EVALUATION OF THE MANAGEMENT AND IMPACT OF WATER QUANTITY AND QUALITY FOR AGRI-PARKS IN GAUTENG PROVINCE, SOUTH AFRICA

Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

South African Agri-parks

The South African Government is planning to implement Agri-parks across the country, aiming to revitalise agriculture, catalyse rural industrialisation and support emerging farmers (Department of Rural Development and Land Reform, 2016). An Agri-park is defined as '*a networked innovation system of agro-production, processing, logistics, marketing, training and extension services, located in a District Municipality. As a network it enables a market-driven combination and integration of various agricultural activities and rural transformation services*' (Department of Rural Development and Land Reform, 2016). The Agri-park model includes the following three units:

1. The Agri-hub (AH) that would essentially provide financial and technical support to all farmers within a 20 km radius;
2. Each Agri-hub would encompass several Farmer Production Support Units (FPSU) that will provide support on a local level; and
3. The Rural Urban Marketing Centre (RUMC) will assist farmers with marketing of produce and the relevant administration.

Agri-parks have the potential to provide capital, technical support and knowledge that will address many of the challenges facing agriculture today. Through the Agri-parks initiative, it could also be possible to uplift emerging farmers, which is an important goal towards achieving food security and limiting the rural-urban migration in South Africa. The way in which the Agri-park model integrates catchment- and local-scale management could enable more sustainable practices in agriculture and water management.

This research was conducted to assess the impact and management of water quantity and quality for South African Agri-parks. Two Agri-parks in the Gauteng Province were selected as research sites, namely the Rooiwal Agri-park in Pretoria and the Westonaria Agri-park in Johannesburg. However, none of the existing 'Agri-parks' in Gauteng resembled the model Agri-park, as they are only a few hectares in size and are being operated by only a few selected farmers who mostly farm with limited support structures. The current Agri-parks therefore still resemble traditional government-supported production units. In their current form, the Gauteng Agri-parks will not have the desired impacts of revitalising agriculture, uplifting emerging farmers and promoting sustainable agricultural development. For the purposes of this study, it was assumed that the existing Agri-parks will be developed and expanded in the future into the envisaged multi-dimensional Agri-parks. Through this research, a better understanding was acquired on how to assist Agri-park managers and farmers towards achieving these goals as set out in the model, particularly in terms of water use and management.

The sustainable use of water resources in agriculture requires management on a local (farm) and regional (catchment or aquifer) level. The challenge is to identify sustainable water use management practices at local level that are useful and acceptable to the farmers who will implement them, management tools that will improve decision-making of water use on a catchment scale, and also to have local and catchment level water management systems that are fully integrated. Through this research a framework was established for making Agri-parks more sustainable, and to provide essential capacity building for rural farmers. Therefore, the proposed aim was reached through a two-pronged approach that focused on the catchment and farm level, as follows.

1. On a catchment level the following aims were applicable:
   1.1. To assess the feasibility of the selected Agri-parks, if they resemble the proposed model, in terms of quantity and quality of water available in the catchment; and

1.2. To determine the optimum crop yields, crop selection and rotation in terms of water availability in the relevant catchment and acceptable environmental impacts for each study area.
1.3. To assess the available tools that can be used by an Agri-park to better manage water in a simplified way.
2. On a local / farm level, the following aims will be applicable:
2.1. To co-design sustainable agricultural practices through active cooperation between small-scale farmers, FPSUs and scientists using principles of sustainable intensification; and
2.2. To develop a programme for capacity building of rural farmers that will include guidelines on the most appropriate and user-friendly tools available that can be used for good water management.

Water feasibility of Rooiwal Agri-park

The Rooiwal Agri-park is located in the Apies River Catchment of the Crocodile (West) Marico Water Management Area (WMA) and currently abstracts groundwater for irrigation. All farmer groups at Rooiwal indicated that limited water supply is their main challenge. Data on long-term groundwater levels is not available, and it is recommended that a long-term monitoring programme is developed to better understand the impact of current abstraction and potential future increases. Our desktop study indicated that approximately 78.8 Mm^3 of water is annually available in the Apies River Catchment Area. However, it is unlikely that all the available water would be allocated to Agri-parks, for the following reasons:

- This 78.8 Mm^3 of water is the total volume available in the entire Apies River Catchment which is a very large area, and on-site monitoring could give more detailed information on the availability at a particular location;
- The average increase in the Apies River flows does indicate potential water availability, if the necessary infrastructure can be developed. However, with the current small scale of the existing Agri-park such investments may not be justified; and
- It is unlikely that all of the available water will be allocated to the Agri-park, because there are many competing water users within the catchment. The allocation of water is done by the Department of Water and Sanitation (DWS) and approval to abstract irrigation water must be obtained through the application for Water Use Licenses.

A wastewater treatment work (WWTW) adjacent to the Rooiwal Agri-park is currently operating above its capacity and is discharging poorly treated sewage effluent. Early in 2019, during the second year of the project raw sewage was leaking from a manhole into one of the farmers' fields. The groundwater quality is poor and not fit for human consumption due to high concentrations of nitrates (indicating sewage pollution) and fluorides. Farmers also have to manage moderately high levels of salinity when irrigating with the groundwater. Water quality in the Apies River is relatively better than the groundwater, with low salinity and a predicted equilibrium root zone salinity of 152 mS/m falling within the *Ideal* range according to the South African Water Quality Guidelines Decision Support System (SAWQG DSS). According to the DSS, use of the Apies River water for irrigation purposes would theoretically supply over 100% of the crop N, P and K requirements. Actual plant availability of these nutrients, and effects of these high concentrations of macro-nutrients on micro-nutrient availability would need careful monitoring. Routine soil and leaf analyses to guide fertility management is recommended.

The effluent discharged at the neighbouring WWTW can also be a potential source of water available to the Rooiwal Agri-park. The monthly discharge of effluent is approximately 1.3 Mm^3 and could potentially irrigate 1477 ha and 375 ha of leafy vegetables in summer and winter respectively, calculated in terms of the water footprint of Swiss chard. This volume could also potentially irrigate

512 and 220 ha of root vegetables in summer and winter respectively, calculated in terms of the water footprint of carrots. The discharged effluent could therefore supply agricultural land of up to 246 times larger than what is currently cultivated by the Rooiwal Agri-park. Currently, monthly irrigation water requirements for the 5 ha of cultivated land at the Rooiwal Agri-park is approximately 2 283 m^3 in summer and 4 473 m^3 in winter. Potential monthly production that can be achieved with the volume of discharged water from the WWTWs is 57 609 tonnes and 14 247 tonnes of leafy vegetables in summer and winter respectively, calculated for Swiss chard. The available volume of discharged effluent could potentially produce 36 806 tonnes and 15 057 tonnes of root vegetables monthly in summer and winter, respectively, calculated for carrots. Production potential of the volume of water from the WWTWs is notably higher in summer, compared to winter, because the area is a summer rainfall region, receiving no rainfall during winter, and the additional rainwater therefore enables higher production in summer. If effluent water can be developed into a safe resource for irrigation at Rooiwal, it will solve the problem of water scarcity on the farm, as well as the WWTW's problem of operating above its capacity. Future research should address potential risks associated with irrigation with sewage effluent, for example the fate of organic pollutants, disease causing micro-organisms, high nitrate levels, etc.

Water feasibility of Westonaria Agri-park

Westonaria is within the Zuurbekom compartment which is located within the Upper Vaal Water Management Area (WMA) and more specifically in the sub-area downstream of the Vaal Dam. Both the WMA and the sub-area are water-stressed. It was found that there is no surplus groundwater available in the Zuurbekom compartment for expanding farming activities. The Westonaria Agri-park does not have a water use license to abstract groundwater for irrigation, and therefore they currently use municipal water. This is not a sustainable practice and the situation should be rectified as soon as possible.

A slight increase in flows in the Wonderfonteinspruit, which is near the Westonaria Agri-park, may suggest that some surface water may be made available for expanding the agricultural activities. However, accessing surface resources at Westonaria may technically not be possible for several reasons:

- River flows are variable and the increases that are seen may only be temporary.
- The Agri-park must compete with many other water users within the catchment.
- Currently the infrastructure is not available to abstract the water from the Wonderfonteinspruit. Given the relatively small size of the Agri-park, it may not be economically feasibility to develop the necessary infrastructure.
- Poor water quality in the Wonderfonteinspruit due to mining activities, as observed from DWS water quality data, can also complicate the use of the water for irrigation.

Engaging with Agri-park farmers to select and develop tools at farm level

Agri-park farmers were engaged to better understand the tools and technologies that are most transferable to them. The research team worked on-site with the farmers at Rooiwal. During the duration of the project, the team installed soil moisture sensors in Pretoria Agri-parks (Rooiwal and Soshanguve), and determined the farmers' attitudes towards sustainable practices such as irrigation scheduling, mulching, composting and using chicken manure. In the final year of the project, the project team worked alongside the Rooiwal Agri-park farmers to initiate the process of co-developing a practice of irrigating with sewage effluent from the neighbouring WWTWs. The purpose of this process was to evaluate the farmers' attitude towards irrigation with effluent, their skills and farming styles in terms of mulching, weed removal and irrigation scheduling. The different technologies that were presented were accepted by the farmers with varying success.

Mulching was praised as very valuable by some, and not accepted by others. Some of the complaints on mulching was that it is too labour intensive and the local sources of mulch material always contained seeds that became weeds. However, considering the enormous weed pressure at Rooiwal, the labour and costs required to apply mulch is likely less than that required for getting rid of weeds and should be worthwhile considering the potential to increase yields. If care is taken not to let mulch material go to seed, and to find a manageable size farm, mulching would probably be well accepted by all farmers.

Similar to mulching, the use of chicken manure was accepted by some and criticized by others. Some farmers claimed that the plants wilt when they apply chicken manure. This could possibly be due to high nitrate content if too much manure is applied. The Vundisa Manure Application Tool (VMAT) was developed to assist farmers to use and apply chicken manure correctly. The tool aims to assist the Agri-park farmers, but they would require assistance from Agri-park managers and support systems to obtain the soil and manure analysis information required as VMAT inputs.

The Chameleon soil moisture sensors (CS) and Fullstop Wetting Front Detectors (WFD) installed at Rooiwal and Soshanguve Agri-parks north of Pretoria were used with limited success, but definite interest was shown by the farmers involved. In one case the equipment was destroyed due to a misunderstanding between the farmer and a contractor who ploughed up the land.

Several online applications that assist small-scale farmers in other African countries, for example Kenya and Nigeria, have successfully been developed in recent years. The Agri-parks initiative presents an opportunity to develop a similar system in South Africa. Through this study, the potential of implementing an online system for training and extension services was assessed. However, due to the small scale and the limited number of Agri-park farmers, the research had to be open to all interested users. In 2019 the University of Pretoria's Facebook Ingesta platform was used to test the potential of hosting free e-learning programmes aimed at small-scale farmers. We piloted a 14 'chapter' course on the fundamentals of weed science. Thirty-four individuals from six different countries, as well as eight of South Africa's provinces, successfully completed the learning programme. Feedback from the learning programme was overwhelmingly positive, with 90% of the final participants finding the programme to be at least 'easy to understand' and 91% indicating the length of the chapters was 'just long enough'. All final participants indicated that they had learnt information that they felt would better help them manage weeds in their fields, with 17 expressing additional positive comments. As a result, the pilot study was considered a success and social media proven to be a viable platform to provide access to agricultural science learning material for small-scale farmers in Sub-Saharan Africa. The participants had to write tests and those that passed everything at the end were posted a certificate. The course and interaction can be viewed here: https://www.facebook.com/IngestaFarming/posts/975465866130400. Due to the small number of Agri-park farmers, it is unfortunately not possible to make any conclusions on potential uptake of social media by the Agri-park farmers as a way of accessing extension services and markets.

Finally, of all the technologies and solutions that were introduced at the Rooiwal Agri-park, farmers were most enthusiastic about the idea of using sewage effluent for irrigation, highlighting the observation of Van Niekerk (2020) that 'a pre-requisite for end-user acceptance is that the technology must become part of the the daily practices of the existing system'. Irrigation is an existing practice at Rooiwal, and as long as the sewage effluent can be used within the current irrigation system, user-acceptance is expected to be successful. The farmers' positive attitudes towards using sewage effluent further highlights the desperation of the farmers to access more water, but it may also show a more relaxed attitude towards water quality and potential risks that the effluent water may pose. The following comment from someone at Rooiwal is proof of this more relaxed attitude: "The effluent water, it is good, it is only really 'human manure'". The overwhelmingly positive reaction towards irrigation with sewage effluent, is however, a good motivation to conduct further research on potential health risks of organic pollutants, diseases and excessive nitrates in the effluent water.

Education of and demonstrations to end-users to use the given technology seldom succeed. Cultures, socio-economic status, age and personal preferences can all have an impact on how technologies are received. The particular conditions of the local environment and water resources will also play an important role in the success of a technology or tool in a particular location. An Agri-park manager will have to engage with the farmers to better understand their needs and requirements, before deciding which technologies to implement.

Innovations developed for South African Agri-parks through this research

The project has developed three innovations, namely:

- **The Water and Nutrient Balance Framework** to assist Agri-park planners or catchment managers in their decision-making processes. It combines water accounting using a water footprint approach and simple crop macro-nutrient accounting. The framework requires input values including volume of available blue water (such as DWS streamflow and groundwater information) and crop data, such as water footprint, the size of the farm, yields per hectare and the length of the growing season to calculate potential production in terms of blue water availability and feasibility of current production. To determine potential production in terms of nutrient availability, the concentrations of nitrogen (N), phosphorus (P) and potassium (K) within the water source as well as crop N, P and K requirements should be provided. The main output of the tool is the information on the potential size of the Agri-park and potential production. The framework was applied using Rooiwal and Westonaria as case-studies, and is simple enough to be used by a wide range of stakeholders.
- **Vundisa Manure Application Tool (VMAT)** to give farmers an indication of the amount of chicken manure they have to apply to substitute fertilizers. The tool requires inputs on the N, P and K content in the available chicken manure and in the soil. It also requires bulk density and soil depth as well as fertilizer requirements of the crops. The output of the tool is the number of shovels or wheelbarrows of chicken manure that a farmer has to apply to specific crop areas.
- **A social media platform** was developed and tested to supply Agri-park farmers with extension services and training. The Ingesta Facebook Page was used to provide an online learning program on weed science.

Recommendations for future research

It is recommended that future research be conducted on developing and managing water resources on a catchment scale. Tools, such as the SAWQG DSS and WNB should be introduced to catchment managers. Research is required to assess the safety of irrigating with sewage effluent in terms of possible uptake of organic pollution by crop, transfer of pathogens such as Covid-19 and health risks of high levels of nitrates in the irrigation water. A long-term groundwater monitoring plan is required to determine suitability and sustainability of the current and future abstractions.

On a farm scale, research is required to co-develop daily farming practices for using tools, such as the soil moisture sensors, social media, VMAT, mulching and, if the water is proven safe, irrigating with sewage effluent. Future research can also improve on the tools, like VMAT, that were developed in this study.

While the small-scale and poor roll-out of Agri-parks hampered the planned research in this project, a framework now exists to optimize the integrated water resources planning and farmer level agronomic management of Agri-parks. A study on the return of investment of government funding in Agri-parks as well as feasibility assessments are recommended.

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LIST OF ABBREVIATIONS

AMD	Acid Mine Drainage
ARC SCW	Agricultural Research Council: Soil Climate Water
Ca	Calcium
CH	Compost heap
Cl	Chlorine
CoT	City of Tshwane
CS	Chameleon soil water sensor
DWS	Department of Water and Sanitation
EC	Electrical conductivity
ET	Evapotranspiration
GDARD	Gauteng Department of Agriculture and Rural Development
K	Potassium
Mg	Magnesium
N	Nitrogen
Na	Sodium
P	Phosphorus
SAWQG DSS	South African Water Quality Guidelines Decision Support Tool
SD	Sawdust
SI	Sustainable Intensification
SSFs	Small-scale Farms
TDS	Total dissolved solids
UP	University of Pretoria
VMAT	Vundisa Manure Application Tool
WF	Water footprints
WFD	Fullstop wetting front detector
WMA	Water Management Area
WNB	Water-and-nutrient-balance
WRRS	Water Resource Reconciliation Strategy
WWTW	Wastewater Treatment Works

LIST OF UNITS

g	Gram
ha	Hectares
kg	Kilogram
km	Kilometre
L	Litre
m	Metre
m^3	Cubic metres
mg	Milligram
Mm^3	Mega cubic metres
mS/m	Millisiemens per metre
nm	Nanometres

1 INTRODUCTION

In the first quarter of 2017 the unemployment rate in South Africa increased to 27.7% (Statistics South Africa, 2017). According to Statistics South Africa (2019), 15.8% of households in South Africa have reported inadequate access to food, and 5.5% indicated that they experience severely inadequate food access. Currently the South African economy is also facing severe consequences of the Covid-19 pandemic and national lockdown of the economy. Statistics South Africa (2020) did a survey on 2 688 respondents and reported that those who experienced hunger increased from 4.3% to 7.0% during the first month of lockdown, 8.1% had to close their business or lost their jobs. Small-scale agriculture presents an opportunity to uplift rural poor people, however, many rural households that have previously managed to successfully cultivate crops to supplement their incomes have now ceased production because of rural-urban migration (men migrate to the cities to find alternative sources of income from industries) and because of competition from commercial agriculture that is producing food more effectively and at lower prices (Mnkeni et al., 2011).

While food security is currently a problem in South Africa, future food production is expected to become even more challenging. Food production worldwide is threatened by increasing water scarcities. Water requirements are increasing due to population and economic growth, however, good quality water is declining (Postel, 1999) and current water uses, such as over-exploitation of groundwater, are often unsustainable (Wada et al., 2012). Climate change is also expected to impact on the availability of water resources and farmers need ways to continue farming under conditions of uncertain and varying water availability. In South Africa, water scarcities are of particular concern. In February 2018 the ongoing drought in three provinces in South Africa, namely Northern Cape, Western Cape and Eastern Cape, has been declared as a national disaster. The year 2015 was the driest year on record, since nationwide recordings started in 1904 and these dry conditions continued in 2016 and 2019 (Agri-SA, 2019; De Jager, 2016). Agriculture in the Western Cape, Free State, North West and Northern Cape was severely impacted by this ongoing drought (Agri-SA, 2019). It is therefore critically important to plan agricultural activities on a catchment scale to ensure that sufficient water of good quality is available over the long term.

The sustainable use of water resources in agriculture requires management on a local (farm) and regional (catchment or aquifer) scale. The challenge is to identify sustainable water use management practices at local scale that are feasible and acceptable to the farmers who will implement them, management tools that will improve efficient decision making on water use on a catchment scale, and also to design local and catchment scale water management systems that are fully integrated. The Agri-parks initiative could potentially play an important role in addressing many of these problems.

1.1 Agri-parks in South Africa

The South African Government is planning to implement Agri-parks across the country, aiming to revitalise agriculture, catalyse rural industrialisation and support emerging farmers (Department of Rural Development and Land Reform, 2016). The Department of Rural Development and Land Reform initiated the development of Agri-parks in close collaboration with the Department of Agriculture, Forestry and Fisheries. The relevant provincial departments and local municipalities are also involved in the execution and management of the Agri-parks. An Agri-park is defined as '*a networked innovation system of agro-production, processing, logistics, marketing, training and extension services, located in a District Municipality. As a network it enables a market-driven combination and integration of various agricultural activities and rural transformation services*' (Department of Rural Development and Land Reform, 2016). Agri-parks have the potential to provide capital, support and knowledge that will address many of the challenges facing agriculture today. Through the Agri-parks initiative, it could also be possible to uplift and educate emerging farmers, which is an important goal considering the poverty that is experienced in the country. However, the success of these Agri-parks will depend on how they are implemented, whether the desired production will be feasible in terms of the availability of resources, especially water, and whether the technologies that are used are transferable to Agri-park farmers. Agri-park farmers need appropriate technologies and tools to compete with a very competitive commercial farming sector in South Africa.

The Agri-park model consists of three components (Department of Rural Development and Land Reform, 2016), namely:

1. A Farmer Production Support Unit (FPSU) is the unit that supports rural smaller scale farmers by providing:
   a. Agricultural input supply control;
   b. Extension support and training;
   c. Mechanization support (tractor driving, ploughing, spraying, harvesting, etc.);
   d. Machinery servicing workshop facilities;
   e. Local logistics support (delivery of farming inputs, transportation postharvest transportation to local markets);
   f. Primary produce collection;
   g. Weighing of produce and stock;
   h. Sorting of produce for different markets;
   i. Packaging of produce for local markets;
   j. Local storage;
   k. Processing for local markets (small scale mills, etc.);
   l. Auction facilities for local markets;
   m. Market information on commodity prices (ICT);
   n. Farmers wanting services and support from the FPSU will register with the FPSU of their choice;
   o. Small Business Development and Training center;
   p. Banking; and
   q. Fuel (energy center).

2. An Agri-Hub (AH) which supports a number of FPSUs by providing:
   a. Storage and warehousing facilities; cold storage, dehydrators, silos, etc.;
   b. Weighing facilities;
   c. Agri-processing facilities (mills, abattoirs);
   d. Enterprise development areas that lease space to high intensity start-up industries that can benefit from the inputs or outputs of the Agri-hub, i.e. piggeries, tunnel grow crops, bio-gas production, etc.;
   e. Large scale nurseries to supply FPSUs;
   f. Packaging facilities for national and international markets;
   g. Logistics hubs for collection of goods from the FPSUs;
   h. Transport service workshops and spare parts for larger maintenance tasks of Agri-hub and FPSU equipment;
   i. Agricultural technology demonstration parks to train farmers in the Agri-park catchment area;
   j. Soil testing laboratories;
   k. Accommodation for extension training and capacity building programmes;
   l. Housing and recreational facilities for workers and Agri-hub staff; and

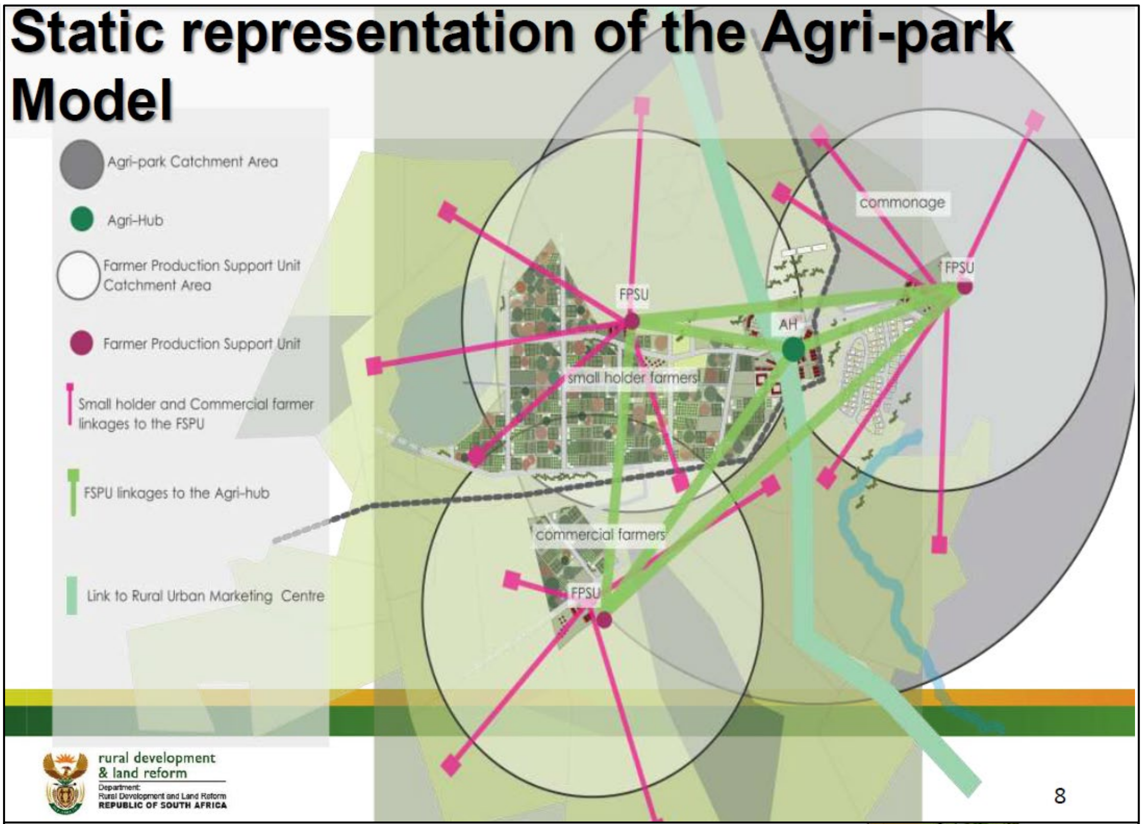
m. Business, marketing and banking facilities.

