolium hirtum* (Rose clover) and *Lotus corniculatus* (Birdsfoot Trefoil) or *Trifolium vesicolosum* (Arrowleaf clover) and *Trifolium repens* (White clover). In the warmer areas, Jordaan (2013) recommended the following mixtures to be planted in autumn: *Biserrula pelecinus* (Biserrula) and *Medicago sativa* (Lucerne) or *Medicago truncatula* (Barrel Medics) and *Lespedeza cunneata* (Lespedeza) or *Ornithopus compressus* (Serradella) and *Trifolium repens* (White clover). Annual single species that are recommended for both the cooler and warmer areas are: *Biserrula pelecinus* (Biserrula) and *Trifolium vesicolosum* (Arrowleaf clover).

Aspects to be address with the PRA:

- Well defined rules for preventing animals from entering the croplands and homestead gardens during the production period.
- Revival of village police forums. All the villagers can be actively involved in crime prevention and work towards food production for themselves and their families.
- Introduction of a rangeland monitoring system.
- Rules and regulations on the control of livestock numbers need to be revitalized or newly contextualized.
- All soil erosion.
- Animal health programmes and marketing practices need to be developed to ensure sustainable animal production.
- Fencing or alternatives for all croplands and rangelands.
- A culture of market orientation should be developed amongst the farmers and villagers.
- If necessary new markets need to be developed.
- Effective and positive support from the government, stakeholders, private sector and other organizations is needed to address the lack of management skills, financial advice and services, technological exposition, proper drinking water for both people and animals, roads, medical assistance, etc.

4.2 LIMPOPO: LAMBANI

A. Croplands

Outcome of environmental and soil analyses:

The climate of Lambani is characterized mainly by a frost-free winter with an average annual rainfall of 587 mm. The Hutton soil form occupies the largest part of the area, followed by Clovelly and Avalon. Other soils identified were: Pinedene, Valsrivier, Swartland, Shortlands and Mispah.

Most of the farmers in the wards comprising the village of Lambani are involved in homestead gardening. Large portions of Lambani are situated on hilly slopes with limited opportunities for crop production within both homestead gardens and croplands. Many farmers and villagers are forced to utilize whatever piece of land is available for agricultural production, irrespective of whether the soils are suitable for crop production or not. Croplands utilized are mostly located on very steep mountain slopes. In such cases trees are chopped down and maize is planted between the rocks on extremely shallow soils. On these steep slopes the runoff is very high.

The size of the homestead gardens ranges from 0.2 - 0.5 ha. Some farmers in Lambani produce most of their products (mangoes, spinach, carrots, cabbage, tomatoes, onions, green peppers, butternut, maize and pumpkins) in their homestead gardens and not in the croplands. Most of these crops are mainly produced for household consumption. Mangoes are normally sold within the village or to passing tourists.

Villagers in Lambani do not have tanks to collect rainwater from the roof tops. Most of the houses in Lambani have thatched roofs without gutters. Most of the taps and hand water pumps along the main gravel road are out or order. These taps are far from most of the homesteads and water carried by women and children is used for drinking, cooking, bathing purposes or watering of their crops.

Farmers acquire croplands through the headman, who consults the Chief for a final decision. Croplands are rarely larger than 10 ha and financial constraints are the main reason why it is not utilized for crop production. In 1980 the SA government started a project for the community whereby 50 ha were made available for crop production under irrigation. Unfortunately most equipment was either washed away by the floods in 1988 or stolen afterwards and sold as scrap metal.

Only 20% of the farmers make use of a limited amount of fertilizers in their croplands while others use organic fertilizer like manure. Inputs are bought in bulk through committees from the Northern Transvaal Co-operative which is situated in Thohoyandou. Over 60% of the farmers tried to cultivate their croplands with spades and just over 12% use donkey and/or cattle draught implements for cultivation. Tractors are privately owned and do not belong to either the village or the Traditional Council. Some farmers hire a tractor from fellow farmers at a cost of R190 to over R250 per hour for ploughing and planting purposes. Despite lack of implements, finance and the continual hot weather, the backyards never remain empty or unplanted.

In the eastern side of Lambani, near the river, a group of farmers are producing a variety of organically grown vegetables under drip irrigation. Most of the vegetables are sold to other villagers. A number of farmers are also producing maize in their croplands under dryland conditions. Their yields are usually low due to low soil fertility and rainfall. Losses also occur due to damages by baboons and monkeys coming from the nearby mountains.

Recommendations:

- Proper land use planning will assist the headman and farmers to utilize the soils correctly and reduce the risk of crop failure. There are high potential soils like Hutton, Oakleaf, Avalon, Pinedene, Clovelly, Westleigh, Valsrivier and Swartland for crop production.
- It is recommended that farmers use the RWH&C practices on the open areas around the sub-villages (wards) for crop production. This will improve crop yields and reduce the risk of crop failure. Application of mulches is recommended.
- Rehabilitation of the irrigation infrastructure can be addressed within a PRA approach.
- Training on the successful use of suitable RHW&C techniques in crop production.