3. A Rural Urban Market Centre (RUMC) will support more than one Agri-park by providing:
   a. Market intelligence;
   b. Assistance to farmers in managing contracts;
   c. Large warehousing and cold storage facilities to enable market management;
   d. Logistic and transport in collection of produce from FPSUs or AHs; and
   e. Both FPSU's and AHs provide inputs to the RUMC.

Figure 1-1 A shows the Agri-park model and **Figure 1-1 B** shows the Agri-park network map that was included in a presentation by the Department of Rural Development and Land Reform (2016). According to this model and map an Agri-park would be a new management structure that connects and assists a relatively large region of farmers, most of which probably exist already. According to the Department of Rural Development and Land Reform (2016) the Agri-park initiative is guided by the following principles:

- That one Agri-Park per district municipality will be established;
- That Agri-parks be controlled by farmers;
- That Agri-parks must stimulate rural industrialization;
- That Agri-parks must initially be supported by government to ensure economic sustainability;
- That agricultural production is supported by providing farmers with services, such as water, energy, transport and training and by developing existing markets and creating new markets;
- That farmers are supported to benefit from existing state land with agricultural potential;
- That access to markets is maximised, with a bias to emerging farmers and rural communities;
- That the use of high value agricultural land is maximised;
- That existing agro-processing, bulk and logistics infrastructure, roads and available water and energy is utilised to full potential; and
- That growing and rural towns are revitalised, by stimulating economic growth and promoting rural urban linkages.

A



B

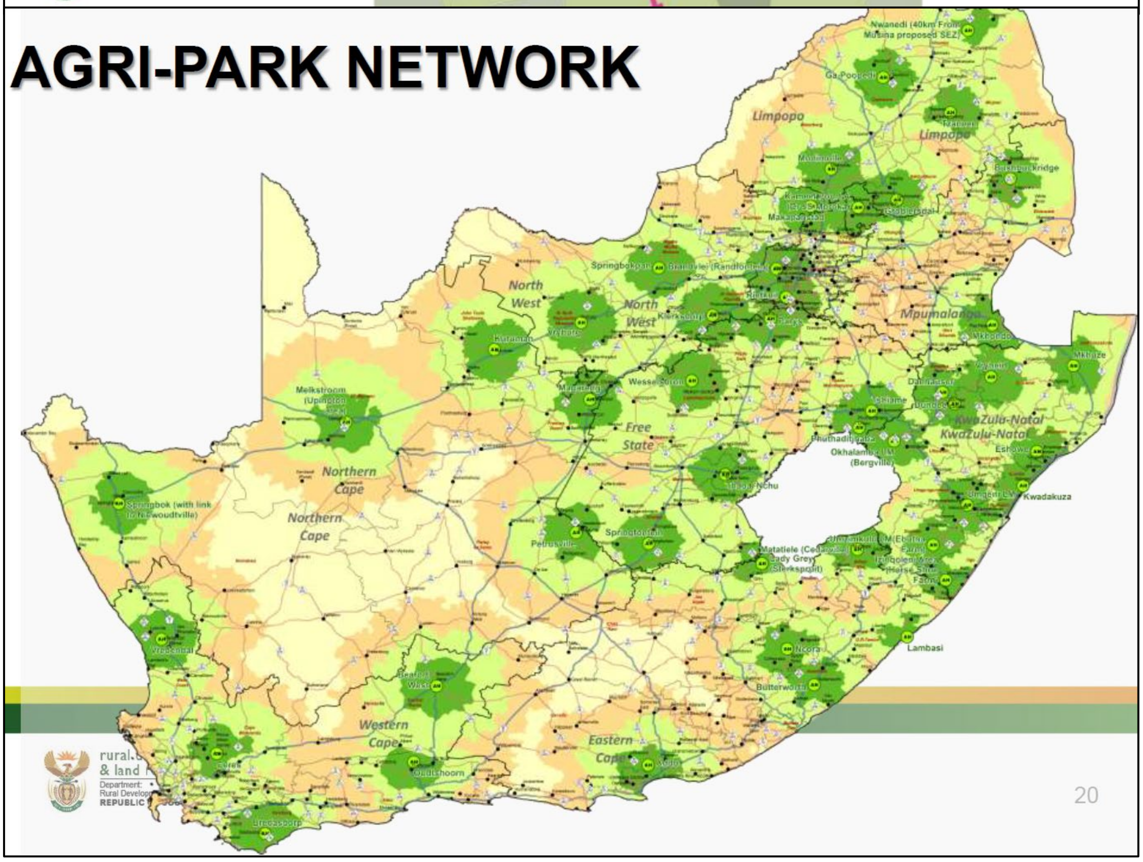


Figure 1-1: The Agri-park model and planned network (Department of Rural Development and Land Reform, 2016)

With the focus on uplifting previously disadvantaged emerging farmers and the integration of local and regional scale management, Agri-parks can play a very important role in addressing many problems, including future food production, eradication of poverty and redressing past inequalities, that we are facing today. The Covid-19 pandemic and the national lockdown has further highlighted the urgent need to address these issues. Therefore, it is important that research is done to assist Agri-parks to manage their resources better and to become the ambitious structures they were meant to be. One of the most important challenges that need to be addressed by the Agri-parks is the management of water resources.

1.2 Project Aims

The Water Research Commission requested this research project, to assess the impact and management of water quantity and quality of selected South African Agri-parks. This research study was therefore conducted to achieve the following aims:

1. To evaluate the management and impact of proposed Agri-parks on the quality and quantity of water resources in South Africa. Since Agri-parks are still in a development phase, through this research a framework was established for making Agri-parks more sustainable, and to provide essential capacity building for rural farmers. The proposed aim was reached through a two-pronged approach that focused on the catchment and farm level;
2. On a catchment level the following aims were applicable:
    2.1. To assess the feasibility of the selected Agri-parks, as currently planned, in terms of quantity and quality of water available in the catchment;
    2.2. To determine the optimum crop yields, crop selection and rotation in terms of water availability in the relevant catchment and acceptable environmental impacts for each study area; and
    2.3. To assess the available tools that can be used by an Agri-park to better manage water in a simplified way.
3. On a local / farm level, the following aims will be applicable:
    3.1. To co-design sustainable agricultural practices through active cooperation between small-scale farmers, FPSUs and scientists using principles of sustainable intensification; and
    3.2. To develop a programme for capacity building of rural farmers that will include guidelines on the most appropriate and user-friendly tools available that can be used for good water management.

1.3 Study Sites

Although a number of Agri-parks in Gauteng were visited and engaged with during the project, the majority of the research was conducted at two Agri-parks. The Rooiwal Agri-park is north of Pretoria and the Westonaria Agri-park is along the R28 Highway in the West Rand District Municipality, south of Johannesburg.

1.3.1 Rooiwal

The Rooiwal Agri-park (25.553°S; 28.233°E) is north of Pretoria in the City of Tshwane municipality and is located approximately 700 m to the west of the Apies River (**Figure 1-2**). Between Rooiwal and the Apies River is the Rooiwal Power Station that is currently not operational. Approximately 400 m north of Rooiwal is an old ash tailings dam from the power station. To the south, Rooiwal borders a wastewater treatment works (WWTW). To the west of Rooiwal there are old agricultural fields. Similar to all Agri-parks in Gauteng, Rooiwal was found to be small-scale production units, which is a serious deviation from the Agri-park model.

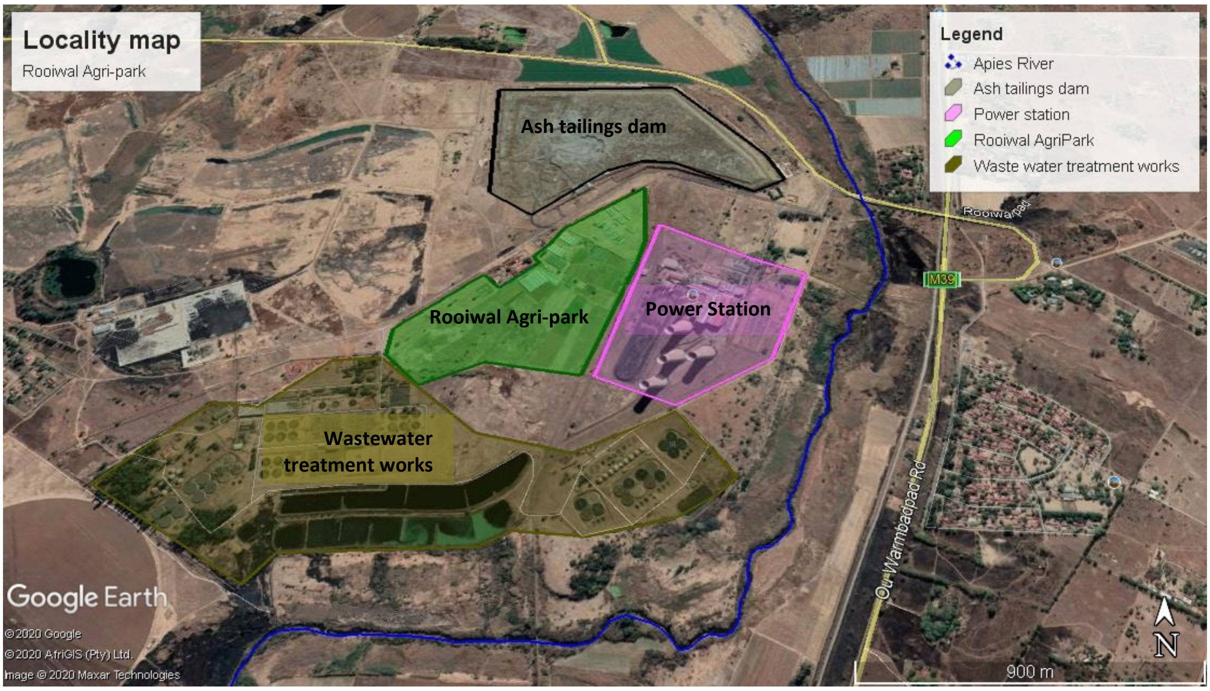


Figure 1-2: Locality map of the Rooiwal Agri-park with surrounding land uses (25.553°S; 28.233°E)

1.3.1.1 *Climate*

The Rooiwal Agri-park is north of Pretoria, which is a summer rainfall region with dry winters (**Table 1-1**). Annual precipitation is between 500 mm and 700 mm. The area experiences a cool dry season from May to mid-August, a hot dry season from mid-August to October and a hot wet season from November to April. Frost is not a common occurrence in this area.

Table 1-1: Long-term climate data from a nearby station (From https://en.climate-data.org/)

Kwalata Monthly Climate Means

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Min. temperature (°C)	16.8	16.5	14.8	11.2	6.2	2.7	2.5	5.1	9.3	13.3	15.1	16.3
Max. temperature (°C)	29.9	29.6	28.5	26.4	23.7	21.4	21.6	24.5	27.6	29.4	29.2	29.8
Rainfall (619 mm)	111	85	70	40	17	6	6	6	15	56	102	105

1.3.1.2 *Topography*

The Apies River is close to the eastern boundary of the Rooiwal Agri-park, and therefore the topography slopes downwards towards the east. However, the slope is gradual and topography is relatively flat. No rocky outcrops are found in the area, with only the old ash tailings dam from the Power Station to the north of the site.

1.3.1.3 *Vegetation type*

According to Mucina and Rutherford (2006), the Rooiwal Agri-park occurs within the Central Sandy Bushveld. This vegetation type is vulnerable with less than 3% statutorily conserved. The area is a grass-dominated herbaceous layer with relatively low basal cover sands.

1.3.1.4 *Geology and soils*

The geology is characterised by dominant sedimentary rocks like sandstone, siltstone, conglomerate and shale. Soil samples were tested in 2019 and results indicated that soil is sandy with an average of 74% sand. An average pH of 6.2 and 6.3 was reported at 15 cm and 30 cm respectively. Macronutrients tested were nitrogen (N), phosphorus (P) and potassium (K). Average N percentage at 15 cm depth was 0.07%, which was much higher than average nitrogen of 0.04% at 30 cm depth. Phosphorus ranged from an average of 133.2 mg/kg at 15 cm depth to an average of 120.0 mg/kg at 30 cm depth. Potassium ranged from 80.6 mg/kg average at 15 cm depth to 74.9 mg/kg average at 30 cm depth. Average calcium (Ca) and magnesium (Mg) concentrations at 15 cm depth was 804.0 mg/kg and 58.6 mg/kg respectively. The micronutrient sodium (Na) was reported to be 23.5-45.9 mg/kg. Cation imbalances shown in this analysis have been corrected.

1.3.2 Westonaria

The Westonaria Agri-park (26.277°S; 27.684°E) is located to the west of the Donaldson Dam (**Figure 1-3**). The Bekkersdal settlement is located on the eastern boundary of the Donaldson Dam. The major land uses in the area surrounding the Westonaria Agri-park is mining and residential settlements. Westonaria is also a small-scale production unit that does not resemble the Agri-park model.

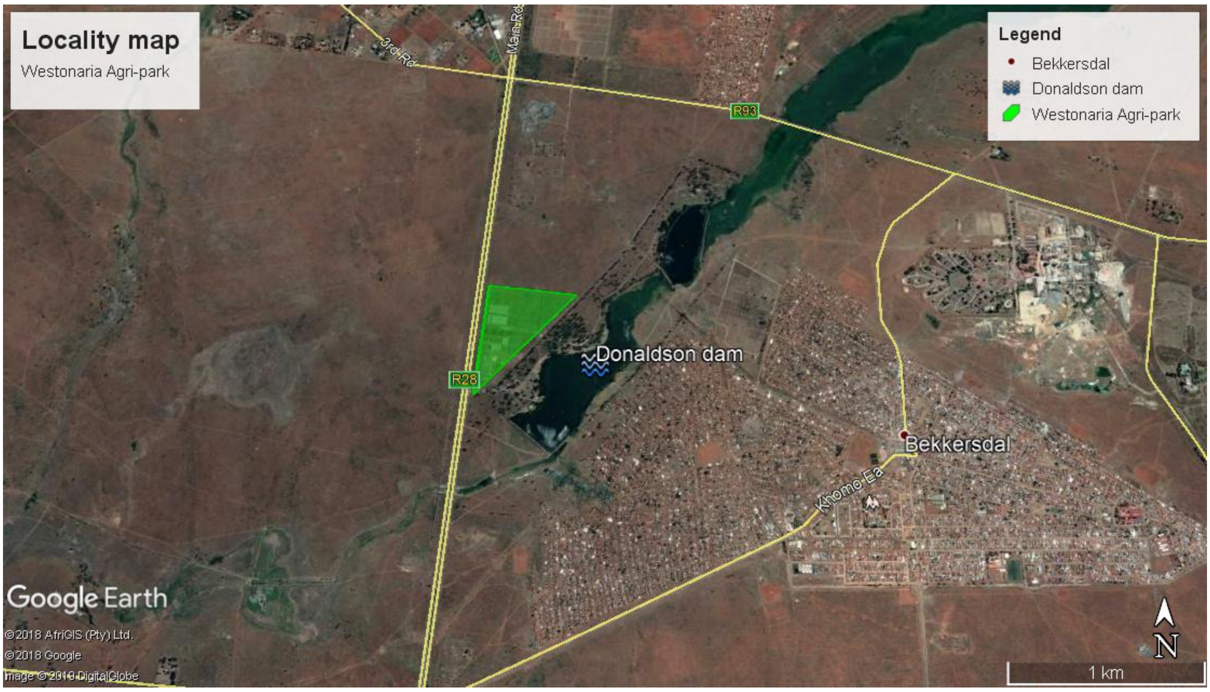


Figure 1-3: Locality map of the Westonaria Agri-park (26.277°S; 27.684°E)

1.3.2.1 *Climate*

The area is a summer-rainfall region with a warm to temperate climate. Summer temperatures are high and frost is common during winter. Mean annual precipitation is approximately 600 mm (Mucina and Rutherford, 2006).

1.3.2.2 *Topography*

The topography of the area in general is slightly undulating plains with some rocky chert ridges (Mucina and Rutherford, 2006). The Westonaria Agri-park site is flat, with a gentle slope towards the Donaldson Dam at the south east border.

1.3.2.3 *Vegetation type*

According to Mucina and Rutherford (2006), the Westonaria Agri-park is located within the Carletonville Dolomite Grassland vegetation type. This vegetation type is vulnerable, with very little being conserved. Approximately 25% of the Carletonville Dolomite Grassland has been transformed by cultivation, urban developments, dams and mining. Very little erosion occurs.

1.3.2.4 *Geology and soils*

The Westonaria Agri-park is located on dolomite and chert of the Malmani Subgroup (Transvaal Supergroup). This geology mostly supports shallow Mispah and Glenrosa soil forms (Mucina and Rutherford, 2006)

1.3.2.5 *Proposed Agri-Hub for Johannesburg Agri-Parks*

According to the Gauteng Department of Agriculture and Rural Development (GDARD) all existing production units, such as Rooiwal and Westonaria, will be incorporated by the Agri-parks, forming FPSUs. Officials from GDARD were unable to say whether the Agri-Hub, once established, will serve all farmers within 20 km radius, as per the original concept. However, if current production units like Westonaria will form the FPSUs, is seems likely that surrounding farmers will not be included in the Agri-parks. A location has been selected for the proposed Agri-Hub that will serve the Johannesburg FPSUs. The area selected for the Agri-hub is located in Brandvlei and is 0.5 km^2 in size (**Figure 1-4**). Nothing has been developed there yet, but the entire site has been fenced off (**Figure 1-5**). The large distance between the proposed Agri-hub and the various existing FPSU's like Westonaria is a deviation from the model and will be a problem in terms of logistics in the management of the Agri-park.

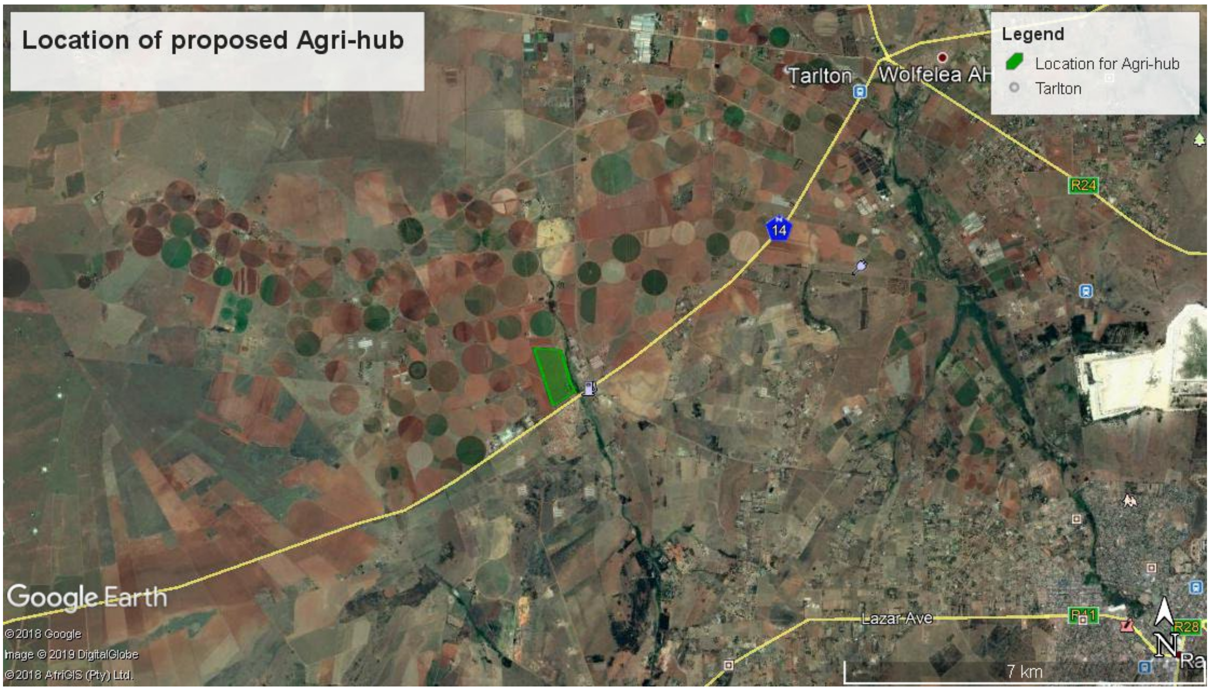


Figure 1-4: Location of the site selected for the proposed Agri-hub that will serve the Johannesburg Agri-park

Figure 1-5: The selected location for the proposed Johannesburg Agri-Hub, indicating the fence surrounding the site

1.4 Challenges Encountered During the Project and How They Were Addressed

The following challenges have been encountered:

- A desktop survey on the Agri-park initiative indicated that multiple departments collaborated with the Department of Agriculture, Land Reform and Rural Development (DALRRD), (Department of Rural Development and Land Reform, 2016). In 2016, the names of the departments involved were: Department of Agriculture Forestry and Fisheries, Economic Development Department, Department of Trade and Industry, Department of Science and Technology, Department of Small Business Development, Department of Water and Sanitation, The Department of Environmental Affairs and Department of Cooperative Governance (Department of Rural Development and Land Reform, 2016). Locally, Agri-parks in Pretoria are managed by the City of Tshwane and in Johannesburg by the Department of Agriculture and Rural Development. Because of this complex management structure, the responsibility of taking actions often gets lost and it is difficult to find the right people to get the necessary information.
- The small scale of the existing Agri-parks in Gauteng does not justify a large-scale water feasibility assessment, as originally planned. For this reason, the feasibility assessment of the conceptual Agri-parks was conducted with recommendations on potential growth of these Agri-parks.
- Current production and water quantity and quality data is poorly recorded by the farmers and Agri-park managers, impacting the accuracy of the feasibility assessment. A proper monitoring program is recommended if Agri-parks are to expand to the intended scale.
- Initially the plan was to conduct Mother – Baby trials to determine which tools and technologies are most suitable to the Agri-park farmers. However, due to the small scale of current Agri-parks it was not possible to implement the Mother – Baby trials, which is a quantitative research method and requires a large number of participants in one location. As agreed with the WRC in a meeting held on 18 November 2019, it was decided that the team can still reach the aims of the project, although the methodology of large-scale quantitative research is not possible. Alternatively, the project team committed themselves to conducting qualitative research with the one or two farmers available at the Rooiwal Agri-park and through interaction with them to develop sustainable agricultural practices for the particular site. Quantitative research was, however, conducted during a Farmers' Demonstration Workshop at the Westonaria Agri-park, where 50 Agri-park farmers from Johannesburg was in attendance.

2 LITERATURE REVIEW

2.1 Introduction

The Agri-park model aims to uplift emerging farmers and revitalise agriculture in South Africa. However, what are the challenges that the country faces in terms of future food production? How can more food be produced without harming ecosystems and depleting resources? What knowledge, tools and technologies are available to improve decision making, resource use efficiency and better productive outcomes? Finally, how do you facilitate change in current management practices at farmer and catchment level?

Sustainable food production is increasingly becoming a problem, especially in developing countries. It is estimated that agricultural outputs have to increase by 60-70% by 2050. This increase in demand for agricultural products is not just driven by population growth, but also by the changes from plant-based diets to increased meat consumption, growing markets for biodiesel from grains, and urbanization and improvement of infrastructure that allow for increases in consumption of more perishable foods (Silva, 2018). Food security has become a well-debated topic in the past few decades, and different approaches ranging from small- to large-scale production have been considered. Challenges in future food production include climate change, population growth, limited agricultural lands, limited water resources and water pollution. A comprehensive understanding of the challenges and opportunities in future food production is necessary to plan and manage Agri-parks in a sustainable way.

2.2 Challenges in Future Food Production

2.2.1 Population growth

In the year 2020 the world population is 7.8 billion compared to 2.5 billion people in 1950 (United Nations, 2019). Numerous technological advances explain this unprecedented growth. Several advances during the 'Green Revolution', such as chemical fertilizers, might have been the main enablers that resulted in the global population to double between 1960 and 2000 (Stirzaker, 2010). The world population continues to grow and it is expected to almost reach 10 billion by 2050 (Food and Agriculture Organisation, 2017). Global population growth is slowing down, with very little average growth in developed countries, but average growth in developing countries still continues. It is expected that in 2050, the population in developing countries will be 8 billion, compared to 1.2 billion people in developed countries (Silva, 2018).

2.2.2 Rural-urban migration

The current trend in rural-urban migration worldwide and in Sub-Saharan Africa (**Figure 2-1**) has several negative impacts, including urban sprawl, poverty and high unemployment rates in urban areas, higher costs of living (particularly housing), crime, environmental impacts, inequality, etc. (Zhang, 2016). In terms of food production rural-urban migration can reduce food security, because in urban areas people are generally not able to produce their own food like they do in rural areas, and are more dependent on food purchases (Armar-Klemesu, 2000). Another potential long-term impact of rural-urban migration, is that traditional knowledge of practicing subsistence farming in rural areas are lost when young people move to cities.

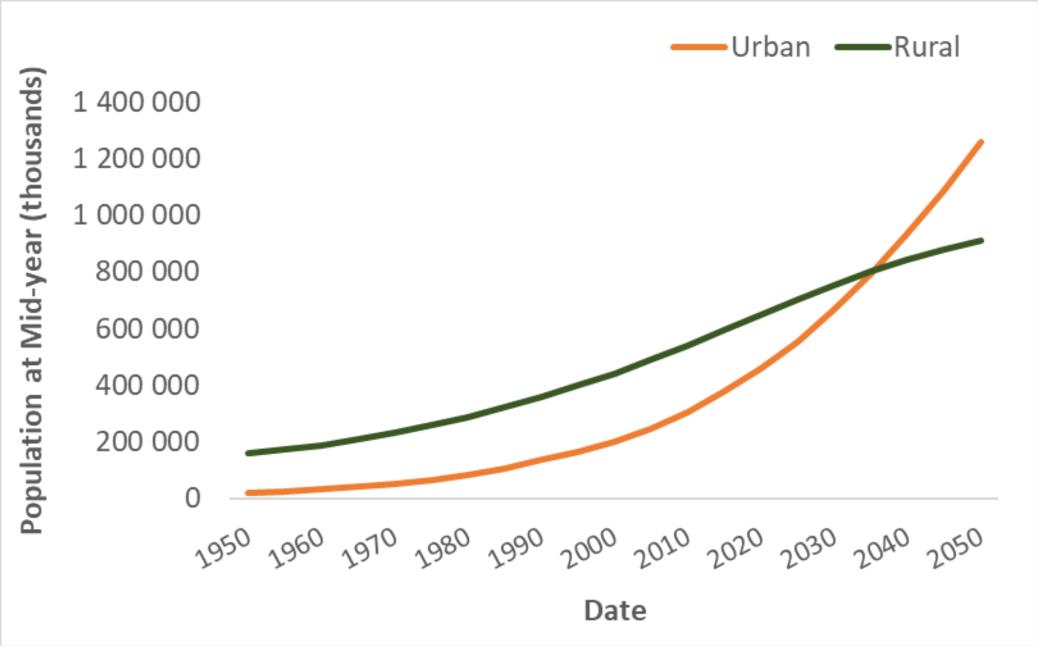


Figure 2-1: Past and projected trends in urbanisation in Sub-Saharan Africa (United Nations, 2018)

2.2.3 Resources

2.2.3.1 *Arable Land*

In 1960 the available arable land per capita was 0.42 ha and this is expected to decrease to 0.19 ha per capita in 2050 (Silva, 2018). In order to overcome this dilemma, the present food production system must change: more land should be made available, or more food must be produced on current land, or food distribution and storage must change, or eating habits must change, or all of these must change. Making more arable land available, which is almost fully developed already, may be at the expense of natural ecosystems. If productivity is to be increased per surface area, low productivity systems will have to be transformed.

2.2.3.2 *Water Resources*

Globally, water is also becoming a limited resource. Between 2015 and 2020, a water crisis was among the top 5 risks identified by the Global Risk Report (World Economic Forum, 2020). In the future, water scarcity is expected to intensify due to climate change as well as population and economic growth. The increase in future water scarcities is one of the factors that make global food production an issue of particular concern. Current sources of good quality water are declining, making it difficult to maintain current food production, and even more difficult to meet the future requirements in food production (Postel, 1999).

South Africa is a water-stressed country. The average annual rainfall is only 490 mm (World Wildlife Fund, 2016). The variability of rain regionally and over time adds compounding factors to water supply (Binns et al., 2001; Department of Water Affairs, 2011). The annual run-off of South Africa's rivers is on average 49,000 million m^3 per year, of which 50% is from catchment areas which account for only 8% of the country's surface area (Department of Environmental Affairs, 2012; World Wildlife Fund, 2016). South Africa is also faced with water quality challenges which are mainly induced by human activities. These human activities often accelerate natural processes and, along with an increase in industrialisation, result in river water quality issues. The water quality impacts of the following two land uses are of particular importance in the context of this report:

- Wastewater treatment works that discharge untreated or poorly treated effluents introduce coliforms and excessive amounts of nutrients like nitrates and phosphates, and
- Agriculture that uses pesticides, herbicides and fertilizers introducing salts and other toxic substances into the water (Department of Environmental Affairs, 2012).

2.2.3.3 *Nutrients*

Unlike the availability of arable land and water, nutrients are generally not the main limiting factor in agriculture yet. However, the ecological impacts of chemical fertilizers on water quality and in terms of climate change make it a very relevant topic to sustainable food production. The use of chemical fertilizers is currently a linear pathway. At the supply end, the production of nitrates has a high carbon footprint while phosphate is a limited resource that is mined. The nutrients are finally disposed into the environment through sewage generated by the now much larger human population. Both the supply end of the nutrients and the way in which they are disposed of have severe ecological impacts, especially on climate change and water quality.

Climate change

According to the IPCC, agriculture contributed 10% to 12% of total greenhouse gas emissions in 2005. These emissions included methane (CH_4) from animal husbandry and nitrous oxide (N_2O) from agricultural soils. Nitrous oxide is an intermediate compound in the natural denitrification of nitrates in fertilizers to N_2 gas (Smith et al., 2007).

A carbon footprint is also found along the supply chain of resources and chemicals used in agriculture, such as the production of fertilizers. Nitrate (NO_3), which is an important nutrient in fertilizers, are produced through the Haber-Bosch process, by fixing N_2 gas in the atmosphere into ammonia (NH_3), and then converting NH_3 to NO_3. The Haber-Bosch process is an energy intensive process that requires constant pressure above 100 bar and high temperatures of about 500 °C (McPherson and Zhang, 2020). Daghash (2012) estimated that the carbon footprint of ammonia production ranges from 785 kg to 999 kg CO_2 per ton ammonia. Currently, ammonia production through the Haber-Bosch process accounts for 1% of the world’s energy supply and contributes 1.4% of global CO_2 emissions (Capdevila-Cortada, 2019).

However, different agricultural systems have different impacts on climate change. Large-scale industrial agriculture contributes to the majority of agricultural greenhouse gas emission, whereas smaller scale farms that incorporate agro-ecological principles that generate less carbon emissions can potentially become a carbon sink (Bezner-Kerr et al., 2012). The major differences between large-scale industrial farms and small-scale agro-ecological farms that influence the difference in carbon footprints is:

- Large-scale industrial farms are more energy intensive, while small-scale farms are generally more labour intensive;
- The two systems differ in terms of their use of resources such as fertilizers and crop management choices; and
- Large-scale industrial farms require more transportation of inputs, outputs and products, while small-scale farms generally use more local resources and access more local markets (Bezner-Kerr et al., 2012).

Water quality

Nutrient waste through the now much increased sewage production of the current human population represents the main impact at the end of the fertilizer life cycle. Increased nutrient levels from wastewater treatment plants and fertilisers from agriculture enrich river systems in a process called eutrophication (DEA, 2012). Eutrophication is a major cause of water pollution and leads to multiple effects, including:

- Growth of aquatic plants and harmful algae that depletes dissolved oxygen in the water, causing ecosystem degradation and reduction in aquatic species diversity;
- Algal toxins in eutrophic waters that directly threaten human and animal health if consumed. Toxins from cyanobacteria can be taken up by fish that will become a health risk if consumed by humans. If ingested, the toxins cause reactions ranging from respiratory difficulties, gastrointestinal symptoms, skin rashes, ear pain and eye irritation to liver and nerve damage;
- A smell and appearance of the water that reduces the recreational value of a dam; and
- An increase in the cost of purifying the water to drinking water standards (DEA, 2012).

The South African aquatic environment is phosphate limited, meaning that any addition of phosphates is usually the driver of eutrophication. Nitrates also have potential human health impacts, causing methaemoglobinaemia, which is especially hazardous in infants due to their increased capacity to convert nitrate to nitrite (Ward et al., 2005). The effects of methemoglobinemia are less reversible than in adults due to infant's low levels of cytochrome b5 reductase, the enzyme which converts methemoglobin back to haemoglobin (Ward et al., 2005). The World Health Organization (2017) sets the maximum nitrate concentration at 50 mg/L, to protect against "methemoglobinemia and thyroid effects in the most sensitive subpopulation, bottle-fed infants, and, consequently, other population subgroups" (World Health Organization, 2017). Nitrate at high doses can competitively inhibit iodine uptake, and induce hypertrophic changes in the thyroid (Ward et al., 2005). Ward et al. (2005) further reports that nitrate is a precursor in the formation of N-nitroso compounds (NOC), of which many have been shown to be carcinogenic in multiple animal species, but conflicting claims have been published (Chowdhury and Das, 2015). Some studies have showed positive associations, many showed no association, and a few showed inverse associations; and so further research is needed (Ward et al., 2005). Studies looking at the impact of nitrate levels and the outcomes of spontaneous abortions, stillbirths, premature birth, or intrauterine growth retardation have been inconsistent, although Ward et al. (2005) indicated that this could be attributed to differing levels of water nitrate across studies or differences in exposure to other cofactors. According to the South African Water Quality Guidelines (Department of Water Affairs and Forestry, 1996) nitrate concentrations above 30 mg/L "may stimulate excessive vegetative growth and cause lodging, delayed crop maturity and poor quality", as well as promote the growth of algae within irrigation equipment causing blockages.

Although the environmental interactions and crop genetics complicate the process of nitrate uptake by plants, it has been observed that increased application rates result in nitrates being stored in leaf vacuoles. Therefore, there is a risk of consuming toxic levels of nitrates through fresh vegetables, especially leafy vegetables that have been grown with too much nitrates (Blom-Zandstra, 1989; Chowdhury and Das, 2015; Maynard et al., 1976; Qiu et al., 2014). Elevated nitrate levels in animal feed can also be lethal to livestock (Stanton and Whittier, 2006). Eutrophication and accumulation of nitrates in natural water resources may therefore become another threat to future food production.

Globally, nitrate accumulation in aquatic ecosystems due to agriculture is a concern. It has been found that the nitrate accumulation in the vadose zone of agricultural lands across the world is highest in North America, Europe and China, partly because of the thickness of the vadose zone and because of the long agricultural histories in those countries. This means that nitrate leaching from these areas will have a longer lag effect, once more sustainable agricultural practices are implemented to reduce nitrate inputs (Ascott et al., 2017). The problem of nitrate pollution of water resources in the Netherlands, which is one of the top food producing countries in the world, is particularly severe. Stokstad (2019) warns that the pollution of nitrates in the Netherlands is now a crisis that threatens the environment and the economy.

In South Africa, the poor state of wastewater treatment works (WWTWs) is currently a major cause of nutrient accumulation in aquatic ecosystems. According to the 2012 Green Drop Progress Report, which is the last report on the condition of South African WWTWs published by the Department of Water and Sanitation (DWS), 39% of all municipal WWTWs deteriorated from 2011 to 2012 and 44% of all municipal WWTWs can be categorised as at high or critical risk. More recently, AfriForum (2019) evaluated the WWTWs of 124 towns in South Africa and found that 52% did not comply with the required water quality standards. According to the World Wildlife Fund (2016), a quarter of South Africa's major rivers are 'critically endangered'. Twenty nine of the 100 major dams in South Africa have a 'red' health risk from either high nutrient levels or toxins dangerous to humans. According to the Department of Water Affairs (2012), 88% of South African freshwater resources have unacceptable levels of orthophosphate concentrations, mainly due to poorly functioning WWTWs. The discharge of poor-quality wastewater into the aquatic environment poses numerous risks to public and environmental health. The question is: how urgent is the situation? Impacts that are currently experienced and reported are mostly ecological degradation and sometimes polluted water affects the recreational industry. Recorded cases of human health impacts and acute toxicity is scarce. However, the chronic impact of long-term exposure to polluted water is a concern. Nutrients and organic chemicals accumulate in water bodies and are not removed; therefore, the problem will escalate over time. It would be wise to manage this situation proactively.

2.3 Sustainable Food Production

2.3.1 Defining sustainable food production

The concept of sustainable food production has originated from different schools of thought for various reasons. The diverse ways of approaching, thinking about and understanding sustainable food production, therefore make it difficult to define and use the concept in a consistent way. Several studies have been undertaken to review the various approaches and to find a useful definition. Hansen (1996) classified different definitions of sustainable food production as:

- **Sustainability as an ideology**: Emphasis is on the values and philosophies of sustainability;
- **Sustainability as a set of strategies:** Emphasis is placed on sustainable technologies and practices, such as sustainable sources of nutrients and pest control;
- **Sustainability as the ability to fulfil a set of goals:** Emphasis is placed on the outcomes of sustainable agriculture, such as improved quality of the environment and human life; and
- **Sustainability as the ability to continue.**

Brklacich et al. (1991) identified three perspectives and six approaches to define sustainability. Two of these approaches originate from an ecological perspective, two originate from an economic perspective and two originate from a social justice perspective:

- Ecological perspective:
    - **Environmental accounting**, which identifies agricultural production limits by quantifying the impacts of chemicals such as fertilizers and pesticides and distributions of ecological degradation, such as soil erosion, climate change, etc. (Brklacich et al., 1991); and
    - **Carrying capacity**, which describes the number of animals that can be sustained by the natural ecosystems.
- Economic perspective:
    - **Sustained yields** to understand and address decreases in yields due to environmental degradation. It is a common phenomenon that yields tend to decrease after several years of farming a certain field (Stirzaker, 2010); and

  - **Production unit viability** focusses on the ability of farmers to withstand and adapt to stress. Currently, this is a particularly relevant issue for South African farmers who are confronted with various problems, including an ongoing drought, impacts of Covid-19 pandemic and a lack of government support (Van der Walt, 2020).
- Social justice:
  - **Production supply and security**: according to the Food and Agriculture Organisation (2006) a person is food secure if food is consistently available, if he/she has access to the food and if the food is utilized in a way that promotes general well-being; and
  - **Equity:** includes both intergenerational (equal distribution of food over generations) and intragenerational (equal distribution of food over the world) equity (Brklacich et al., 1991).

Being an extremely complex subject, it is not possible to say that any of the above is incorrect. In a remarkable way, natural ecosystems are able to achieve all of the above, as long as all species within it remain within their natural limits. As humans we are not able to reduce the number of people in order to bring them within the carrying capacity of the earth. Therefore, it is not always possible to achieve sustainability in all of the above. However, the ecological concept of recycling remains an extremely important principle to achieve sustainability that will be required irrespective of any other modifications that can and should be made in future food production systems.

As Uphoff (2014) explores, the boundaries of what would be considered sustainable in the future are inherently impossible to define at present, due to the variability of future conditions. Thus, it is impossible to define with absolute certainty the sustainability of any practice extending beyond the immediate short-term. Instead Uphoff (2014) proposes that it is more appropriate to judge an agricultural practice on the probability of it being unsustainable in the long-term, than it is to judge an agricultural practice on what is currently perceived as sustainable. Gleeson et al. (2012) proposed the use of multi-generational sustainability targets with continuous monitoring and adaptation strategies.

Quantifying the sustainability of a system requires the clarification of (1) what is being sustained, (2) over what time period and area it is being sustained, (3) at whose benefit and cost it is being sustained, and (4) by which criteria will sustainability be measured (Pretty, 1997). In the context of this study sustainability can be defined as (1) catchment-level irrigation-water resources being sustained, (2) over the predicted lifespan of the individual Agri-park and beyond, (3) for the benefit of the farmers within the greater catchment area and (4) measured by the increase in agricultural production of the catchment region relative to the ecological upper limit of water extraction.

2.3.2 Comparing approaches to sustainable food production

Food security has become a well-debated topic in the past few decades, and different approaches ranging from organic and industrial agriculture to small- and large-scale production and sustainable intensification have been considered. Different approaches are explored in the light of future food security and ecological sustainability.

2.3.2.1 *Organic versus industrial agriculture*

Industrial agriculture is mainly criticized for its dependence on fossil fuels, low crop diversity, impacts on ecosystems and high requirements for external inputs such as fertilizers and pesticides (Altieri, 2008). Unsustainable agricultural practices have resulted in a decrease in ecological integrity, with the loss of ecosystem services, such as pollination and beneficial insect predation (Kumaraswamy and Kunte, 2013).

In reaction to these problems organic farming proposes a set of strategies to minimize these impacts. In terms of crop nutrients, organic farming prescribes the use of natural sources, such as manure and crop rotation with legumes that are able to fix atmospheric nitrogen. The primary focus of organic farming is to maintain a healthy soil, assuming that it will necessarily produce healthy crops. Reganold et al. (1987) reported that soils under organic agriculture had more organic matter, deeper topsoil and less soil erosion.

However, organic farming has also received much criticism. Studies have shown that yields on organic farms are up to 45% lower than conventional farms, lower yields are a result of poor nutrient uptake and periods of no production on fallow lands (Kirchmann and Ryan, 2004). Connor (2013) argues that upscaling organic farming is a key issue that hampers its potential to feed the growing world population. Commercial farmers in general, with a few exceptions, say that organic farming is not possible on a larger scale. Stirzaker (2010) said that, although he practiced organic agriculture on a small-scale, he was not able to apply those principles on a large commercial scale. According to Kirchmann and Ryan (2004) nitrate leaching under organic agriculture can exceed that of conventional agriculture, because of less efficient absorption of the nutrients by the crops. And organic agriculture often depends on manure from commercial farmers for their nutrient requirements (Nowak et al., 2013). Kirchmann and Ryan (2004) criticises organic farming for excluding wastewater as a source of nutrients, which will become an important source in the future as new technologies are developed. Although the philosophy behind organic agriculture is sound, the rules that are formulated from it can become an aim in itself, sometimes missing the original goals (Kirchmann and Ryan, 2004). Rotating crops with legumes that are able to fix nitrogen more naturally may prevent the carbon emissions of the production of chemical fertilizers, but similar to chemical fertilizers it still represents an additional input of nitrates into ecosystems.

2.3.2.2 *Small-scale / subsistence versus large scale*

With the rise of commercial agriculture, the number of small-scale farms (SSFs) has declined globally. In 1935 the number of farms in the United States was 6.8 million, but this reduced to 1.9 million in 1997 (Stam and Dixon, 2004). Annually the number of farms in Europe is falling by 3% and this trend is also observed in developing countries like South Africa (Boyce, 2006). Small scale farmers need support in order to compete with commercial industrial farms in terms of production quantity and quality as well as prices. There are widely diverging opinions about what kind of farming system is most suitable to achieve the required increase in current food production by about 60% to 70% in 2050. According to Phalan et al. (2011) empirical data is lacking to fully understand whether, in terms of ecological conservation, it is better to separate agricultural land, in the form of intensive commercial farms, from protected ecosystems, or to integrate farm land with ecosystems, as found in SSFs. Intensification, which aims to maximise production per surface area, is often considered to be the only viable option, considering the constraints in making more agricultural land available and the competition for land with the expansion of urban areas and other land uses (Silva, 2018). Others claim that SSFs incorporating more diverse habitats and supporting more biodiversity are more sustainable (Altieri, 2008).

Small-scale farms usually support a higher diversity of crops and crop varieties. The term agro-ecology refers to application of ecological principles in food production and is mostly associated with SSFs. At a smaller scale, it is more feasible to use organic sources of nutrients, such as compost or manure. According to Food and Agriculture Organisation (2012), 80% of the farmland in sub-Saharan Africa and Asia is managed by SSFs working on up to 10 ha, and 80% of the food is supplied by them. They play an important role in maintaining biodiversity by keeping many rustic and climate-resilient varieties and breeds alive. It may also be that, compared to commercial farmers, SSFs will be in a better position to implement farming methods that reduce carbon emissions and adapt to climate change (Bezner-Kerr et al., 2012). This is an important contribution, although these nations still need support to supply sufficient food for themselves. Small-scale farms are criticized for their lower yields, thus increased surface area requirements, but by applying sustainable intensification principles, it has been shown that small-scale farmers can become very productive (Food and Agriculture Organisation, 2012). Pretty (2008) remains optimistic that sustainable intensification is possible, proposing that more can be taken out of a certain land by farming according to ecological principles. Sustainable intensification is further discussed under **Section 2.3.2.3**.

The Agri-park model is unique in the sense that it aims to support emerging farmers to maximise production and collectively the farmers in the Agri-park forms a large-scale operation. With good management, such a model can potentially have the benefits of small-scale and large-scale agriculture.

2.3.2.3 *Sustainable intensification*

Sustainable Intensification (SI) as a school of thought emerged in the mid-1990s, during a time when the future of agricultural development in the 21st century was placed at the centre of the political agenda. Pretty (1997) first used the term to describe regenerative, low-input agricultural practices which increased productivity of SSFs in unimproved, or degraded regions, while simultaneously conserving or regenerating natural resources and ecosystem services. Since then, the term has been used to describe various industrial agriculture practices which, although starkly contrasting to Pretty's (1997) envisioned usage in small-scale agriculture, also seek to increase productivity while decreasing environmental footprints. However, there is widespread criticism over the term's lack of specificity, and fears of its potential for being used to "greenwash" conventional, and potentially unsustainable, agricultural practices (Pretty and Bharucha, 2014).