B. Rangelands

Outcome of rangeland survey:

The rangeland in Lambani is Soutpansberg Mountain Bushveld. This veld type typically consists of a dense tree layer with a canopy cover of 60 - 70%, and a poorly developed grass layer. At the top of the mountains there is a plateau with relatively open savannah sandveld on both deep and shallow quartzite sands. It is this plateau that is mainly used as communal grazing area by the people of Lambani, as well as neighbouring communities. During the survey in March 2008 it was found that most of the perennial grasses one would expect according to Acocks (1953), species like *Themeda triandra*, *Loudetia simplex*, *Eragrostis racemosa*, T*rachypogon spicatus*, *Tristachya leucothrix, Andropogon schirensis, Sporobolus africanus, Panicum natalense* and *Brachiaria serrata*, were replaced by pioneer grasses, due to overgrazing of the area over a long period. The area of Lambani has a long-term grazing capacity of 7 ha LSU^{-1}.

Rangelands are located, not more than 1 km from the homesteads. Livestock is allowed to graze freely in and around the village or designated areas, and impact negatively on both crop production and stability within the village. The main rangelands are on top of the mountain and not easily accessible by livestock and its owners. A trip to the rangelands on the mountains takes 1 - 2.5 hours and is dangerous. There are also no watering points on the mountains and animals have to walk long distances to get to the river. The rangelands on the mountains are characterized by bare open patches, dense shrubs and non-palatable grass species. Most of the cattle used to graze on the mountains during summer. During the winter period, grazing takes place next to the roads and in the croplands close to the homesteads. The villagers also prefer not to use the rangeland on the mountains due to wild animals from the Kruger National Park. Camping systems were introduced, but eventually discontinued due to theft and livestock losses by predators. That has led to farmers keeping their animals in homemade kraals. During the day livestock graze within the village and at sunset they are returned to the homesteads.

Problems identified:

- Overgrazing due to the non-existent camp system and no summer rest.
- Dense tree layer and bush encroachment.
- Poorly developed grass layer with bare patches and weeds.
- No camps or fences.

- Soil erosion, especially old lands and bare patches.
- Encroachment of the dwarf shrub *Helichrysum kraussii* on the plateau.
- The shrubs within the rangelands are of poor quality, especially during the dry season. Many forage shrubs that are valuable for feeding livestock have been almost eliminated in many areas by overgrazing of cattle, donkeys and goats and non-selective bush control practices.
- There is no rotational grazing system in Lambani and no limitations on livestock numbers in the rangelands.
- Animals mainly have access to water from the nearby Levubu River. This is not safe because of crocodiles and hippopotami.
- Lack of fencing for croplands, rangelands and the village itself causes animals to destroy crops, creating conflicts and accidents in the village. The Traditional Council assists livestock and crop owners in reaching a consensus in terms of compensation.

Recommendations:

- Chopping down unwanted trees and shrubs and re-seeding can contribute significantly to the improvement of the grazing capacity on the mountains.
- Establishment of stock ponds on top of the mountains.
- Training of villagers in more efficient crop production.
- Bush encroachment needs to be addressed by proper assessment and recommendation by specialists of the Department of Agriculture.
- On the disturbed rangelands the alternatives are re-seeding and/or cultivated pastures. A grass/legume mixture of star grass (*Cynodon nlemfuensis*) and siratro (*Macroptillium atropurpureum*) is recommended.

Aspects to be addressed with the PRA:

- Well defined rules for preventing animals from entering the croplands and homestead gardens during the production period.
- Introduction of a rangeland monitoring system
- Predators on the mountains.
- All soil erosion.
- Animal health programmes and marketing practices need to be developed to ensure sustainable animal production.
- Rules and regulations to control livestock numbers.
- Fencing or alternatives for all croplands and rangelands.
- Effective and positive support from the government, stakeholders, private sector and other organizations is needed to address the lack of management skills, financial advice and services, technological exposition, proper drinking water for both people and animals, roads, medical assistance, etc.

Star grass *(Cynodon nlemfuensis)*

Siratro *(Macroptillium atropurpureum)*

4.3 FREE STATE: THABA NCHU

A. Croplands:

Outcome of environmental and soil analyses:

The annual rainfall varies from 600 mm for Gladstone to 564 mm for Merino and Feloane. It is mostly a summer crop production area with the main rainfall during the period of October to March. Frost occurs during winter. The evaporative demand is 1637 mm in Thaba Nchu, with an AI of 0.35 for Thaba Nchu.

The cropland sites in Thaba Nchu are dominated by shallow clay and duplex soils, e.g. Arcadia, Valsrivier, Bonheim and Swartland, with an effective rooting depth of less than 1000 mm. The dominant soils found in this part of the Free State are not recommended for commercial crop production due to the high clay content and AI. Therefore they are recommended for grazing or cultivated pastures.

Based on the policies of the previous government of Bophuthatswana, whenever a villager was given a homestead (plot) by the Traditional Council or government, he/she was also given a piece of land to be used as a cropland irrespective of whether they had applied for it or not. Therefore every household has a cropland. Croplands are situated between 0.5 - 1 km from the homesteads and range between 2.6 - 5.1 ha. The size of the cropland allocated to an individual was based on the number of family members and assets (e.g. livestock).