The definition of sustainability is already discussed under **Section 2.3.1**. We now focus on the definition of intensification. Similar to the concept of sustainability, defining a system as intensive requires the consideration of a frame of reference, and characterising any agricultural system as "intensive" offers as much commentary on the reference system as it does on the system under investigation (Uphoff, 2014). Intensification has traditionally been defined in three ways: (1) by increasing yields per area of land, (2) increasing cropping or livestock intensity per unit of land or other physical input, and (3) adapting the system from low to high value commodities (Pretty and Bharucha, 2014). In a broader sense intensification can also be defined as making greater use of various external and internal inputs, such as fertilizers and manures, virtual energy and fossil fuels, labour, and germplasm (Struik et al., 2014). However, limiting the definition of intensity to include only physical inputs has been criticised as inaccurate, and going against the original tenants of SI. When initially defining SI, Pretty (1997) concluded that "productivity in agricultural and pastoral lands is as much a function of human capacity and ingenuity as it is the result of biological and physical processes", and so the intensification of intangible inputs such as knowledge must also be considered (Uphoff, 2014). This more holistic stance on intensification is required to address problems such as poor knowledge transfer and skills development. If successful SI of the Agri-parks is to be achieved, support structures such as agricultural extension services which aim to equip farmers with the necessary skills and knowledge must be incorporated.

Defining "SI" from an agricultural perspective thus appears to bring together two seemingly contrasting, and highly subjective concepts. Although one can define SI in a number of ways, there is growing consensus that the emphasis should be placed not on the semantics of the term, but rather on the premises of the term (Vanlauwe et al., 2014). These premises are defined as (1) increased production being a necessity, (2) increased production must be achieved through higher yields, as opening up new land for agriculture carries an environmental cost that renders any production system unsustainable, (3) food security requiring both increased productivity and increased sustainability, and (4) SI not specifying through which methods it is to be achieved (Garnett et al., 2013). Pretty et al.

(2011) proposed that a sustainable agricultural system that conforms to the above premises would exhibit most, if not all, of the following general traits:

1. The use of crop cultivars and livestock breeds which are the most productive, relative to the external and internal inputs;
2. The reduction, if not total elimination, of unnecessary external inputs;
3. An increased use of ecosystem services and processes;
4. The reduction in the use of practices and/or technologies with known or potential adverse effects on human and ecosystem health;
5. A more productive use of human capital; and
6. The quantification and minimisation of system impacts on the surrounding ecosystems, and biosphere at large.

Sustainable Intensification practices which exhibit these traits are numerous and highly varied. These include integrated soil fertility management, integrated crop and livestock systems utilising dual-purpose crops, fertilizer micro-dosing; seed technologies such as seed priming, diverse range of crops and crop combinations for rotation and intercropping, genotype improvements; small-scale irrigation and mechanisation, soil water management such as tiered ridges, terracing, and swales; conservation agriculture practices such a zero-tillage; agroforestry; and patch intensification (Claessens et al., 2014). Thus, SI agriculture is diverse enough to be applied in every aspect of production in the Agri-park context.

2.4 Available Tools and Technologies to Improve Water Management in Small-Scale Farms

2.4.1 Catchment-scale management tools

2.4.1.1 *Developing irrigation water sources from sewage effluent*

Despite the massive challenges to keep up with the increasing waste flows and the threats to the environment, sewage effluent is also a rich source of water and nutrients, and could potentially become an important resource to farmers. If these nutrients are recycled it will reduce environmental impacts at both the supply end (climate change impact and depletion of resources) and of the final wastage (sewage pollution) generated through the fertilizer life cycle. Therefore, using treated effluent from dysfunctional WWTWs for irrigation potentially has the following benefits:

- Assisting farmers to maximise production in areas with limited water availability or during dry seasons;
- Creating job opportunities;
- Reducing the amounts of expensive fertilizers required and subsequently the impacts on climate change; and
- Improving the water quality of the region.

Irrigation with sewage effluent is a common practice throughout the world and a number of studies have been conducted to determine the safety of irrigating with sewage effluent. The impact of irrigating with treated sewage effluent on soil properties, crop yields, nutrient uptake and leaching was found to be insignificant (Musazura et al., 2015). Risks of using sewage effluent for irrigation was low in terms of certain human pathogens, especially if the water is disinfected (Chale-Matsau, 2005) or if the crop is cooked before consumption (Al-Lahham et al., 2003). Heavy metal accumulation has been studied and may pose some risks that require monitoring and management

(Ogbazghi et al., 2015). However, much research is still needed to address all potential risks, including the transmission of some viruses and organic pollutants.

Re-using nutrients in sewage effluent presents an opportunity for both small- and large-scale agriculture to become more sustainable. The generally high level of management capabilities and education found in industrial farming makes this practice even more suitable for large-scale agriculture, because better risk management can be expected. However, considering how poorly sewage is managed in rural areas, such a practice could present an important opportunity to the rural poor. If rural areas are less exposed to environmental pollution and products containing organic pollutants, there may be fewer human health risks to manage.

Re-using sewage effluent could become a very important strategy to achieve sustainable food production. The concept of lifecycles or circular economies, as opposed to linear supply chains, is an ecological principle, which should naturally result in a more sustainable system (**Figure 2-2**). From a social perspective, the practice could address sustainable food production in terms of food security and equity, because sewage waste is freely available to all people. From an economic perspective, the practice could help to achieve production unit viability, because the consistent supply of sewage can make production units more resilient to stresses.

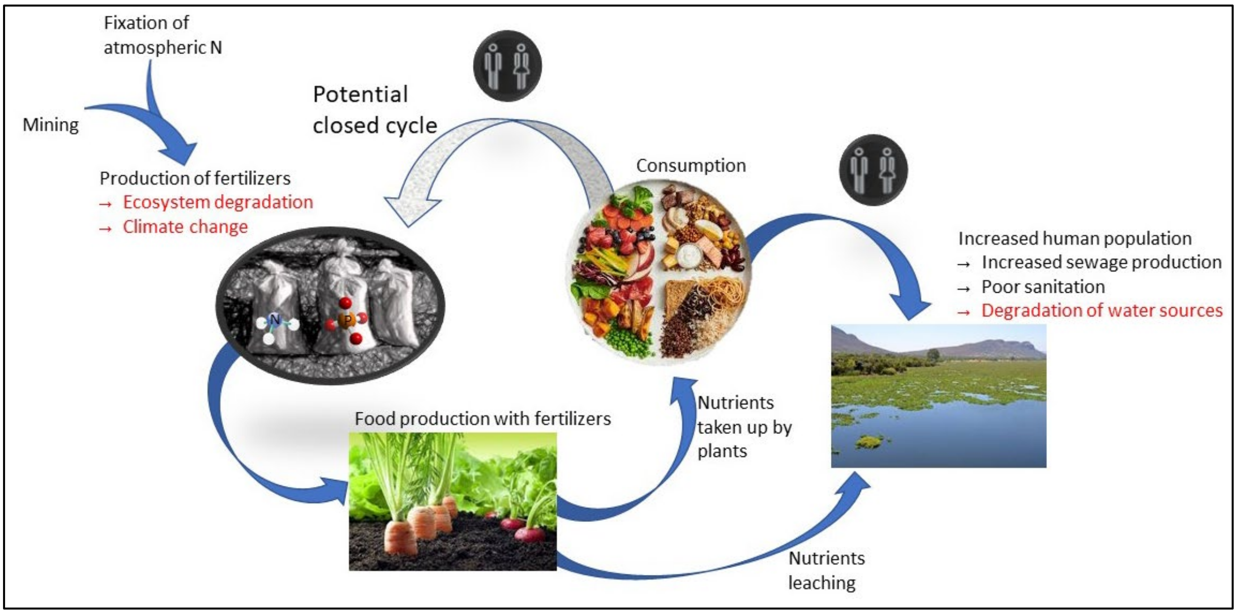


Figure 2-2: A schematic illustration of the potential to create a circular economy of nutrients (where waste products become a resource) versus a linear supply chain of nutrients (including production, use and wastage)

2.4.1.2 *Water quality decision support system (DSS)*

The Irrigation Water Quality Decision Support System (DSS), based on the South African Water Quality Guidelines (SAWQG) is multi-tiered open-access software that allows the user to assess either the fitness-for-use of, or the water quality requirement for irrigation water. The software performs analyses based on the following suitability indicators:

- **Soil Quality**: Root zone salinity, soil permeability, oxidisable carbon loading, trace element accumulation
- **Crop Yield and Quality:** Root zone effects, leaf scorching when wetted, contribution to N, P and K removal, microbial contamination, qualitative crop damage by atrazine
- **Irrigation Equipment**: Corrosion or scaling of irrigation equipment, clogging of drippers

Tier 1 resembles the generic guidelines of Volume 4 of the 1996 SAWQG, relying on the minimum user defined input and providing a conservative water quality assessment (Du Plessis et al., 2017). Although the reports produced by this tier are based on conservative estimates, they are sufficient for identifying problems in advance. Tier 2, however, allows for site-specific analyses through crop-growth, soil water balance, and chemistry modelling, simulating response of soils, crops and irrigation equipment to irrigation water composition under different climatic and water management conditions (Du Plessis et al., 2017). These analyses are therefore a better reflection of what can be expected to be encountered under the real-world conditions of the site. Further details of the DSS can be found in Du Plessis et al. (2017), however both tiers of the DSS would be beneficial to the Agri-parks. The software is user-friendly, requiring only a basic understanding of water-quality analyses in order to input data to generate reports. In both tiers the DSS provides reports with a 4-colour fitness-for-use ranking, simplifying interpretation for all users. This software should be incorporated into the Agri-parks model and used by Agri-parks managers and extension officers in order to make evidence-based decisions regarding irrigational water quality. The DSS installation files can be downloaded from https://www.wateradmin.co.za/sawqi.html.

2.4.1.3 *General water resource management plan*

Managing water is not a simple process, and will need regular inputs from different qualified water specialists. However, a generic water management plan is outlined below to provide guidance to an Agri-park manager. The plan contains a list of all the essential activities that have to be done, and the people that has to be involved during the various stages. As shown in **Figure 2-3** and **Table 2-1** any management plan should start with a goal in mind. It is not always possible to achieve social upliftment, ecological conservation and maximum economic growth at the same time, however, the quality of life of people and the health of the ecosystems are important for a sustainable future and should therefore receive the necessary attention. Different management responsibilities are applicable to the catchment and local scales, but communication and cooperation between different role-players are key to the success of water management.

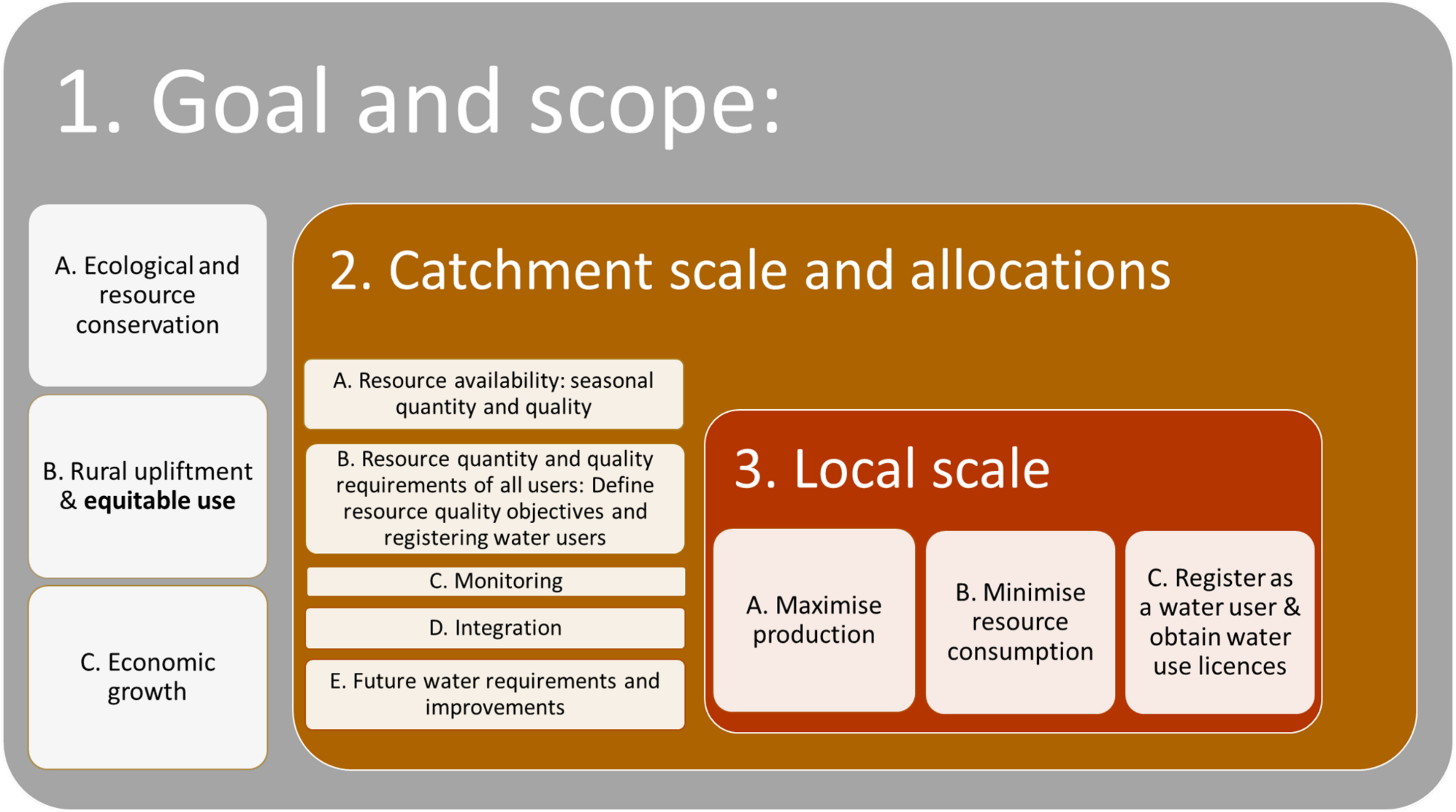


Figure 2-3: Outline of the water management plan

Table 2-1: Summary of the water management plan and tools

<table>
<tr><th>Description</th><th>Available tools</th></tr>
<tr><td colspan="2">1 Goal and scope</td></tr>
<tr><td colspan="2">Integrated Water Resource Management (IWRM) starts by defining the goal and scope of the water management plan. The overriding principle is to allocate water based on equitable use, and to minimise contamination of the resource. While the goal and scope of one area could be to protect important and sensitive ecosystems (1A)*, another area could seek to uplift rural poor (1B)* or stimulate economic growth (1C)*. Specialist inputs and engagement with all role-players, including government departments, water users and residents, are required to make an informed decision</td></tr>
<tr><td colspan="2">2. Catchment management and water allocation</td></tr>
<tr><td>Water management on a catchment scale must allocate available resources to all water users, redress past inequalities while conserving the aquatic ecosystems and ecosystem services.

2A*: Water resource assessment: One of the key inputs to the process is the amount of water available in the catchment. Additionally, the seasonal nature of the water needs to be defined. Available water resources can include surface water, groundwater, return flows, wastewater, etc. Water quality must be assessed and managed so that it will be suitable for the specified uses in the catchment and to prevent ecosystem harm

2B*: Water use requirements: The water quality and quantity requirements of various water users in the catchment must be managed so that all requirements are met. Receiving water quality objectives must be defined for the river based on the broad scope of users including the aquatic environment. An aquatic ecosystem reserve must be determined and implemented, to ensure sufficient volumes of water to remain in the resource for conservation of the ecosystem. There must also be a mechanism to register all users of water.

2C*: Monitoring plan: Water resources cannot be managed without a proper monitoring plan to be followed. This monitoring plan must determine the quality and quantity of available water as well as the water quality and quantity required by the users. Specialist inputs are required to compile a site-specific monitoring plan that will allow all relevant data for a specific catchment be recorded at optimal frequencies.</td><td>• Catchment water footprint framework to assist catchment managers to develop new water resources for irrigation from wastewater
• Water quality DSS can be used by extension officers to advise farmers on water quality management.
• Water use licencing</td></tr>
</table>

Description	Available tools
2D*: Integration of activities and role-players: Integration of all role players and governing bodies is important at this stage and could potentially be a complex part of the water management plan. **2E*: Future planning:** Finally, future planning objectives are necessary for determining how the water will be used in the future in a more efficient way and what measures can be put into place to improve the quality of the water.	
3. Local / farm scale	
In the past DWS used to build dams to supply water. But, with the increasing demands and limited options to develop water resource a different strategy is now being followed. The water user is now responsible to use the available resources better and to pay for the water. So, the onus is on the user to find the best solution between production and water use. **3A*: Maximum production:** Resource use efficiency and maximum production is extremely important in South Africa, because of the increasing demands for food production and widespread poverty. **3B*: Minimise resource consumption:** In a dry country like South Africa, it is very important to minimise water use and increase water use efficiency to ensure maximum production with the limited resources available. The ecological reserve is now the minimum user. Agricultural development may require additional water to be found, while it already utilises large volumes of the available water. This either means importing water from elsewhere or using the water more smartly. **3C*: Registration and water use licences:** While the DWS has a general authorisation process for certain volumes of abstraction either from boreholes or the river, many users are not registering. This makes planning difficult because many small-scale unknown abstractions could result in a big drawdown which is allocated to unknown losses. By recording and disclosing their water requirements the catchment managers can better plan for adequate water supply.	• Soil moisture sensors can be used by **farmers** for irrigation scheduling • Social media can connect **farmers** to each other and to **extension services** • Mulching can be applied by **farmers** to reduce evaporation and weeds. • Decision support tool for using chicken manure can be used by **farmers** and **extension officers** to determine the amount of manure that has to be applied to their fields.

*** Refer to Figure 2-3**

2.4.2 Farmer scale tools to manage water use and crop production

2.4.2.1 *Using chicken manure to replace chemical fertilisers*

Soil salinity, heavy metal accumulation, eutrophication and accumulation of nitrates are among the long-term adverse effects of excess or mismanaged fertilisation (Kulkarni and Goswami, 2019; Savci, 2012). Several authors suggest that to improve the sustainability in farming systems there should be a decrease in the use of synthetic fertiliser (Geng et al., 2019; Muktamar et al., 2017). Animal manure can be a useful source of nutrients and provides an overall more sustainable way to fertilise the soil. There is, however, inadequate literature on manure application and technologies to support it on farmland. Available literature on manure utilization in South Africa and around the globe is discussed here.

Micro- and macronutrients

Nutrients are categorized into three categories namely: macronutrients, secondary/essential nutrients and micronutrients. Categorization is determined by the amount required by plants to develop. Macronutrients are required in large amounts for plant growth and includes N, P and K. Nitrogen is involved in plant proteins and chlorophyll synthesis in the plant, therefore, contributes to photosynthesis, pigmentation and leaf development. Phosphorus is responsible for metabolic transfer processes, photosynthesis, respiration and is a component of phospholids, these influence root growth and flower development. Potassium is involved in sugar and starch formation and helps the plants function properly. Essential nutrients such as calcium (Ca) and magnesium (Mg) support growth and the uptake of other nutrients by plants and are just as important as P. Micronutrients such as Na and manganese (Mn) are needed in minute amounts (Power and Prasad, 1997). Soil acidity affects crop growth by influencing root systems and therefore the whole crop growth and development. High acidity has to be corrected with an application of lime / calcitic lime and calcium sulphate dehydrate for basic soils (Miles, 2013; Power and Prasad, 1997).

Manure management practices among Sub-Saharan Farmers

Manure management aims to stop surface and ground water pollution as well as using manure nutrients efficiently for increasing soil fertility. Further, proper manure management protects the health and safety of the public. It includes practices for storage, handling, management and utilization of manure (Bradley, 2008). Nicholson et al. (2013) suggested that land is the best outlet for manure and other organic material to effectively reduce farm waste. Lory (2008) claimed that it is accepted as a disposal mechanism from a livestock farm. Ndambi et al. (2019) affirms that co-benefits include reduction in leaching of nitrates and phosphates as well as reduced levels of ammonia, nitrous oxide and methane emissions.

Proper management practices for storage include reducing the probability of runoff and percolation into the soil before application. Manure storage units should be at a level and impermeable area so nutrients do not accidently seep into the ground (Bradley, 2008; Spiehs and Goyal, 2007). Bradley (2008) suggested that manure not be placed near water sources, to prevent water pollution, or near building as it can damage walls. Composting reduces most pathogens and reduces the chances of plant burn (Spiehs and Goyal, 2007). Storage units should be roofed and treated so as to maintain their nutrient composition, modifying manure characteristics through composting and drying so it enhances manure spreading ability (Moore et al., 1995). Composting takes place when organic material reacts with oxygen to create a more biologically stable and odour free substrate (Moore et al., 1995).

Ndambi et al. (2019) found that there was no specification for manure management in agricultural policies in the countries of sub-Saharan Africa. The lack of recognition of importance of manure management is evident in the poor adoption of recommended manure management practices. For instance undesirable practices such as roofing in animal houses, manure covering during storage and water proof floors are found, which leads to nutrient losses, increases greenhouse gases and results in the decline in manure quality (Bradley, 2008; Ndambi et al., 2019).

Poultry manure benefits for soil properties

Chicken manure is known for its high nutrient content compared to all other animal wastes (Kidinda et al., 2015). Poultry manure is the organic fertiliser that is most beneficial for crop growth, but is not being used to its full potential (Ritz and Merka, 2009). This is possibly because of a failure to realize its agronomic and economic value. Also contributing to its inadequate use, is a lack of knowledge on how to use it (Ritz and Merka, 2009). Mkhabela (2002) documented the determining factors of poultry and cattle manure use among SSFs. South African farmers felt that manure application demanded labour and transport, had low nutrient content, and required technical knowledge. Further they felt manure use encourages weed overgrowth, has a bad odour and had a time lag between application and yield increase. Farmers felt particularly negative about chicken manure because they believed it would 'burn' their crops. Another factor that caused a limited use of chicken manure was that use of chicken manure was not a customary practice as most chickens were free range. Farmers were more familiar with cattle manure as it is often more available in the surrounding area (Mkhabela, 2002).

A high N content is one of the attributes that distinguishes chicken manure from other animal waste (Kidinda et al., 2015) and more of it is produced per body weight (Bradley, 2008). Nitrogen, as the element essential for the leaf and fruit development, is often a limiting nutrient for crop growth (Blumenthal et al., 2008). Different studies show that concentrations of P, K and organic carbon are significantly higher in chicken manure than in cattle manure, if the chicken received an adequate diet (Afriyie, 2013; Lory, 2008). Its characterisation further includes a good water holding capacity, ability to enhance soil structure and improve soil organic matter and provides benefits for the soil mineral balance (Geng et al., 2019). It provides increased cation-exchange capacity, which implies an improved ability to hold onto essential nutrients and prevent soil acidification (Yunan et al., 2018). Nutrient content in manure varies between different species of poultry, the diet of the poultry, composting/decomposition time and whether there are other materials present in the manure (Ritz and Merka, 2009).

Factors influencing crop nutrient availability

The ways in which manure is stored and applied result in different levels of nutrients available in the soil. Nutrient availability after application to soil is largely affected by time, as a limited proportion of N, P and K is released in the first year. Factors influencing mineralisation rates after application include manure composition, soil type, microbial activity and environmental factors which influence soil temperature and moisture levels (Eghball et al., 2002). Literature concludes that 40-70% of total N is usable within the first few weeks of application. However, Alberta Agriculture and Food (2015) found that 25% of N becomes available in one year after application. Ritz and Merka (2009) state that P becomes available in the soil more slowly while Alberta Agriculture and Food (2015) suggests that 70% is usable in the first year. Potassium is readily available in soil, but there is a higher risk of leaching if not incorporated. Alberta Agriculture and Food (2015) estimated that approximately 90% of P is made available within the first year of application.

Estimating manure application rates

Determination of mineralisation rates should always be taken into consideration when calculating manure application rates (Eghball et al., 2002). Thompson et al. (1997) found that crop nutrient requirement was seldom the basis for manure application rates. Most often farmers applied manure to merely get rid of excess produced. In many cases, farmers have no comprehension of the level of nutritional value the application results in. Estimating the application rate is important so as to reduce the possibility of over-fertilization or under-fertilization. The former can result in leaching, groundwater contamination and affect crop productivity and quality. The latter means that the optimum yield will most likely not be reached. Therefore, precision is important and application rates should be calculated before manure utilization.

Manure application tools documented in literature

There are manure application tools available to improve the precision in manure application. Lengthy and complex calculations are used to calculate manure application rates in conjunction with information such as availability of manure nutrients (Thompson et al., 1997). MANMOD is a manure management tool that estimates nutrient loss in manure through production or storage that influences the nutrient content of the manure. It uses sophisticated programming to allow for representation of the most complex manure management systems. It ultimately shows how certain manure management practices can affect nutrient loss (Shepherd et al., 2002). Thompson et al. (1997) investigated 12 decision support computer programs; which use software namely BASIC, PASCAL, FORTRAN, Microsoft C, Clipper, Prolog, Crystal, AMANURE and Vermont MNM. These decision support tools were released between the years 1993-1995, with nine out of the 12 having American authors or designers.

SMART fertilizer software is a tool to create a fertilizer plan for farmers and large organizations. The software uses algorithms developed by agronomists and encompasses a database consisting more than 215 crops. The software, contrary to the other tools, makes recommendations based on chemical or synthetic fertilizer (Smart fertilizer, 2020).

Olesen et al. (2004) introduces a Denmark-developed software system by the name of BEDRIFTSLOSNING that estimates the crop N demands for farms. Moreover, the system estimates the effect of residuals from manure application, previous crops and other applications of organic matter on soil N availability. The user is meant to supply the software with information of the previous crops planted on the farm and expected yield. Mineralised N and manure-supplied N are subtracted to obtain the recommended application rate for mineral fertiliser.

Some tools are simple worksheets that show user calculations and give instructions on how to arrive at a final calculation. Users need to consult information sources for figures that indicate nutrient availability for year of application and subsequent years, etc. These also require the user to choose on what basis to apply manure and whether it is based on P or N. However, often such information is not readily available to farmers or extension practitioners.

2.4.2.2 *Mulching*

Mulching is the agronomic practice of applying a material onto the soil surface to function as a permanent or semi-permanent protective cover. A wide variety of materials, such as vegetative residues, biological geotextiles, gravel and crushed stone, are used as mulches (Prosdocimi et al., 2016). In their review Prosdocimi et al. (2016) found that mulching has been shown to confer several beneficial effects. These included reduced water and soil loss rates, reduced overland flow generation rates and velocity through increased roughness, reduced sediment and nutrient concentrations in runoff, improved infiltration capacity and increased water intake and storage, enhanced activity of soil fauna such as earthworms, reduced topsoil temperature fluctuations, and positive effects on soil nutrients, soil structure and organic matter content. However, the extent of these impacts is dependent on a number of factors.

- **Improved soil moisture:** In their review Chalker-Scott (2007) found that materials such as plastics, geotextiles, fine-textured organic mulches, sheet mulches, and mulches with waxy components may initially increase soil-water retention through reduced evaporation, but can limit recharge while increasing runoff and erosion thereby creating unnaturally dry soils in the long term. The review also found that organic mulches typically conserve water more effectively than inorganic mulches, that cover crops are generally less effective than either organic or inorganic mulches as they compete for water, and, while organic and inorganic mulches are better soil moisture conservers than synthetic, all mulches are better than bare soil (Chalker-Scott, 2007).

- **Reduced soil erosion and compaction:** Mulches provide soils with protection from various types of erosion, with even comparatively thin layers of organic mulch such has a 1.5 cm layer of straw mulch reducing soil erosion by up to 86% (Borst and Woodburn, 1942). Chalker-Scott (2007) further report that organic mulches disperse the direct impact of water droplets, feet, and tires, restoring soil aggregation and porosity and reducing compaction. However, mulching is a preventative approach and was found to have little impact on reversing compaction when applied retrospectively (Chalker-Scott, 2007).
- **Maintenance of optimal soil temperatures:** Mulches have been found to prevent the extreme fluctuations in temperature that have the potential to kill off fine roots near the soil surface and induce chronic stress in newly-established plantings (Chalker-Scott, 2007). Inorganic mulches were found to have less of a moderating effect than living and organic mulches, with organic mulches found to reduce soil surface temperatures by up to 10^{o}C in tropical climates (Chalker-Scott, 2007; Martin and Poultney, 1992). Coarse mulches where found to have a higher moderating effect than finely textured mulches of the same category as did thicker applications of similar mulches in comparison to thinner applications, however thicker layers of finely textured mulches can inhibit gaseous exchange and reduce infiltration and it was concluded that coarse mulches were superior in this regard (Chalker-Scott, 2007). Synthetic mulches such as fabrics and plastics were found to have poor moderating effects, with black plastics either raising or lowering soil temperatures while clear plastics routinely raised soil temperatures (Chalker-Scott, 2007). Some mulches do exhibit heat-reflecting properties which was shown to increase transpiration in some instances as well as have positive impacts on fruit maturation, while living mulches have the opposite effect by decreasing temperatures through evapotranspiration (Chalker-Scott, 2007). In both instances the trade-offs for increased water demand must be calculated against the other positive effects of the mulches.
- **Soil fertility:** Living and organic mulches were reported to have a wide range of impacts on soil nutrients, due to their individual composition and interactions with microbes and the soil constituents as they decompose. Chalker-Scott (2007) found that green and animal manures supply nutrients at higher rates than mulches such as straw and wood chips, but that these low nutrient mulches can also play an important role in reducing pollutants such as nitrates in some scenarios. Organic mulches were also found to reduce the effect of salt toxicity on plant growth, actively accelerate soil desalinisation, and degrade pesticides and other contaminants through increased biological activity (Chalker-Scott, 2007). Living mulches have also been shown to aid in the binding and removal of heavy metals in and from soils, however some mulches such as mill wastes can also be a source of contamination (Chalker-Scott, 2007).
- **Plant growth and establishment:** Chalker-Scott (2007) report that mulching has been found to enhance seed germination and survival of seedlings and transplants in nursery and field production, silvopasture systems, forest plantations, and restoration sites, but that competitive cover crops can increase mortalities. They further report that organic mulches have consistently found to have the largest positive impact on plant growth, however slow decomposers such as bark can result in nutritional deficiencies for some annual crops. Living mulches may exhibit competitive effects on crops, while organic mulches may be a source of allelopathic compounds, which would have negative effects on crop growth and establishment.

- **Pests and diseases:** As with soil nutrients, Chalker-Scott (2007) found a wide variety of effects on diseases. Increased temperatures under mulches such as plastics can solarise the soil; however, this may also have negative impacts on the crop itself. Chalker-Scott (2007) do report that organic mulches such as straw and wood chips are more effective in suppressing disease than landscape fabric and black polyethylene, and this is likely due to increased biological activity under organic mulches. However, these interactions are highly complex, and heavily dependent on specific properties of individual mulch types as well as indigenous populations of soil microbes. Chalker-Scott (2007) do report that the perception that many organic mulches attract and harbour pests is largely false, however as this remains a possibility it should be monitored. The review found that mulching has a large impact on weed pressure, either through the reduction of light to the soil surface reducing weed seed germination or through competition for light, nutrients, and water, in the case of living mulches. However, this also may have negative impacts on the crop, while the positive impacts of many types of mulches on crop growth will positively affect weed growth. Organic mulches may also present a source of seeds into the weed seedbank, which would negatively affect weed control measures and increase weed pressure in the field.

The positive impacts of mulches, particularly organic materials, make them a sound recommendation for the Agri-parks. However, selection and use will still largely depend on individual farmers due to the financial and management implications.

2.4.2.3 *Small-scale irrigation*

There are several indirect social benefits associated with increased investment in small-scale irrigation (Collier and Dercon, 2014). Firstly, farmers are able to grow more staple and high-value crops, improving both household food sovereignty and income (Takeshima and Yamauchi, 2012). This increased positive productivity could result in economic impacts such as increased labour and land productivity, reduced food prices, and stimulation of the local economy (Burney and Naylor, 2012). Small-scale irrigation technologies that provide a more stable irrigation supply, such as water storage tanks, result in an increased number of farmers being confident enough to invest in productivity-enhancing fertilizers, agricultural management strategies, and agrochemical inputs (Takeshima and Yamauchi, 2012). The cumulative effect of these benefits can lead to communities of SSFs transitioning to a more commercial production model (Takeshima and Yamauchi, 2012). The result is an increase in the number of wage-paying agricultural jobs available, as well as an indirect reduction in poverty by increasing non-agricultural rural and urban employment (Takeshima and Yamauchi, 2012). While the direct economic benefits may arguably be less than those achieved by industrial agriculture, Christiaensen et al. (2011) reports that in low-income and resource rich countries SSF agricultural development has been shown to be up to 3.2 times more effective than other industries at reducing the proportion of the population living on $1 per day (Christiaensen et al., 2011).

However, the success of small-scale irrigation schemes has been mixed and a significant number are reported to have been underutilized or abandoned (van Rooyen et al., 2017). This is largely attributed to the costs associated with water diversion, extraction and storage infrastructure, and the institutional arrangements required for managing water resources and finances, scheduling repairs and maintenance, resolving disputes, and ensuring equitable distribution (van Rooyen et al., 2017). The following sections discuss four important challenges that prevent small-scale irrigation schemes from realising their potential to uplift communties, and how it could be addressed through the Agri-park initiative.

Policy Changes

Small-scale irrigation has remained largely unnoticed by researchers, policy makers, and donors; is rarely included in official statistics and public policies; and as a result, remains largely unregulated and uncoordinated (Giordano and de Fraiture, 2014, Namara et al., 2010). This uncoordinated approach has resulted in increased conflict in regions where water resources are limited and has inadvertently increased the environmental impact of the agricultural sector (Giordano and de Fraiture, 2014). To reduce these impacts, it is necessary for local and national governments to implement policies relating specifically to the water-rights of SSFs and pastoral communities (Giordano and de Fraiture, 2014, Namara et al., 2010). This could reduce the negative impacts associated with the currently uncoordinated system approach prevalent in sub-Saharan Africa. Namara et al. (2010) further adds that it is important to consider water rights holistically, connecting the water access and withdrawal rights, operational rights and decision-making rights of all stakeholders. Equitable distribution of water must be ensured, not only within each Agri-park itself, but also within the catchment that the Agri-park draws its water resources from. Equitable distribution must lie within the ecological limits of the catchment in order to ensure that irrigation remains a sustainable practice and align with the development goals of both the Agri-park and the catchment region.

Importance of Water Use Efficiency Managed on a Catchment Scale

Currently much of the investment by SSFs in sub-Saharan Africa into irrigation equipment has been made by individual farmers, on the advice of local irrigation suppliers (Giordano and de Fraiture, 2014). Without the influence of an irrigation scheme or water user association (WUA), these individual farmers make water-withdrawal decisions automatically with the aim of maximising their own production (Wichelns, 2014). They are thus unlikely to consider either the effects on long-term agricultural production of the region, or the implications of their decisions on the water resource in the catchment or aquifer (Wichelns, 2014). Subsequently any expansion of small-scale irrigation must be coupled with an increase in usage efficiency to ensure long-term sustainability. Although the initial cost of water-saving irrigation technology has been identified as a major limiting factor to its adoption amongst SSF irrigators, a three-year study by Zou et al. (2013) found that significant long-term economic savings were associated with all technologies investigated. Although this study was done in the context of SSFs in China, similar trends are expected in the context of sub-Saharan Africa due to the similarities between these agrarian societies. Thus, it is logically possible that the expansion of small-scale irrigation systems in sub-Saharan Africa can be coupled with an economically justified drive towards the use of water-saving irrigation technology. Increased irrigation efficiency can result in a number of positives for agriculturalists such as increased yields, economically viable conversion to high-value crops, decreases in irrigation costs, and a reduction in environmental impact (Pfeiffer and Lin, 2014).

There is, however, evidence to suggest that an increase in the efficiency of an irrigation scheme may also lead to an increase in water usage. In energy economics this effect is referred to as the Jevon's Paradox or "Rebound Effect", whereby an increase in consumption is experienced as a result of an increase in efficiency (Pfeiffer and Lin, 2014). Although irrigation efficiency increases the "effectiveness" of every unit of water, the installation and running costs of the technology alters the profit margins of the enterprise, leading to increased production (Pfeiffer and Lin, 2014). This has been observed in various scenarios, including vehicle use, heating and cooling, lighting, and irrigation water extraction from the aquifers in the central U.S.A (Hertwich, 2005; Pfeiffer and Lin, 2014). The Rebound Effect can result in usage increases of 5-65%, which may place increased pressure on limited water resources. A rebound effect of over 100% over the 10 year period due to an increase in irrigation efficiency through more efficient centre-pivot nozzles has been reported (Hertwich, 2005; Pfeiffer and Lin, 2014). The increased system efficiency reduced the unit cost of irrigation water for the farmers, resulting in a number of changes in management practices that resulted in increased water usage.

Farmers were less-likely to leave fields fallow or unirrigated, fields that were partially irrigated in the past were irrigated more extensively, and farmers opted for more water-intensive crop combinations such as corn, lucerne, and soybeans (Pfeiffer and Lin, 2014). It must be noted that this drive towards the adoption of a more efficient irrigation system was driven by the farmers' concern for the future of their limited water resources. The conversion to more efficient centre-pivot nozzles was seen as the most viable way to reduce water losses from runoff, evaporation, and drift; with the ultimate goal being to prevent further reductions in well capacity attributed to a falling water table (Pfeiffer and Lin, 2014).

This case study demonstrates the importance of considering the full impact of a conversion to any new system or technology, which should be communicated to managers of the Agri-park initiative. Claims of increased efficiency must be backed by scientific data pertaining to the system and the catchment as a whole.

Access to Technology

One of the largest criticisms for the failure of the Green Revolution to increase agricultural production in sub-Saharan Africa was the unsuitability of many of the imported technologies to fit within the context of the SSF. In the 1980s the promotion of treadle pumps in Bangladesh saw the creation of 75 private-sector manufacturers and several thousand distributors, well drillers, and marketers (Namara et al., 2010). In a span of 15 years, 1.5 million pumps were sold to small-scale farmers, increasing the total irrigated land of Bangladesh by 300 000 ha (Namara et al., 2010). The total investment cost of this project amounted to $49.5 million, was financed entirely by small-scale farmers, and is now generating a net income of $150 million per annum for these small-scale farmers (Namara et al., 2010). In comparison, a traditional dam and canal system of the same magnitude would have cost in excess of $1.5 billion (Namara et al., 2010). This, along with similar projects such as low-cost drip and sprinkler irrigation systems in India and Nepal, indicates the potential effectiveness of locally developed technology in facilitating the expansion of small-scale irrigation systems in developing nations (Namara et al., 2010). When complimented with low-cost water storage facilities, Namara et al. (2010) reports that these systems may be even more effective. This is attributed to the farmers' ability to utilise stored irrigation water and maximise production in relation to market highs, particularly in arid and semi-arid environments. Although the costs of small-scale irrigation technology remain higher in sub-Saharan Africa than in other comparable regions of the developing world, in areas where small-scale farmers are receiving adequate assistance the investment of small-scale irrigation technologies has proved to be profitable (Calzadilla et al., 2013; Giordano and de Fraiture, 2014).

One of the objectives of this study is to assess the suitability of available tools and technologies that can improve agricultural water use efficiency that can be presented to Agri-park farmers. **Section 4** further explores some of the available technologies that can be provided to SSFs, through the support and training unit in Agri-parks.

Access to Finance and Markets

Finance remains a major constraint inhibiting technology investment by SSFs in sub-Saharan Africa, particularly in resource-poor communities. Giordano and de Fraiture (2014)reported that in patriarchal societies such as sub-Saharan Africa it is the more financially stable, male farmers who can afford to invest in small-scale irrigation systems. In these societies women tend to have less access to public support structures, private agricultural equipment, input stores, energy supplies, finance, transport, and markets than men (Giordano and de Fraiture, 2014). Policies and support structures that cater solely for women, such as equipment leasing-with-buying-option arrangements, micro-finance, and equipment vouchers; have been proven to accelerate investments into small-holder irrigation technologies (Van Koppen, 2002). Such investments are not only important from an agricultural perspective but also for stimulating local economy. This has the potential to overcome local market-inefficiencies, another stifling factor negatively impacting on the rate of irrigation investment in sub-Saharan Africa (Giordano and de Fraiture, 2014). Exploring these strategies should be recommended to the larger management plan of the Agri-park initiative.

Improving market-access, which is one of the aims of Agri-parks, is another method for increasing investment into small-holder irrigation, by presenting more economically viable opportunities for small-scale farmers. Aggregation of small-scale farmers into cooperatives allows them to collectively access bulk markets such as supermarket buyers (Namara et al., 2010). This is particularly important for ensuring the economic viability of labour-intensive, high value cash crops where profit margins can be greatly increased through access to larger markets (Namara et al., 2010). Vertical integration remains a key strategy for many sub-Saharan African countries to increase the number of SSFs involved in the production of high-value commodities (Namara et al., 2010).

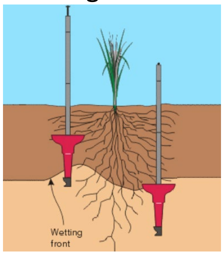
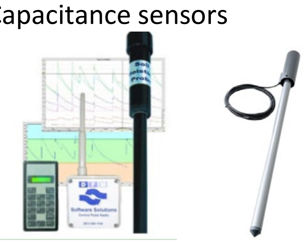
2.4.2.4 *Measuring soil water content to inform irrigation management*

Several tools have already been developed to assist small-scale irrigators to better schedule their irrigation to improve efficiency, such as the Fullstop wetting front detector (WFD) (Stirzaker, 2003) and Chameleon soil water sensor (CS) (Stirzaker et al., 2014). Both tools provide the user with a simple indication of soil moisture conditions within the soil profile, albeit with minor differences. The WFD intercepts and concentrates the wetting front to the point of saturation within a simple funnel, where the water then flows through a filter and collects in the funnel base activating a magnetically latched indicator at the soil surface (Stirzaker et al., 2017). The WFDs are typically buried in sets of two, at the edge and within the root zone, in order to ensure that irrigation was sufficient to create a wetting front that moved through, but did not surpass, the root zone. The water sample captured by the WFD can also be extracted for the monitoring of electrical conductivity, nitrates, and other constituents (Stirzaker et al., 2017).

The CS consists of an array of three or four tensiometric sensors, permanently installed at different depths in the soil, which can be connected to a portable hand-held reader (Stirzaker et al., 2014). The reader displays a series of coloured lights which indicate soil-moisture at each sensor, with blue indicating wet soil conditions (<20 kPa), green indicating moist soil conditions (20-50 kPa), and red indicating dry soil conditions (>50 kPa) (Virtual Irrigation Academy, 2020). Much like the WFDs, the CS arrays indicates soil water conditions throughout the root zone, allowing the user to ensure that irrigation is sufficient to keep the root zone moist without incurring losses through deep percolation.

There are trade-offs between cost, accuracy and ease of use of the various tools. **Table 2-2** below is an assessment of different sensors available and popularly used in South Africa, and has been prepared with the small-scale farmer in mind.

Table 2-2: Different soil moisture sensors available in South Africa to guide irrigation management and the advantages and disadvantages of each

Tool	Type of measurement	Advantages	Disadvantages
Tensiometer  https://www.irrometer.com	Soil suction (water potential)	Easy to install and understand Provides useful information for decision-making. Long lasting. Cost (> R1 000 each).	Requires regular maintenance Limited measurement range
Chameleon  Six pack of single Chameleon Soil Water Sensors  https://www.via.farm	Soil suction (water potential)	Easy to install Cost-effective to install at various depths or when using high number of sensors.	Card reader is expensive (± R990, but can be used on many sensors (R150/sensor). Sensors last a season or two. Limited information through colour coded lights: • Red: dry soil • Green: field capacity • Blue: over irrigation (But simplicity can be an advantage)
Wetting front detector  https://www.via.farm	When wetting front has reached a certain depth in soil profile	Low cost (R550 for a pair) Easy to understand Salt and fertiliser can also be monitored	No indication of soil water content so does not provide information on when to irrigate. Difficult to move.
Capacitance sensors  https://aquacheck.co.za https://www.dfmtechnologies.co.za	Soil water content	Regular measurements at different depths to make decisions and understand trends over the season.	High cost May need PC/smart device to check data Measurements sensitive to good contact between soil and sensor wall.
Automated water potential sensors  https://www.irrometer.com	Soil suction (water potential)	Easy to install Can act like automated network of tensiometers with relatively lower cost if bought in bulk. Robust measurement.	Not suitable is some soils (e.g. high salinity soils) Sensors eventually dissolve.

However, even the cost-effective sensors, such as the WFD, are relatively expensive for SSFs, meaning that farmers most often cannot purchase them themselves. This limits application of these devices on Agri-parks. Investing in more tensiometers for Agri-parks by state departments is recommended. It is further suggested that an extension specialist be trained on the use of soil water measurement devices who can then visit and provide training at all the Agri-parks in Gauteng.

2.4.2.1 *Accessing extension services through social media*

In the digital age social media is becoming an ever-increasingly important component of society, with 40.1% of all South African's predicted to use social media at least once per month by 2023 (Statista, 2020). In the agricultural context early research indicates that small agricultural operations benefit from using social media personally to achieve greater social capital and increase revenue (Abrams and Sackmann, 2014), and that these sites can function as information hubs for consumers (Cui, 2014). Initial investigations by the research group found that a strong online Facebook community of SSFs across SSA has already established itself, primarily for sharing knowledge and stories as well as connecting to markets, although there is little formal research in this regard. Research from Kenya does indicate that social media can play a significant role in building feedback mechanisms by allowing for the monitoring and evaluation of the impact of agricultural projects, and is a cost-effective way for organisations who want to disseminate agricultural information (Kipkurgat et al., 2016). In the context of agricultural extension, research from Nigeria recommends that agricultural extension training should encourage e-learning programmes using various social media platforms (Thomas and Laseinde, 2015).

2.5 Brief Reflections on the Application of Agricultural Technologies in South African Rural Communities

Many research projects have been conducted to determine ways of improving agriculture in rural communities in South Africa with varying successes. Van Averbeke (2008) found that social and institutional arrangements are extremely important in irrigated agriculture in rural areas. Rural farmers interact with each other to manage irrigation water, to maintain irrigation infrastructure, to access and prepare land and they form co-operations to improve their access to markets. At all of these common boundaries where farmers interact (especially when institutional systems have been withdrawn), conflict may arise and this may affect the success of the irrigation scheme. Voluntary co-operation between farmers to maintain irrigation infrastructure was found to be much more successful than a system where labourers were paid to do the maintenance (Van Averbeke, 2008). He also indicated that the western model of a co-operation was not successful in the African small-scale sector. And when government subsidies were withdrawn, people adopted various strategies to continue land preparation, such as offering collective cultivation services, leaving land fallow, share cropping and using animal draught or manual labour (Van Averbeke, 2008). Combining crop and livestock is a potentially beneficial system, because the animal manure can be used as fertilizer and the vegetable waste can be used as animal food. However, according to Van Averbeke (2008), this beneficial system is seldom practised. Van Averbeke (2007) noted that community farms were much less productive (only 7% of the potential) than home gardens, in terms of production per crop area, mostly because of the uncertainty of access to land and water.

Stirzaker et al. (2017) found that the combination of the CS (Stirzaker, 2014) and the WFD (Stirzaker, 2003) was successfully implemented and used by small-scale irrigators. Within a short time, rural farmers were able to learn from these tools and changed their irrigation management accordingly. The tools indicated to the farmers that over-irrigation resulted in leaching of fertilizers and they responded to this information by reducing irrigation inputs. However, farmers discontinued using these tools when the project ended. Stirzaker et al. (2017) hypothesise that by distributing the tools free of charge could partly explain the failure of the farmers to continue using them.