The Bophuthatswana government built a flood irrigation scheme in Sediba, Feloane and Woodbridge. Farmers used it effectively and produced a variety of crops, such as maize, watermelons, soybeans, lucerne and wheat. More than 75% of village members produced maize. Planting in the croplands was mainly done by making use of animal traction until the government of Bophuthatswana contributed some tractors. Maize was sold to the grain mill at Thaba Nchu. Apart from the assistance farmers received from the Traditional Council, the Bophuthatswana government also provided seed, fertilizer and herbicides. All croplands were properly fenced and it was difficult for animals to enter. Animals were only allowed into the croplands after harvesting.

Since the collapse of the Bophuthatswana government the croplands were no longer used due to lack of access to tractors, implements and seed. Consequently most of the croplands were cultivated 15 – 25 years ago. With no maintenance on the irrigation schemes, it also disintegrated. All fences were either removed or disintegrated to such a condition that animals cannot be kept out of croplands. It is very difficult to differentiate between croplands and rangelands. Croplands are covered by thick shrubs and unpalatable grasses.

Recommendations:

- The area is marginal for crop production due to low and erratic rainfall and high evaporation from the soil surface. It is therefore recommended that farmers increase the effective rainfall by employing appropriate RWH&C practices and reduce the risk of crop failure. The use of organic mulch will minimize water losses through evaporation. The IRWH technique proved to be suitable for maize production in Thaba Nchu.

B. Rangelands:

Outcome of rangeland survey:

Both Gladstone and Merino are situated in a transition veld type between *Themeda*-grassveld and *Themeda-Cymbopogon*-grassveld. In practice it means that in a wet cycle the vegetation tends to the latter type and in a dry cycle to the former type. Overgrazing occurs close to the villages due to the animals being housed in kraals at night. Lack of a grazing system, veld management knowledge, camps and water supply for animals are the reasons for the identified degradation, especially erosion on certain areas, of the rangeland. The current grazing capacity of Gladstone and Merino, far from the village (where no grazing takes place), is better than the long-term grazing capacity. Disturbed rangeland (old cultivated) areas are in a sub-climax ecological stage. The shrub *Felicia muricatus*, which dominates the area, is very palatable and high in protein, and therefore very important for sheep production. The grazing capacity on the disturbed rangelands is 7.4 ha LSU^{-1} compared to 6 ha LSU^{-1} for the rangelands. The latter is equal to the long-term grazing capacity.

Before 1994, all the villagers preferred to keep their livestock in the rangelands where they were safe and rangers often patrolled the area, including the borders. Each household was responsible for their own livestock. Very few households had shepherds. A shepherd was shared among those who needed one, provided that the latter helped with his wages. Livestock included goats, sheep, cattle, horses and donkeys. The herds used to be returned to the homesteads at sunset and released for grazing at dawn if the owner preferred to do so. Fences were well looked after by livestock owners together with the rangers. Law-breakers were punished by the relevant authorities including the Traditional Council and magistrates. Rangelands were well looked after by the government of Bophuthatswana. Dipping tanks were built by the government so that farmers and villagers could dip their livestock. Few windmills were also constructed. The number of livestock per household that were allowed in the rangelands was controlled.

Since 1994, windmills, camp systems and control systems gradually deteriorated. Villagers did not respect the Traditional Council anymore. Theft and destruction of fences led to poor rotational grazing, a lack of camping systems and ultimately overgrazing. There are no watering points in the rangeland. In cases like Merino, livestock depends entirely on the streams and a river that passes by the village. Livestock numbers have increased dramatically. Farmers from neighbouring villages, even as far as Botshabelo, graze their livestock within Merino's rangelands. There are daily conflicts between livestock and crop owners. Farmers are responsible for medicating and vaccinating their own livestock. Government only assists them if there is an outbreak of diseases such as rift valley fever.

Recommendations:

All possible stakeholders need to be involved to ensure development of a community or area based strategic plan with proper ownership per community for implementation. Aspects to be covered are:

- Both the Traditional Council and the Free State Department of Agriculture and Rural Development (FSDARD) can introduce a rangeland monitoring system to detect degradation in plant species composition induced by overgrazing or other poor management practices or veld improvement resulting from sound management principles.
- Overgrazing of the areas surrounding the villages.
- Rangeland specialists from the FSDARD need to assess veld condition on a regular basis to quickly identify any degradation in rangeland condition. Farmers can then be advised on steps to improve the situation in the rangelands and croplands.
- All soil erosion.
- Animal health programmes and marketing practices.
- Rules and regulations on the control of livestock numbers need to be revitalized or newly contextualized.
- Fencing or alternatives for all croplands and rangelands as well as a functional plan of maintenance and prevention of theft.
- It should be determined whether the resources can economically support crop or rangeland farming when linked to the commodity prices and availability of markets.
- A culture of market orientation should be developed in the farmers and villagers.
- If necessary new markets need to be developed.
- Effective and positive support from the government, stakeholders, private sector and other organizations is needed to address the lack of management skills, financial advice and services, technological exposition, proper drinking water for both people and animals, roads, medical assistance, etc.

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