2.6 Discussion

Finding a sustainable way of producing food in the future has become a very complex problem. The concept of sustainable food production has various definitions and approaches. Food production systems have to manage the growing demand for food, which puts increasing pressure on limited resources. All of this must be achieved while minimizing ecological impacts. The concept of carrying capacity is particularly relevant considering the growing human population, as discussed under the next section. Thereafter, two important principles: 1) diversifying responses and 2) establishing circular economies are discussed. Next the potential role of Agri-parks in sustainable food production is considered and finally the gaps in current literature is listed.

2.6.1 Earth's carrying capacity

In terms of the concept of carrying capacity, the question is asked whether the current size of the human population is still within its natural limits. According to ecological principles, population growth can be restricted by a single limiting resource. If this resource limitation is overcome, the population will continue to grow until another resource becomes limited. It is also possible for a population to grow beyond natural limits, if a resource can be provided artificially. But then this larger population cannot be sustained by natural resources, in the absence of the artificial resource. Today, technology has made numerous artificial resources, such as irrigation water and chemical fertilizers, available to agriculture, which has made population growth possible. The question is discussed whether the current food production level that is now supported by chemical fertilizers can still be supported by natural nutrient sources, such as compost, animal manure or rotating crops with legumes, or whether we have crossed the limits of the earth's natural carrying capacity in terms of nutrients. Advocates of organic agriculture seems to consider it a possibility that natural resources can still support the current and future human population, but it is uncertain whether they have considered the issue at a global scale. Critics of organic agriculture believe that the population size is already above the earth's natural carrying capacity. Considering the rapid increase in human population and changes in diet preferences that requires highly productive farms, it seems reasonable to assume that natural sources of nutrients will not be able to support the current and future human population. Clearly, the status quo of producing chemical fertilizers for food production which eventually pollutes natural water resources is not a sustainable practice. That does not mean that sustainable food production is necessarily impossible, a new balance may be achievable if waste products are used as resources. For example, the possibility of using wastewater for irrigation will enable nutrients in the wastewater to be recycled, and can potentially solve many of these problems. If sewage effluent can be developed into a safe water resource for irrigation purposes, it could increase resilience and viability of agricultural production in Agri-parks.

2.6.2 Establishing circular economies of nutrients for crop production

Industrial agriculture, with its efficiency to produce food for many people will be with us in the foreseeable future. Vertical farming may provide a good alternative to increasing production per surface area, but these systems still require fertilizers and water, and will not be able to produce the quantity of cereals that are required. To become more sustainable, industrial agriculture must develop circular economies. In terms of nutrients, chemical fertilizers must be used efficiently and leaching from agricultural fields must be minimised. Ultimately, with better research, nutrients should be extracted from wastewater and reused by industrial farms to minimise the carbon cost and pollution of producing fertilizers and discharging the nutrients into the aquatic environment.

2.6.3 Diversifying food production responses

In **Section 2.3.2** different kinds of food production systems were discussed. Although it is clear that industrial agricultural practices are far from sustainable, finding a better alternative can be rather complex. For example, the general principle of using waste, which is advocated by organic farming, is key to a sustainable future in food production. Livestock manure, which would normally have gone to waste are utilized by organic farmers, thereby reducing the impacts of producing more chemical fertilisers and diverting the waste stream away from aquatic ecosystems towards food production. This way a circular economy is established with a notably positive impact. However, this means that organic farming cannot be viable in the absence of intensive, large-scale livestock farms. Livestock production, especially cattle, has a high carbon and water footprint. To truly achieve a sustainable food production scenario, it is also important that production systems are not dependent on other unsustainable practices.

Different food production systems, including SSFs, agro-ecological farms (including organic agriculture and sustainable intensification) and industrial farms will be appropriate in different situations. Currently, agro-ecological principles are more suitable for SSFs. Such farms must be supported to use these principles and still achieve optimal food production and remain viable production units. Most people in urban areas do not have enough space available to produce all the food they need, and will always be dependent on commercial farms. However, with arable land becoming more limited, even an urban garden presents an opportunity to contribute to food production. Grey water coming from an urban household and the rainfall that falls in the garden are potential water resources that can be used in food production. If urban households can grow a percentage of their food requirements, it will reduce the pressure on commercial farms. According to Kruger (2020), rural households in Makhathini are able to produce all the vegetables and fruits they need in gardens that are less than 200 m^2 in size. Some people are able to generate an income of up to R2000 in homestead gardens, if they farm intensively with high value crops. In order for a household of 5 people to be self-sustained in terms of their grain requirements, a garden of about 2500 m^2 is required (Kruger, 2020). Household-based farming increases resilience of a household. It was observed during the Covid-19 pandemic that rural households in Makhathini that produced food in their gardens were more able to provide food for their families (Kruger, 2020).

Rural-urban migration is a continuing trend, resulting in more people exiting their SSF existence and becoming residents in small urban households. People in urban areas are dependent on large-scale industrial farms that are often far away from the consumers. Globalisation of agriculture has led to a disjunct relationship between consumers and the production of their food, causing numerous problems. Without understanding the impacts of their choices, consumers drive the decisions made by farmers, including unsustainable actions that cause pollution and resource depletion. Communities that are dependent on large-scale agriculture have little understanding or control over the risks they face. When communities produce their own food, agriculture becomes integrated with the community and they are more able to respond to risks and the consequences of their choices. A community can potentially become more independent and resilient if it is able to effectively practice small-scale agriculture. Many of the problems that arise from food production, such as the pollution of water resources or the instability of communities in terms of food security have to be dealt with on a local scale. If systems operate on a global level, but the results and consequences are experienced on a local level, sustainability becomes a difficult target to achieve. In a modified world we need a diversity in agricultural approaches, small- and larger-scale, to address future food security. But all agricultural systems must focus on increasing sustainability as well as productive outputs.

2.6.4 The potential role of Agri-parks in future food production

Emerging farmers in South Africa are in a particularly difficult position. Not only do they often lack access to good quality land, but often they also do not have access to water, knowledge, tools, etc. Advances during the Green Revolution enabled large-scale industrial farmers to produce large quantities of crops at extremely low prices. Small-scale farmers generally operate without technologies and tools are not able to compete with commercial farms in terms of prices, yield and quality. Agri-parks, which aim to uplift these emerging farmers, and provide them with the tools, support, finances and resources that they need, could potentially make a contribution to reduce the growing gap between rich and poor as well as the trend in rural-urban migration. In this way, Agri-parks are also able to revitalise agriculture and contribute to future food security. Furthermore, the integration of management at the farmer and catchment scale is a very important component of the Agri-park model and could potentially make a remarkable contribution to future food production.

Currently the South African Government is negotiating land expropriation, aiming to give land to rural, previously disadvantaged individuals in the country. Previously disadvantaged individuals will need support and education to farm successfully when they receive land, in order for them to farm in an environmentally sustainable way. Successful Agri-parks could become important models for these new farmers and farming communities.

2.7 Conclusion and gaps in the literature

Agri-parks have the potential to uplift previously disadvantaged individuals and address sustainable food production and security. However, some research is required to assist Agri-parks in achieving these goals. The impact and management of water use by proposed Agri-parks has not previously been assessed, and this was part of the aims of this project. Systems and tools that will simplify the decision-making processes of catchment managers in South Africa on water use feasibility, potential production in terms of water availability and land requirements are mostly unavailable or too complex to facilitate quick management decisions. A simplified tool has been developed as part of this research to help address this shortcoming.

One of the largest criticisms for the failure of the Green Revolution to increase agricultural production in Sub-Saharan Africa was the unsuitability of many of the imported technologies to fit within the context of the small-scale farmer. Much research is needed to develop new tools or to select suitable existing tools that better suit previously disadvantaged, emerging farmers. Some of the work done during this project can be considered a step in the direction of better understanding the kind of technologies that Agri-park farmers prefer and require. According to Van Niekerk (2020) technologies and tools are used within daily household / farming practices. Successful transfer to tools depends on the successful establishment of the daily practice within which the tool is used. Such practices are mostly not developed for any of the tools available to improve water management and water use efficiency.

Small-scale farmers can benefit from the integration of chicken and vegetable farms where the nutrients in the chicken manure is used as fertilizer. This practice can reduce input costs, improve soil health and increase productive outcomes. However, a user-friendly, cost effective decision support tool is lacking to guide small-scale farmers on how much manure to apply to their fields. For this reason, a simple decision support tool was developed to assist Agri-park farmers in manure application.

Technologies must be developed to safely utilize sewage water for irrigation, especially in terms of organic pollutants and certain viruses. In this study some work has been done to better understand the perceptions and willingness of Agri-park farmers to irrigate with sewage effluent.

3 ASSESSMENT AND MANAGEMENT OF WATER FOR AGRI-PARKS AT THE CATCHMENT SCALE

3.1 Introduction

This section specifically addresses **Aim 2** of the project to '(1). assess the feasibility of the selected Agri-parks, as currently planned, in terms of quantity and quality of water available in the catchment; (2) to determine the optimum crop yields, crop selection and rotation in terms of water availability in the relevant catchment and acceptable environmental impacts for each study area; and (3) to assess the available tools that can be used by an Agri-park to better manage water in a simplified way' (**Section 1.2**).

Gauteng Department of Agriculture and Rural Development (2017) indicated that several Agri-parks are already in operation, including the Rooiwal and Soshanguve Agri-parks in Tshwane and the Merafong, Bekkersdal (Westonaria), Eikenhof and Sebokeng Agri-parks in the West Rand. However, water feasibility studies have not been conducted yet. This project aimed to assess the impact and management of water used by the Agri-parks. It was also found that the operational Agri-parks do not represent the Agri-park model, as they are small-scale operations between 3 to 6 ha. According to GDARD the 'Agri-parks' mentioned above, which is better described as 'production units', were established by GDARD several years ago, and was not established as part of the Agri-park initiative. Several challenges seem to be responsible for the delay in the development of the Agri-parks as per the model described. On a government level, challenges include the completion of the Agri-park policy and incentive packages to attract investors, lack of funding, regulatory requirements and the mobilisation of farmers (Department of Rural Development and Land Reform, 2019). Various challenges were encountered on a farm level, including a lack of water, poor maintenance of infrastructure, a lack of markets, etc. (Department of Rural Development and Land Reform, 2019).

To assist the Agri-park initiative with water management decisions, the Water and Nutrient Balance (WNB) framework was developed to support Agri-park managers with planning the water resources available to Agri-parks in a relatively simple way. The South African Water Quality Guidelines Decision Support Tool (SAWQG DSS) was used to assess water quality impacts. This chapter also presents the findings of the water feasibility assessment of two selected study areas, the Rooiwal and Westonaria Agri-parks.

3.2 Materials and Methods

3.2.1 Development of a water and nutrient balance framework

The WNB framework is a simple, user-friendly, Excel-based tool that was developed to support Agri-park and catchment managers to plan water resources for Agri-parks, to estimate potential production and land requirements if available water resources and nutrient contents are known. The WNB combines crop water footprints (WFs) with available water to calculate the potential production. The WF of a crop is the volume of irrigation water needed to produce one tonne of produce (Hoekstra et al., 2011). Hoekstra et al. (2011) also distinguish between blue, green and grey water. Blue water is irrigation water from rivers, aquifers and dams (Hoekstra et al., 2011). Green water, which is water in the soil, originating from rainfall is not considered in this assessment, because water supply is mainly blue water. It is assumed that crops will replace natural vegetation that would have used similar volumes of green water, therefore the green WF of Agri-parks will not be an additional use. Grey water is defined as the volume of fresh water needed to dilute emitted pollutants to ambient water quality standards (Hoekstra et al., 2011). However, the grey WF concept is unable to address complexities in water quality management (Le Roux et al., 2016; Wichelns, 2011; Wichelns, 2017). The WNB provides information that assists in managing nutrient use, if the irrigation water contains high concentrations of nutrients. For a more detailed water quality impact and management assessment, the SAWQG DSS was used (**Section 3.2.2.3**).

The WNB framework consists of two sections, the one is for the management of water quantity and integrates water availability with requirements in a water balance. The other section focusses on managing nutrients, i.e. a component of water quality management, by integrating nutrient availability and requirements in a nutrient balance to estimate potential production. The WNB framework requires the following input data:

- Volume of blue water available to the farmers (m^3/month).
- Nutrient concentrations in the irrigation water (kg/m^2).
- Crop data (separately for leafy and root vegetable crops):
    - The size of crop fields (ha)
    - Duration of the growing season (months)
    - Yields (tonnes / ha)
    - Required nutrients (N, P and K) application to crops (kg/ha/growing season)
    - Blue water footprint of the crops (m^3/ha and m^3/tonne)

3.2.1.1 *Formulae used in the Water and Nutrient Balance Framework*

The blue water requirements of a crop are multiplied by the number of hectares under production to determine the total blue water used by the crop during the growing season (**Equation 3-1**). This total volume of blue water used over the growing season is divided by the length of the growing season, to determine average monthly blue water requirements (**Equation 3-2**).

$$Seasonal\ blue\ water\ requirement_{farm}\ (m^3) = Crop\ water\ requirement_{blue}\ (m^3.ha^{-1}) \times Field\ size\ (ha)$$

Equation 3-1

$$Monthly\ blue\ water\ requirement\ (m^3.month^{-1}) = \text{Seasonal blue water requirement}\ (m^3) \div Growing\ season\ (months)$$

Equation 3-2

Total blue water availability is divided by blue water requirements per hectare to calculate size of the agricultural land that can potentially be cultivated with the available blue water resource (**Equation 3-3**). Potential production over the growing season is calculated by dividing the total volume of blue water available with the water footprint (**Equation 3-4**). The WNB framework allows for including different size farms and different kinds of crops, such as leafy and root vegetables.

$$Potential\ size\ of\ agricultural\ fields\ (ha) = Available\ blue\ water(m^3) \div Blue\ water\ requirements(m^3.ha^{-1})$$

Equation 3-3

$$Potential\ production\ ito\ water\ availability\ (tonnes) = Available\ blue\ water(m^3) \div water\ footprint\ (m^3.tonne^{-1})$$

Equation 3-4

The WNB framework also determines the potential production in terms of nutrients, N, P and K available in the water, if this water source has high levels of these nutrients, for example sewage water. Total nutrients available in the effluent discharged monthly from the WWTWs, is calculated by multiplying the concentration of each nutrient with the monthly discharge volume (**Equation 3-5**). The nutrient requirement of a farm, for a particular kind of crop (e.g. leafy or root vegetables), is calculated by standard nutrient application rates with the size of the farm (**Equation 3-6**). The potential size of an Agri-park in terms of the available nutrients is calculated by dividing the monthly availability of each nutrient by the nutrient requirements of the crops per hectare (**Equation 3-7**). The production potential of the Agri-park, in terms of nutrient availability, is calculated by dividing the available nutrients with nutrient application rates per hectare, and then multiply with the relative production potential per hectare (**Equation 3-8**). Water footprint data was obtained from literature sources.

$$Total\ nutrients\ (N, P\ and\ K)\ available\ (kg.month^{-1}) \\ = Nutrient\ (N, P\ and\ K)\ concentration\ (kg.m^{-3}) \times Available\ water (m^{3}.month^{-1})$$

Equation 3-5

$$Nutrient\ (N, P\ and\ K)\ requirements\ (kg.month^{-1}) \\ = Nutrients\ application\ rates\ (kg.ha^{-1}.month^{1}) \times Field\ size\ (ha)$$

Equation 3-6

$$Potential\ size\ of\ crop\ fields\ ito\ nutrient\ availability\ (ha) \\ = Available\ nutrients\ (kg.month^{-1}) \div Nutrient\ requirements (kg.ha^{-1}.month^{-1})$$

Equation 3-7

$$Production\ potential\ ito\ nutrient\ (N, P\ and\ K)\ availability\ (tonnes) \\ = [Total\ nutrients\ (N, P\ and\ K)\ available\ (kg) \\ \div Nutrient\ application\ rates\ (kg.ha^{-1})] \times Production\ (tonnes.ha^{-1})$$

Equation 3-8

3.2.2 Water feasibility assessment

3.2.2.1 *Preparations for research*

The project team conducted initial site visits to the Rooiwal Agri-park in March 2018 and the Westonaria Agri-park in November 2018. During these initial site visits the team met the farmers and familiarised themselves with the operations at the two Agri-parks as well as with the surrounding land uses. Notes were made of the crops that were produced, the sizes of the production units, the general management practices and also the challenges that the farmers are facing. On 30 May 2018 permission was formally obtained from the City of Tshwane (CoT) Municipality to conduct research at any of the Tshwane Agri-parks. The permission letter is included in **Appendix 8**. The CoT provided data for sewage effluent from the WWTWs next to the Rooiwal Agri-park, on condition that the name of the works will not be disclosed. Permission was not required for the work that was done at Westonaria, because no on-site experimentation was conducted there.

3.2.2.2 *Water quantity*

A desktop study was undertaken to determine the background and history of water use and management of the relevant catchments. Flow data for the Apies River and the Wonderfonteinspruit was taken from the Department of Water Affairs website (Department of Water and Sanitation, 2018, Department of Water and Sanitation, 2019). Catchment and aquifer scale water balances including the surface and groundwater availability and current water requirements were taken from Water Resource Reconciliation Strategies (WRRS) published by the Department of Water Affairs (Department of Water Affairs, 2011; Department of Water Affairs and Forestry, 2004; Department of Water Affairs and Forestry, 2006; Department of Water Affairs and Forestry, 2008). For Rooiwal, data was taken from the Crocodile (West) WRRS assuming high population growth and medium water demand management. The water that was used by the Rooiwal Power Station in the past (17 Mm^3/year) was excluded from the estimated volume required by mining and power generation, because the Rooiwal Power Station is not in operation anymore. Much research has been done and is available for the two study areas, however, monitoring in general is currently being neglected. Long-term monitoring must therefore be done to verify the data that is presented here, but such an undertaking falls outside the scope of this study. The total volume of effluent discharged from the WWTWs next to Rooiwal was obtained from the CoT.

3.2.2.3 *Water quality*

Water quality data for the relevant surface water resources was provided by the Department of Water Affairs and Sanitation (2019). Data for the Apies River (relevant to the Rooiwal Agri-park), was sampled between 2011/01/04 and 2018/01/03, at the Rondavel monitoring site (monitoring point ID: 90205 25.460 ° S; 28.264 ° E), which is 10 km north of the Rooiwal Agri-park. Groundwater quality data for the Rooiwal Agri-park was given by the City of Tshwane Metropolitan Municipality which contained an analysis of two samples (GPS coordinates: 25.553°S; 28.233°E) in August 2017 to determine the suitability for irrigation purposes. The average of these two samples were used in the analyses.

Surface water quality data for the Wonderfonteinspruit was sampled approximately 1.4 km southwest of the Westonaria Agri-park. A total number of 1221 samples were analysed between 1980 and 2019. Groundwater data at Westonaria was provided by the Department of Water Affairs and Sanitation (2019). A total number of 384 samples were analysed between 1985 and 1990. The sample site is approximately 2 km south of the Westonaria Agri-park.

Water quality data was assessed in terms of the 1996 South African Water Quality Guidelines (Department of Water Affairs and Forestry, 1996). The updated Decision Support System (DSS) of the South African Water Quality Guidelines (SAWQG) to determine the feasibility of crop production in terms of water quality was also tested as part of the water feasibility assessment of the Rooiwal Agri-park.

3.2.2.1 *Applying the WNB framework to assess water feasibility at Rooiwal and Westonaria*

The WNB framework was used to determine the potential production that can be achieved at Rooiwal and Westonaria, if the water potentially available in the Apies River and the Wonderfonteinspruit, respectively, is made available for irrigation. For Rooiwal, production potential of open land Swiss chard was determined in this example, based on field observations that Rooiwal mainly cultivates Swiss card and other similar leafy vegetables / herbs. For Westonaria, potential production of lettuce produced in the hydroponics system was determined.

The WFs used to determine potential water use on the Rooiwal and Westonaria Agri-parks are summarised in **Table 3-1**. Data on the duration of the growing season, average yields and water footprints (including water requirements per ha), were sourced from Le Roux (2017) for carrots and from Matlala (2018) for Swiss chard, because this data was verified for the Gauteng Province and therefore assumed to be relevant to Rooiwal. Matlala (2018) determined WFs for Swiss chard planted in summer and autumn seasons. For this study, the WFs of Swiss chard planted in the autumn season by Matlala (2018), were assumed to be relevant for the winter season, because these crops matured during the winter season. The WFs determined by Matlala (2018) at 2.5 months after planting in summer and at 5 months after planting in autumn were used for Swiss chard grown in summer and winter, respectively.

According to the Westonaria farmer their vertical hydroponic greenhouse has a total capacity of 16 000 lettuce plants. Lettuce is grown in succession, and according to this farmer 300 kg of lettuce is harvested each week. This farmer also indicated that 5 m^3 of water is added every 5 weeks. This results in a WF of 3.3 m^3/tonne, which is much lower than the blue plus green WF of lettuce grown in open lands, determined to be 56 m^3/tonne an 93 m^3/tonne in summer and winter respectively (Le Roux, 2017). This notable difference in WFs was assumed to be correct, based on data from Van Ginkel et al. (2017) which indicates that the water footprint of lettuce in hydroponics in California is 1.6 m^3/tonne and that on average water use in hydroponics is 66 times less than the water use in conservation agriculture.

The broilers at Rooiwal are given starter and growers feed from Feedmaster, which is produced in Upington, Swaziland and Namibia. The water used to produce feed will constitute the biggest proportion of the overall WF of the broilers, but since these feeds are not produced within the study area or within the Apies River Catchment, it will not impact local water resources and is therefore not included in these calculations. The WF of broiler chickens that is included in **Table 3-1** therefore only represents service water used for drinking and cleaning the poultry houses. These water footprints must be updated regularly and adapted for different areas.

Table 3-1: Water footprints of different agricultural produce

	Summer Water Footprint (m^3/tonne)	Winter Water Footprint (m^3/tonne)	All Year Water Footprint (m^3/tonne)
Vegetable crops			
Carrots	36	88	
Swiss chard	23	93	
Lettuce (open fields)	31	93	
Lettuce (hydroponics)			3.3
Animals			
Broilers (excluding feed)			8

3.2.3 Sewage effluent for irrigation

The WNB framework was also used to determine potential production of Swiss chard at Rooiwal, in terms of both nutrient and water availability if the available nutrient-rich water from the WWTWs is used for irrigation. In February 2020, the project team started to work alongside farmers on a small plot at the Rooiwal Agri-park to conduct a feasibility study on the use of effluent water from the WWTWs for irrigation. The objectives of this process were to:

- To initiate a co-design process, with the farmers, for irrigation with sewage effluent system;
- To test Agri-park farmers' ability to implement this practice independently;
- Determine the attitudes of different role-players towards the idea of irrigating with sewage effluent: This was done by interviewing the farmers and explaining to them the possibility of irrigating with effluent. During the interviews the farmers' reactions were noted as well as possible challenges that they foresee regarding the use of irrigating with effluent. Discussions were also held with the City of Tshwane (CoT) and the manager of the WWTW to determine if any cooperation with them will be possible; and

- To get some data on the quality of the crops irrigated with sewage effluent compared to other crops that were irrigated with groundwater.

To prepare for the co-development process, the following activities were undertaken:

- Interaction with CoT:
  - To inform them about the research, as permitted in the contract (Appendix A); and
  - To discuss the possibility of irrigation with effluent water.
- Interactions with Agri-park farmers:
  - On-site meetings with the farmers from Rooiwal;
  - Training of the farmers from Rooiwal;
  - Implementation of irrigation system and planting in cooperation with the farmers;
  - On-going liaison, monitoring and guiding of the two participating farmers at Rooiwal; and
  - Interviews, both informally and during a Focus Group Meeting to discuss their perceptions and ideas.
- Interactions with the manager of the WWTW to discuss their challenges and possible cooperation.

During an initial meeting at the Rooiwal Agri-park with the participating farmers, Takalani and Tshifiwa Mutavhasindi, and the manager from the WWTW (Mr Raymond Phaswana), the activity was discussed and planned. The project team had the responsibility of coordinating and managing the feasibility study and purchasing what was required. Mr Phaswana from the WWTW agreed to assist with providing and transporting effluent water to the farm. The farmers were to assist in cultivating the crops according to their farming practices. Material available on the farm was used as far as possible and the farmers implemented most of the technical logistics of the irrigation system. This approach was followed to ensure that the Agri-park farmers are able to establish these practices independently (**Figure 3-1**).

Sapphire cabbage seedlings were transplanted on 3 February 2020 with an in-row spacing of 40 cm. Four dripper lines, each 5 metres in length were available, of which three was connected to a tank containing sewage effluent and one was connected to a water tank containing groundwater. The sewage effluent was disinfected by adding 5 ml of HTH premixed with 5 L of water to 500 L of effluent. The effluent was transported from the WWTWs using a 500 L water tank. The effluent was then pumped into a 5 m^3 water tank, which was connected to the three dripper lines. Weeds were removed by hand throughout the duration of the growing season.

Figure 3-1: Planting sapphire cabbage and installing the drip irrigation lines on 3 February 2020. The three dripper lines to the left was irrigated with effluent water and the dripper line to the right was irrigated with groundwater

The seedlings were irrigated using a high-density drip irrigation system. Along the dripper lines, Decagon 10HS soil moisture sensors were installed at 0.25 m and 0.5 m depth, linked to a Decagon EM50 logger (based in Pullman, Washington, USA). Soil water content was automatically recorded by the Decagon 10HS soil moisture sensors on a daily basis. The field was cultivated in exactly the way the Agri-park farmers would normally do it. Decisions on fertilisation application were at the discretion of the farmers, however, none were applied or required because of high levels of nutrients in the soil (refer to **Section 4.3.3**) as well as in the effluent and the groundwater.

Weather data measured at Arcadia, Pretoria North (25.739°S; 28.207°E) for the duration of the feasibility study was obtained from the Agricultural Research Council – Soil Climate and Water (ARC-SCW). The data included daily measurements of temperature, rainfall, humidity, solar radiation, windspeed, evapotranspiration, heat and cold units, daily positive chilling units and vapour pressure.

The cabbage seedlings were harvested on 22 May 2020. Samples taken for analyses composed of 4 quarters of different cabbage heads from each of the dripper lines. A sample of the treated effluent that was used for irrigation was also taken. Both the crop and water samples were submitted for analyses at the ARC-SCW laboratories on 22 May 2020. Crop samples were analysed for heavy metal content and leaf nutrients.

The effluent sample was analysed for electrical conductivity, pH, hardness, anions including chloride, fluoride, nitrate, nitrite, sulphate, phosphate, carbonate and bicarbonate and cations including magnesium, calcium, sodium, potassium and boron. Monthly discharge from the WWTWs for April, May and June 2020, was provided by the WWTWs manager.

3.3 Results

3.3.1 Rooiwal

3.3.1.1 *Location and surrounding land uses*

The Rooiwal Agri-park is the largest of three Agri-parks in the Tshwane Municipality, and includes multispan tunnels, open land irrigation, shade net tunnels and plastic tunnels and poultry houses. The Rooiwal Agri-park is approximately 700 m west of the Apies River in the A23E Quaternary Catchment (**Figure 3-2**). Approximately 5 ha of the Rooiwal Agri-park (20% of the total Agri-park) are currently under cultivation. Irrigation is sourced from groundwater that is abstracted and stored on site.

There are three co-operations that farm at Rooiwal and one independent lady who farms informally on the property. The independent lady received the land (open fields) with a drip irrigation system from the municipality. She also receives water and seed from the municipality. She does not, however, make use of the drip irrigation system, and she indicated that water availability is her main concern. Another co-operation is the Mutavhatsindi family that cultivates vegetable crops in open fields and under shade net tunnels that was watered through a drip-irrigation system, which they purchased for themselves. At the time of the site visit the family was harvesting Swiss chard, and had recently planted mustard spinach. A small amount of okra was also produced. In terms of sound agronomic practices, all the open fields at Rooiwal can be improved, for example through weeding and using mulch layers to limit unproductive evapotranspiration (ET) and make better use of the available water.

A CoT representative indicated that the family manages to work together most successfully, because of the family structure in which each person plays a certain role. The mother of the family manages the operation, allocates roles and makes decisions. The second co-operation was run by a former employee of the ARC, with considerable experience. His business, Tau Fresh, supplied coriander and other herbs to restaurants in Midrand. He also produces cucumbers under shade nets (**Figure 3-2 D**). Five ladies formed the third co-operation and had signed a partnership agreement with Tau Fresh to produce coriander under shade net tunnels. The tunnels were irrigated with drip irrigation and seems to be well-managed (**Figure 3-2 C**). After approximately two years the soil may become unsuitable for further crop production, and farmers should convert to hydroponic systems instead.

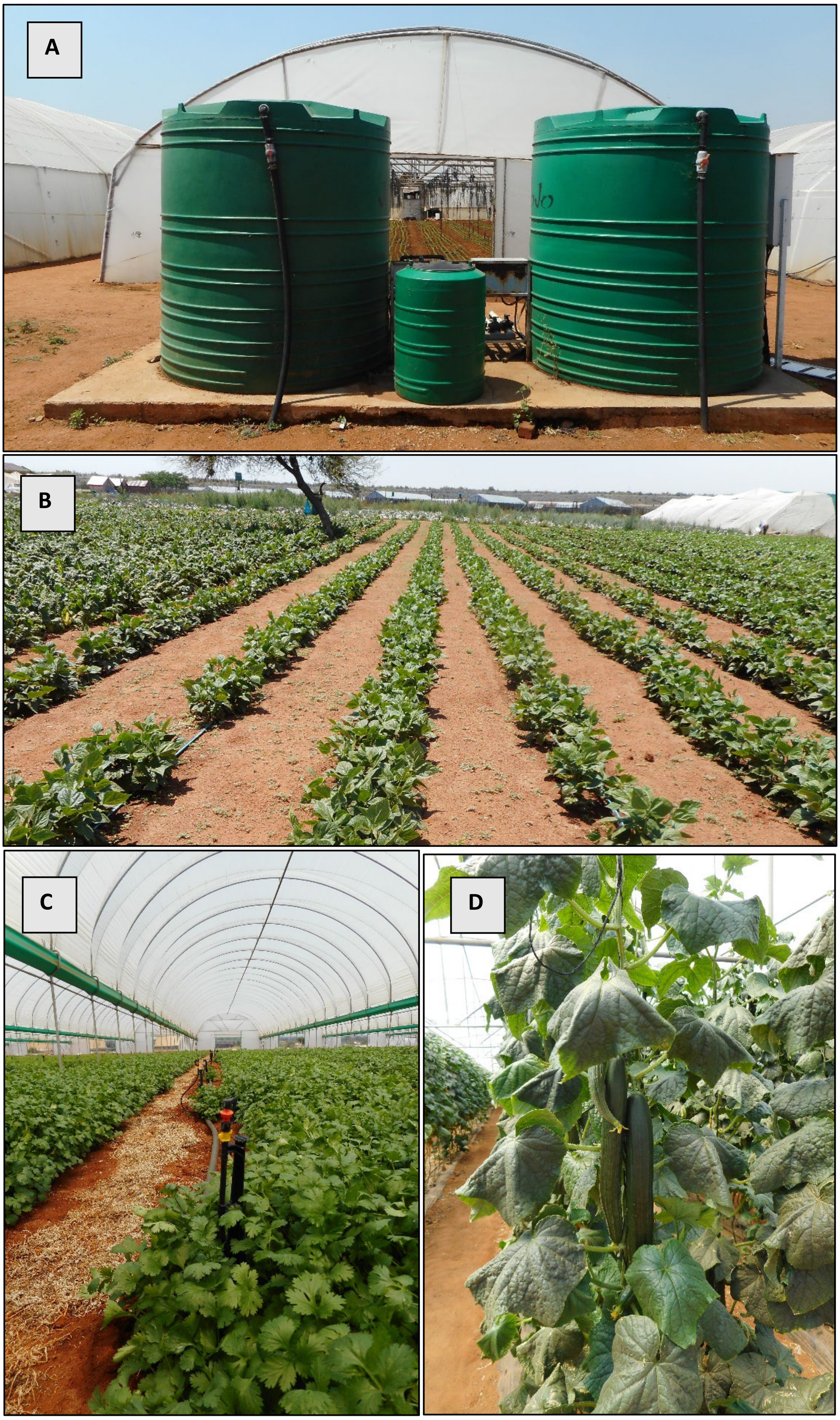


Figure 3-2: Rooiwal Agri-Park: A: Groundwater stored in tanks, multi-span tunnels in the background; B. Open fields; C: Coriander and D: Cucumbers cultivated in tunnels

3.3.1.1 *Water quantity assessment*

The water quantity assessment was done for the Apies River Catchment (**Figure 3-3**), which is a sub-area of the Apies-Pienaars River Basin and includes quaternary catchments A23D, A23E and A23F. The Apies River Catchment has been selected, because it corresponds to the Apies sub-area of the Crocodile (West) Water Resource Reconciliation Strategy (WRRS) (Department of Water Affairs and Forestry, 2008). Data from the WRRS was used to estimate the availability of water for Agri-parks within the Apies River Catchment. Other available data on water quantity included Apies River Flows and groundwater levels.

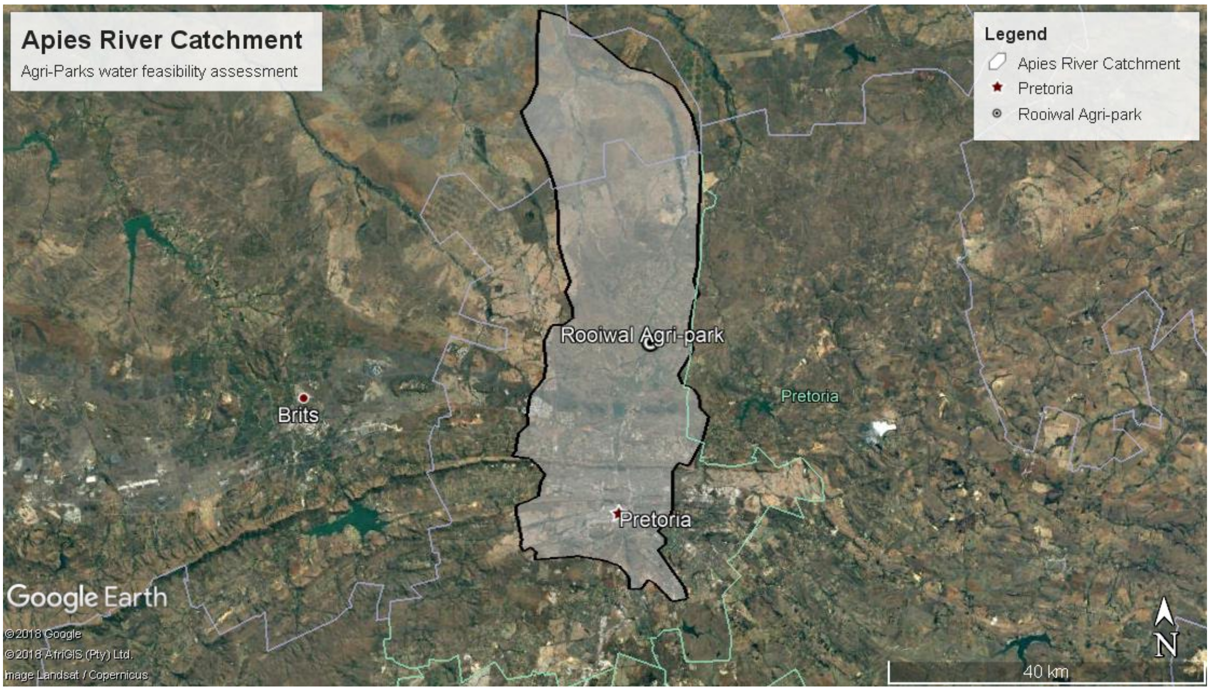


Figure 3-3: Map showing the location and extent of the Apies River Catchment (25.553°S; 28.233°E)

The Rooiwal Agri-park abstracts groundwater for irrigation and does not use water from the Apies River despite its proximity. All farmer groups at Rooiwal indicated that limited water supply is their main challenge. Data on long-term groundwater levels is not available and the only indication of groundwater yields was provided by the water borehole certificates, which are summarised in **Table 3-2**. The groundwater tests were performed on 1 May 2010 by SA Rock Drills cc. It is strongly recommended that groundwater be monitored continuously to obtain long-term data, from which the impact of abstractions for irrigation can be determined.

Table 3-2: Summary of groundwater yield tests for the Rooiwal Agri-park

	Location	Static Water Level (metres from above)	Maximum Constant Yield (m^3 / hour)
Borehole 1	25.599°S; 28.243°E	9.6	12
Borehole 2	25.611°S; 28.243°E	11.7	0.7
Borehole 3	25.929°S; 28.395°E	7.1	5.6

Average annual flow in the Apies River since 1983 is 92 million m^3. River flows are increasing, which is a general trend in urban streams, because of impermeable surfaces resulting in an increase in urban runoff (**Figure 3-4**).

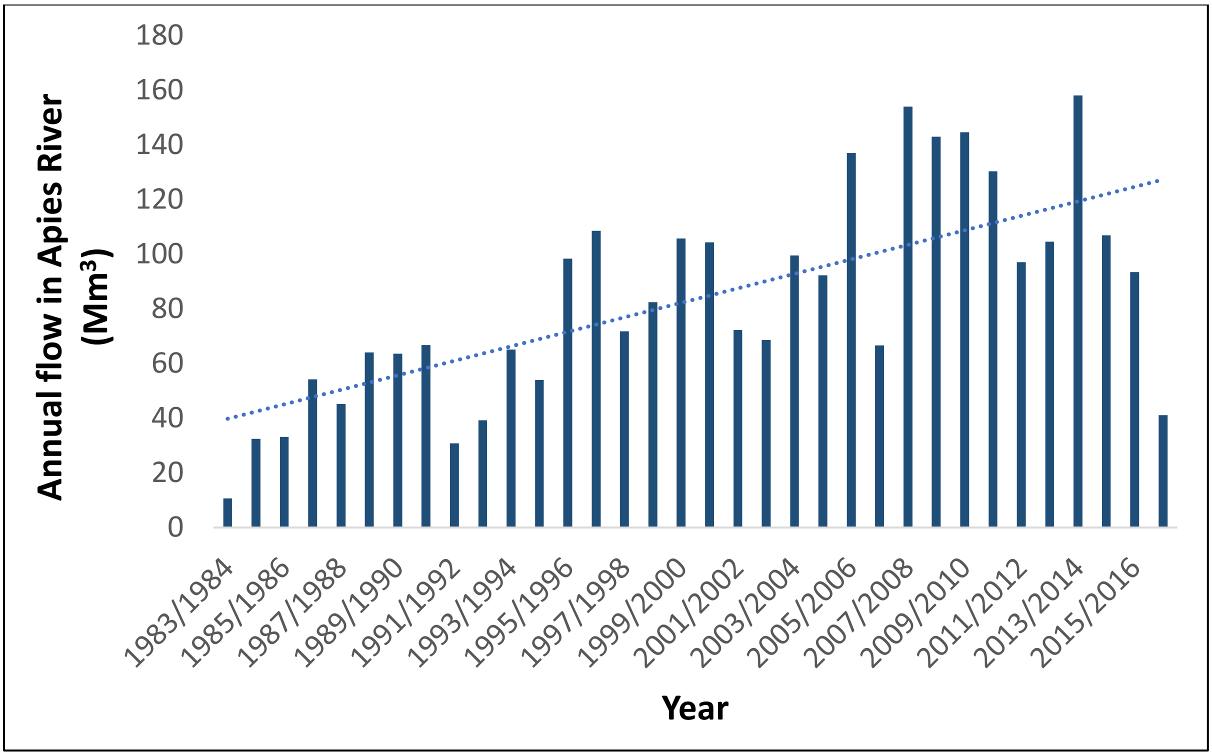


Figure 3-4: Annual flow in the Apies River, 9 km downstream of the Rooiwal Agri-park (Department of Water and Sanitation, 2018).

Table 3-3: Water availability and requirements estimated 2020 (assuming high population growth and medium water demand management) by the Crocodile (West) water resource reconciliation strategy (2008)

	Water Source	**Water Volume (Mm^3/Annum)**
Water Availability	Groundwater	6
	Surface water	2.5
	Urban runoff	0
	Return flows	101.3
	Inter-basin transfers in	161.8
	Intra-basin transfers out	7.6
	Total	279.2
	Exclude EWR (-3.3)	275.9
	Estimated Requirements	**Water Volume (Mm^3/Annum)**
Water Requirements (Excluding Water Required by Agri-parks)	Irrigation	10.4
	Distribution losses	1.1
	Rural	4.1
	Urban	174.9
	Mining and power generation	6.7
	Inter-basin transfers out	0
	Intra-basin transfers out	0
	Total requirements	197.2
Water Balance (Availability Minus EWR And Requirements)		78.7 Mm^3/annum

The availability and use of water in the Apies River Catchment for the year 2020 is given in **Table 3-3**. The WRRS assumed no increase in irrigation water requirements, and large-scale Agri-park developments have not been included in the water balance. Therefore, a positive balance between water availability and estimated requirements, as estimated by the WRRS, is necessary for the water use of Agri-parks to be feasible.

According to **Table 3-3** it is estimated that 78.7 Mm^3 of water is available annually in the Apies River Catchment. Gauteng Department of Agriculture and Rural Development (2009) recommended tomatoes (*Solanum lycopersicum*), peppers (*Capsicum* species), cucumber and pumpkin (*Cucumis* species), Swiss chard (*Beta vulgaris* subspecies *cycla*), cabbage (*Brassica oleracea*) and lettuce (*Lactuca sativa*) as suitable vegetable crops for production at Rooiwal. The report also indicates that intensive poultry and piggeries can be practiced at the Rooiwal Agri-park (Gauteng Department of Agriculture and Rural Development, 2009). The Rooiwal farmers who participated in the research mainly cultivates Swiss chard. According to the WNB framework, 2 851 449 tonnes of Swiss chard can potentially be cultivated each month in the Apies River Catchment, assuming that the volume of blue water available is consistent throughout the year. This would require an actual land area of 73 114 ha. The current size of the crop areas at Rooiwal Agri-park (five ha) can therefore be increased in terms of water available in the catchment. However, it is unlikely that all the available water would be allocated to Agri-parks development, for the following reasons:

- This 78.8 Mm^3 of water is the total volume available in the entire Apies River Catchment which is a very large area, and on-site monitoring could give more detailed information on the availability at a particular location;
- The average increase in the Apies River flows does indicate potential water availability, if the necessary infrastructure can be developed. However, with the current small scale of the existing Agri-parks such investments may not be justified.
- Other downstream users are not accounted for in this assessment and it is unlikely that all of the available water will be allocated to the Agri-park. The allocation of water is done by the DWS and approval to abstract irrigation water must be obtained through the application for Water Use Licenses.

The WNB framework has several advantages, including ease of use and enabling quick decision-making. However, by linking WFs to yield, the outcomes are only as accurate as the data used, including the WF data. Water footprints should be developed locally and updated regularly to account for variation over time and space. Also, WFs do not reflect over-irrigation of water due to poor agronomic practices, and water use efficiency should be considered as a separate goal. Over-irrigation is undesirable, even when excessive water recharges the blue water source, because it may cause salinization of the soil, water logging that in turn affects soil biology, leaches nutrients and other pollutants, and wastes electricity (Mostafa, 1977; Postel, 1999; Zilberman et al., 1997).

3.3.1.2 *Water quality assessment*

Groundwater quality data is shown in **Table 3-4**. **Table 3-5** shows suitability and potential risks associated with irrigating with the groundwater at Rooiwal, given the water quality shown in **Table 3-4**, as determined by the SAWQG DSS's Tier 1 Fitness-For-Use analysis.

Table 3-4: Water quality results for groundwater taken in August 2017 from the Rooiwal Agri-park (Rietvlei Water Laboratory, 2017)

Analysis	Units (based on SANS 241:2015)	Standards Limits	AH0733a; Borehole 1	AH0733b; Borehole 2	Total Number of Samples	Average Result	Quality of Water Supply
WQM Level 1 – Physical and Aesthetic Determinants							
Colour	mg/L Pt-Co	≥ 0.0 to ≤ 15.00	3.35	3.79	2	3.57	Excellent
Conductivity	mS/m	≥ 0.0 to ≤ 170.00	176.2	176	2	176.1	Unacceptable
pH at 25ºc	pH units	≥ 5.0 to ≤ 9.7	7.1	7.2	2	7.1	Excellent
Total Dissolved Solids	mg/L	≥ 0.0 to ≤ 999.00	1200	1200	2	1200	Unacceptable
Turbidity Operational NTU <1	NTU	≥ 0.0 to ≤ 1.0	0.19	0.22	2	0.21	Excellent
WQM Level 3 – Chemical Determinants – Micro Determinants							
Aluminium as Al	µg/L	≥ 0.0 to ≤ 300.00	<7.00	<7.00	2	7	Excellent
Antimony as Sb	µg/L	≥ 0.0 to ≤ 20	3.7	<2.7	2	3.2	Excellent
Arsenic as	µg/L	≥ 0.0 to ≤ 10	<5.0	<5.0	2	5	Excellent
Barium as Ba	µg/L	≥ 0.0 to ≤ 700.00	2.59	3.63	2	3.11	Excellent
Boron as B	µg/L	≥ 0.0 to ≤ 2400	19	14	2	17	Excellent
Cadmium as Cd	µg/L	≥ 0.0 to ≤ 3.0	<0.50	<0.50	2	0.5	Excellent
Cobalt as Co	µg/L	≥ 0.0 to ≤ 499.00	<1.0	1.31	2	1.16	Excellent
Copper as Cu	µg/L	≥ 0.0 to ≤ 2000.00	<5.00	<5.00	2	5	Excellent
Iron as Fe	µg/L	≥ 0.0 to ≤ 300.00	17.77	58.09	2	37.93	Excellent
Lead as Pb	µg/L	≥ 0.0 to ≤ 10.00	<3.50	<3.50	2	3.5	Excellent
Manganese as Mn	µg/L	≥ 0.0 to ≤ 100.00	16.14	14.81	2	15.48	Excellent
Nickel as Ni	µg/L	≥ 0.0 to ≤ 70	<1.4	<1.4	2	1.4	Excellent
Selenium as Se	µg/L	≥ 0.0 to ≤ 40	19	13	2	16	Excellent
Total Chromium as Cr	µg/L	≥ 0.0 to ≤ 50	<0.70	3.3	2	2	Excellent
Uranium as U	µg/L	≥ 0.0 to ≤ 30	<1.0	<1.0	2	1	Excellent
Vanadium as V	µg/L	≥ 0.0 to ≤ 200.00	<0.40	<0.40	2	0.4	Excellent
WQM Level 4 – Chemical Determinants – Macro Determinants							
Ammonia as N	mg/L N	≥ 0.0 to ≤ 1.50	<0.29	<0.29	2	0.29	Excellent

Analysis	Units (based on SANS 241:2015)	Standards Limits	AH0733a; Borehole 1	AH0733b; Borehole 2	Total Number of Samples	Average Result	Quality of Water Supply
Calcium as Ca	mg/L	≥ 0.0 to ≤ 150.00	258.51	260.72	2	259.62	Unacceptable
Calcium Hardness as $CaCO_3$		≥ 0.0 to ≤ 370.00	645.5	651.01	2	648.26	Unacceptable
Chloride as Cl	mg/L	≥ 0.0 to ≤ 300.00	115.98	116.42	2	116.2	Excellent
Fluoride as F	mg/L	≥ 0.0 to ≤ 1.5	2.4	2.4	2	2.4	Unacceptable
Magnesium as Mg	mg/L	≥ 0.0 to ≤ 70.00	20.1	20.3	2	20.2	Excellent
Magnesium Hardness as $CaCO_3$	mg/L CaCO3	≥ 0.0 to ≤ 280	83	84	2	84	Excellent
Nitrate as N	mg/L	≥ 0.0 to ≤ 11	95	95	2	95	Unacceptable
Nitrite as N	mg/L	≥ 0.0 to ≤ 0.90	0.004	0.002	2	0.003	Excellent
Nitrite-Nitrate Ratio		≥ 0.0 to ≤ 1.00	8.67	8.67	2	8.67	Unacceptable
Potassium as K	mg/L	≥ 0.0 to ≤ 50	5.9	6.1	2	6	Excellent
Sodium as Na	mg/L	≥ 0.0 to ≤ 200.00	60.46	61.26	2	60.86	Excellent
Sulphate as SO4	mg/L	≥ 0.0 to ≤ 250.00	95.65	97.43	2	96.54	Excellent
Total Oxidised Nitrogen as N	mg/L	≥ 0.0 to ≤ 10	95	95	2	95	Unacceptable
Zinc as Zn	mg/L	≥ 0.0 to ≤ 5.0	0.011	0.0053	2	0.0082	Excellent
Total Hardness as $CaCO_3$	mg/L CaCO3	≥ 0.0 to ≤ 660.00	728.26	734.59	2	731.43	Unacceptable
WQM Level 5 – Microbiological Determinants							
Confirmed E. Coli	Count per 100 mL	≥ 0.0 to ≤ 0.0	0	0	2	0	Excellent
Faecal Coliforms	Count per 100 mL	≥ 0.0 to ≤ 1.0	0	0	2	0	Excellent
Total Coliforms	Count per 100 mL	≥ 0.0 to ≤ 10.0	0	1	2	0.5	Excellent
Heterotrophic Plate Count	Count per mL	≥ 0.0 to ≤ 1000.00	0	0	2	0	Excellent
WQM Level 6 – Other Determinants as Required							
Alkalinity as $CaCO_3$	mg/L CaCO3	≥ 0.0 to ≤ 500.00	112.03	112.97	2	112.5	Excellent
Orthophosphate as PO_4	mg/L	≥ 0.0 to ≤ 1.0	<0.020	<0.020	2	0.02	Excellent
Silica as Si	µg/L	≥ 0.0 to ≤ 100.00	23.06	23.18	2	23.12	Excellent

Table 3-5: Water quality results for Rooiwal groundwater according to the Decision Support System

Fitness-for-use		Ideal	Acceptable	Tolerable	Unacceptable
A. Root zone salinity					
Root zone salinity (mS/m)		0-200	200-400	400-800	> 800
Predicted equilibrium root zone salinity (mS/m)			331		
B. Soil permeability					
Degree of reduced Permeability		None	Slight	Moderate	Severe
Qualitative indication of the impact on soil permeability as manifested by reduced:	Surface Infiltrability		Slight		
	Soil Hydraulic Conductivity	None			
C. Trace metal accumulation					
Soil Accumulation Threshold (mg/kg)	Al	2500			
	As	50			
	Cd	5			
	Cr	50			
	Co	25			
	Cu	100			
	F				1000
	Fe	2500			
	Pb	100			
	Mn	100			
	Ni	100			
	Se			10	
	U	5			
	Va	50			
	Zn	500			
Years to reach Soil Accumulation Threshold	Al	71429			
	As	2000			
	Cd	1000			
	Cr	5000			
	Co	5000			
	Cu	4000			
	F				83
	Fe	13158			
	Pb	5000			
	Mn	1333			
	Ni	20000			
	Se			125	
	U	1000			
	Va	Infinite			
	Zn	12500			
D. Crop yield					
Relative crop yield (%)		90-100	80-90	70-80	<70
	Salinity (EC)			79	

Fitness-for-use			**Ideal**	**Acceptable**	**Tolerable**	**Unacceptable**
Predicted relative crop yield (%) as affected by:	Boron (B)		100			
	Chloride (Cl)		100			
	Sodium (Na)		100			
E. Potential leaf scorching						
Degree of leaf scorching			None	Slight	Moderate	Severe
Degree of leaf scorching under sprinkler irrigation caused by:	Chloride (Cl)			Slight		
	Sodium (Na)			Slight		
F. Potential nutrient removal						
Contribution to estimated N P K Removal by crop			0-10%	10-30%	30-50%	>50%
% of estimated N P K removal at harvest and amount that is applied through irrigation (High nutrient concentrations may impact development of sensitive crops)	Nitrogen (N)	Removal (%)				1900
		Applied (kg/ha)				950
	Phosphorous (P)	Removal (%)	2			
		Applied (kg/ha)	0			
	Potassium (K)	Removal (%)				600
		Applied (kg/ha)				60
G. Potential corrosion or scaling of irrigation equipment (Langelier index)						
Fitness for Use Category determined by the corrosion or scaling potential indicated by the Langelier Index	Corrosion (Langelier Index)		-0.5 to 0	-0.5 to -1.0	-1.0 to -2.0	<-2.0
			Not Corrosive			
	Scaling (Langelier Index)		0 to +0.5	+0.5 to +1.0	+1.0 to +2.0	>+2.0
			0,00			
H. Potential clogging of drippers						
pH	Standard		<7.0	7.0-7.5	7.5-8.0	>8.0
	Result			7,1		
Manganese (Mn) (mg/L)	Standard		<0.1	0.1-0.5	0.5-1.5	>1.5
	Result		0,0			
Total Iron (Fe) (mg/L)	Standard		<0.2	0.2-0.5	0.5-1.5	>1.5
	Result		0,0			
E.coli (10^6 per 100 mL)	Standard		<1	1 to 2	2 to 5	>5
	Result		0,00			

Groundwater quality for Rooiwal (**Table 3-5 A**) has a relatively high concentration of salts (Average electrical conductivity (EC) of 176 mS/m and total dissolved solids (TDS) of 1200 mg L^{-1} as shown in **Table 3-4**). Crops that are sensitive to irrigation water-induced soil salinity may result in a decrease in yield (DWAF, 1996). However, DWAF (1996) reports that if the EC falls between 90-270 mS/m a "90% relative yield of moderately salt-tolerant crops can be maintained by using a low-frequency application system", provided a leaching fraction of up to 0.15 is utilised and the wetting of foliage of sensitive crops is avoided. The predicted equilibrium root zone salinity (EC) of 331 mS/m (**Table 3-5 A**) was within the acceptable range. Groundwater is predicted to have no impact on soil hydraulic conductivity, and the slight effect on surface infiltrability is acceptable (**Table 3-5 B**).

In most cases groundwater fell within the *Ideal* category in terms of trace element accumulation (**Table 3-5 C**). The only trace elements of concern were fluoride, being in the *Unacceptable* category with 83 years to reach soil accumulation threshold at 1000 mm irrigation per annum, and selenium in the *Tolerable* category with 125 years to reach soil accumulation threshold at 1000 mm irrigation per annum. The fluoride concentration of 2.4 mg/L (**Table 3-4**) is within the maximum acceptable concentration for fine textured neutral to alkaline soils (DWAF, 1996). However, this may still result in the roots and leaves of numerous crops being damaged (DWAF, 1996). Although the selenium concentration of 0.016 mg/L (**Table 3-4**) is within the *Tolerable* fitness-for-use category for the SAWQG DSS, DWAF (1996) states that a concentration below 0.02 mg/L "can be used over the Quality Range long term", and "does not result in the accumulation of selenium in plants to concentrations that are toxic to animals". All heavy metals were within the *Ideal* range, and therefore of no concern. No data were available for Be, Li, Hg, and Mo.

Potential yield reductions are shown in **Table 3-5 D**. According to the analysis the high EC was in the *Ideal* category for irrigation purposes when irrigating a Generic Sensitive Crop with 1000 mm per annum, however yield reduction of 21% was predicted to occur. The DSS indicated that under the same conditions the boron, chloride, and sodium levels were within the *Ideal* range, and predicted that no decrease in relative crop yield would be attributed to these elements. Leaf scorching as a result of sodium and chloride ions was predicted to be *slight*, and so fitness-for-use as irrigation water was deemed to be within the *Acceptable* category (**Table 3-5 E**).

The DSS indicated that, due to the high N and K concentrations of the groundwater, there is no need to apply additional fertilizer (**Table 3-5 F**). Use of the groundwater for irrigation purposes would supply over 100% of the crop requirements for N and K. Removal of these nutrients from the system by the crop could also be seen as an environmental service, by reducing the nutrient load. The exceptionally high level of nitrates is a major concern at the Rooiwal Agri-park, due to potential environmental impacts that are discussed in **Section 2.2.3.3.**

Calcium concentrations (259.6 mg L^{-1}) are high relative to irrigation standards (< 150 mg L^{-1}) indicating potential scale deposits on crop fruits and leaves if sprinkler irrigation is applied. These calcium precipitates do not present any health risks, but reduces the marketability of the crop (Department of Water Affairs and Forestry, 1996). The drip irrigation systems that are currently installed should overcome the problem of scale formation on leaves, because irrigation water is not applied to crop leaves, but directly to the soil. Scale formation, however, can block irrigation equipment. However, based on the Langelier Index, the groundwater was within the ideal range for both corrosion (*Not Corrosive*) and scaling (*0,00*), despite high concentrations of calcium (**Table 3-5 G**). The potential of the water to clog drippers within the drip irrigation system was reported to be unlikely with manganese, total iron, and *E. coli* levels all within the *Ideal* limits, and pH within the *Acceptable* limit (**Table 3-5 H**). The low levels of *E.coli* is surprising, considering the proximity of the wastewater treatment works (WWTW) to the Rooiwal Agri-park. In January 2019 a manhole was leaking raw sewage from the WWTW into the Agri-park fields (**Figure 3-5**). The result in **Table 3-4** in terms of *E.coli* is most likely an underestimation of the current conditions.

Figure 3-5: Raw sewage leaking into the Rooiwal Agri-park fields in January 2019

Water quality data from the Apies River is given in **Table 3-6**. According to SANS 241:2015 Standards, the water quality in the Apies River is suitable for irrigation in terms of most constituents, except ortho-phosphates, for which the median values exceed water quality targets. **Table 3-7** shows suitability and potential risks associated with irrigating with water from the Apies River, given the median values of the water quality shown in **Table 3-6**, as determined by the SAWQG DSS's Tier 1 Fitness-For-Use analysis.

Table 3-6: Apies River water quality for 2011-2018 (DWS, 2018)

Monitoring Variable	Number of Samples	Min	25% P	50% P	75% P	Max	Target (DWA, 1996)	Target (SANS 241:2015)
pH (pH units)	159	4.74	7.78	8.11	8.37	8.7	6.5 to 8.4	5.0 to 9.7
NO_3+NO_2 (nitrogen)(mg L^{-1})	159	0.03	4.00	5.44	7.39	15.99		11.9
Fluoride (mg L^{-1})	151	0.03	0.27	0.32	0.43	0.72		1.5
Sodium (mg L^{-1})	126	23.37	61.69	72.10	78.87	108.81	70 mg/l	200
Magnesium (mg L^{-1})	150	12.90	16.79	18.37	19.81	28.60		70
Ortho phosphate as phosphorus (mg L^{-1})	158	0.005	0.91	1.43	2.11	6.34		1
Sulphate (mg L^{-1})	158	33.44	50.18	55.90	62.36	226.60		250
Chloride (mg L^{-1})	159	20.05	52.63	58.95	64.43	94.59		300
Potassium (mg L^{-1})	130	0.50	10.40	12.02	13.26	16.69		50
Calcium (mg L^{-1})	157	25.53	37.89	40.40	43.26	71.40		150
Electrical conductivity (mS m^{-1})	158	35.90	62.98	69.40	74.28	84.90		170
Total dissolved solids (mg L^{-1})	116	279.58	469.34	521.51	558.87	630.60		999
Hardness as $CaCO_3$ (mg L^{-1})	149	128.54	166.29	177.86	188.04	296.08		370
Langlier index (null)	116	-2.97	0.18	0.52	0.76	1.14	-2 to 2	

Table 3-7: Apies River water quality results according to the Decision Support System

Fitness-For-Use		Ideal	Acceptable	Tolerable	Unacceptable
A. Root zone salinity					
Root zone salinity (mS/m)		0-200	200-400	400-800	> 800
Predicted equilibrium root zone salinity (mS/m)		152			
B. Soil Permeability					
Degree of reduced Permeability		None	Slight	Moderate	Severe
Qualitative indication of the impact on soil permeability as manifested by reduced:	Surface Infiltrability			Moderate	
	Soil Hydraulic Conductivity		Slight		
C. Trace Element Accumulation					
Number of years of 1000 mm irrigation before Trace Elements (fluoride) reach accumulation threshold in topsoil		342			
D. Crop yield					
Relative crop yield (%)		90-100	80-90	70-80	<70
Predicted relative crop yield (%) as affected by:	Salinity (EC)			76	
	Chloride (Cl)	100			
	Sodium (Na)	100			

Fitness-For-Use		Ideal	Acceptable	Tolerable	Unacceptable
E. Potential for leaf scorching					
Degree of leaf scorching		None	Slight	Moderate	Severe
Degree of leaf scorching under sprinkler irrigation caused by:	Chloride (Cl)		Slight		
	Sodium (Na)			Moderate	
F. Potential nutrient removal*					
Nitrogen (N)	Removal (%)				225
	Applied (kg/ha)				112
Phosphorous (P)	Removal (%)				332
	Applied (kg/ha)				33
Potassium (K)	Removal (%)				1526
	Applied (kg/ha)				153
G. Potential corrosion or scaling of irrigation equipment (Langelier index)					
Fitness for Use Category determined by the corrosion or scaling potential indicated by the Langelier Index	Corrosion (Langelier Index)	-0.5 to 0	-0.5 to -1.0	-1.0 to -2.0	<-2.0
		Not Corrosive			
	Scaling (Langelier Index)	0 to +0.5	+0.5 to +1.0	+1.0 to +2.0	>+2.0
			0,84		
H. Potential clogging of drippers					
pH	Standard	<7.0	7.0-7.5	7.5-8.0	>8.0
	Result				8.6

Salinity of the water in the Apies River is relatively low with a median value of 69 mS/m for EC and 521.5 mg/L for TDS. According to the DSS, the predicted EC of 152 mS/m (**Table 3-6**) was within the *Ideal* range (**Table 3-7 A**). Therefore, in terms of salinity, water from the Apies River is more suitable for irrigation than the groundwater from Rooiwal. Median sodium concentration of water from the Apies River is within DWA and SANS water quality standards. Therefore, the general composition of salts in this water will have little impact on soil infiltrability and no impact on soil hydraulic conductivity (**Table 3-7 B**).

Apies River water quality data was not available for most trace elements, except for fluoride concentrations. The DSS indicated the fluoride concentrations are within the *Ideal* fitness-for-use category and will require 342 years to reach the soil accumulation threshold (**Table 3-7 C**). The SAWQG DSS indicated that chloride and sodium levels were within the *Ideal* range, and predicted that these parameters will not result in a decrease in relative crop yield, however a yield decrease of 24% was predicted due to salinity in terms of EC (**Table 3-7 D**). Leaf scorching as a result of sodium and chloride ions was considered to be in the *Moderate* and *Slight* categories, respectively (**Table 3-7 E**).

According to the DSS, use of the Apies River water for irrigation purposes would theoretically supply over 100% of the crop N, P and K requirements. Actual plant availability of these nutrients, and effects of these high concentrations of macro-nutrients on micro-nutrient availability would need careful monitoring. Routine soil and leaf analyses to guide fertility management is recommended (**Table 3-7 F**). Removal of these nutrients by the crop could be seen as an environmental service to reduce the nutrient load within the catchment. As shown in **Table 3-7 G** the water from the Apies River is not corrosive (fitness-for-use category is *Ideal*) and will not cause scaling (fitness-for-use category is *Acceptable*), based on the Langelier Index. The high pH has the potential to cause clogging of the irrigation drippers (**Table 3-7 H**). No data was available for the impact of the Mn, total Fe, and *E. coli* content on dripper clogging.

3.3.2 Westonaria

3.3.2.1 *Location and surrounding environment*

The Westonaria Agri-park (**Figure 1-3**) is in the C23D Quaternary Catchment (**Figure 3-6**) which falls within the Vaal River Water Management Area, in the sub-area downstream of the Vaal Dam. The northern boundary of the C23D catchment borders the Crocodile West Water Management Area, which flows into the Limpopo River towards the Indian Ocean. On the south-eastern border of the Agri-park is the Donaldson Dam, which was constructed within the Wonderfonteinspruit River. The Wonderfonteinspruit River originates south of Krugersdorp in a mining area. The C23D catchment, upstream from the Agri-park, also contains numerous human settlements, including Kagiso, Azaadville, Rietvallei, Toekomsrus and Mohlakeng.

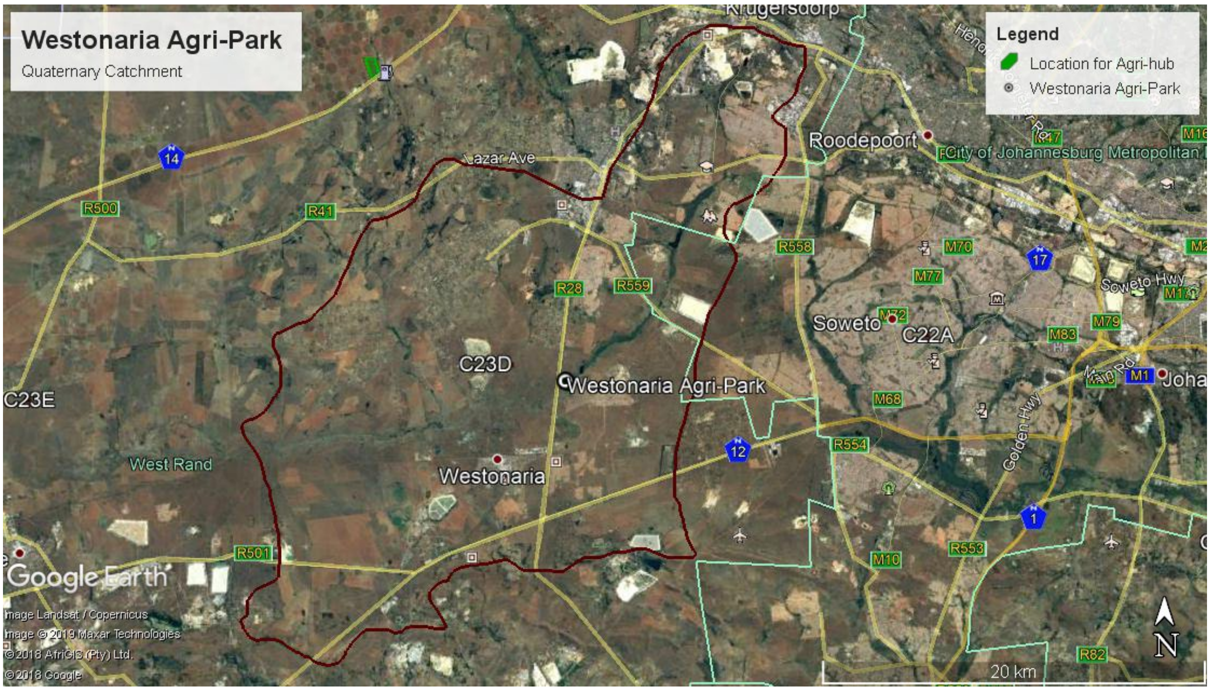


Figure 3-6: Map showing the location and extent of the C23D Quaternary Catchment (26.260°S; 27.661°E)

The Westonaria Agri-park is situated on dolomites that belongs to the Malmani Subgroup of the Transvaal Sequence. These dolomites extent from the Town of Springs in the East to Orkney in the West. Impermeable dykes transvers the dolomites in various places, dividing this dolomitic layer into several dolomitic compartments. The Westonaria Agri-park is situated within the Zuurbekom dolomitic compartment. Fissures and faults in the dolomitic rocks are able to store large volumes of groundwater, which under natural conditions provided an important source of good quality water. However, this area also has a long history of more than 120 years of being impacted on by gold mining activities, which have changed the character of these systems. Underground mining voids naturally fill up with water, which becomes extremely polluted due to various chemical reactions, resulting in

Acid Mine Drainage (AMD). Once the voids are filled up, the AMD decants in the rivers harming the aquatic ecosystems and threatening human health. In order to prevent these impacts, water is continually pumped out of the mines, which in turn affects the stability of the dolomitic rocks. Consequently, sinkholes became more hazardous and impacted many settlements and farms. In the past the aquifers supported many farmers, but they were heavily impacted on by the water quality from the mines.

The Zuurbekom compartment has not been dewatered, but at the western boundary of the Zuurbekom compartment, very close to the Westonaria Agri-park, is the Venterspost compartment, which has been dewatered by mining activities at the Venterspost mine. At the southern boundary of the Zuurbekom compartment, also close to the Westonaria Agri-park, is the Gemsbokfontein compartment, which is also in a dewatered state.

The Westonaria Agri-park is known for its hydroponic greenhouse where lettuce is normally produced (**Figure 3-7**). The hydroponic greenhouse was used to produce lettuce, planted in succession in November 2018, but since the beginning of the year 2019 the greenhouse was not in operation, due to infrastructure failure. The rest of the Agri-park produces vegetables including beans, tomatoes and Swiss chard, peppers and cucumbers under 20 shade net tunnels, most of which were not being used during the site visits. Like the Rooiwal Agri-park, Westonaria resembles a production unit, rather than the Agri-park model.

Figure 3-7: Westonaria Agri-park: Hydroponic system in operation during November 2018 (left) and Shade net tunnels (right)

3.3.2.2 *Water quantity assessment*

Natural water sources potentially available to the Westonaria Agri-park includes the Wonderfonteinspruit and groundwater from the Zuurbekom dolomitic aquifer. An interesting finding of this study is that many of the Agri-parks, including Westonaria, are using municipal water for irrigation. The Westonaria Agri-park farmers also indicated that a lack of water is a challenge and that they do not have permission to abstract surface or groundwater for irrigation. According to the

Department of Water Affairs and Forestry (2006), the Zuurbekom compartment has a surface area of 143 km^2, and between 13% and 16.8% of mean annual precipitation is estimated to recharge the aquifer. It is estimated that the aquifer is recharged by 15 Mm^3 per annum. Existing use was estimated at 17.6 Mm^3 per annum, with 7.6 Mm^3 withdrawn by mining activities and 10 Mm^3 for municipal or industrial uses. Current water abstractions are therefore believed to exceed current recharge of the aquifer. The Zuurbekom compartment can store a volume of 35.5 Mm^3 per annum, given that only 5 m of groundwater can be withdrawn to avoid dolomitic instability and sinkholes. Water levels at monitoring points are still declining, supporting the idea that current abstraction exceeds recharge. Therefore, no surplus groundwater in the Zuurbekom compartment is available for further farming activities.

The Zuurbekom compartment is located within the Upper Vaal Water Management Area (WMA) and more specifically in the sub-area downstream of the Vaal Dam, both of which are also stressed in terms of water quantity (Department of Water Affairs and Forestry, 2004). The water reconciliation base scenario estimated for the year 2025 indicates a total of 2500 Mm^3 available and 2518 Mm^3 required per annum in the sub-area downstream of the Vaal Dam. Thus, considering a larger geographical scale, the Westonaria Agri-park is also located in a water-stressed WMA. **Figure 3-8** shows annual flow volumes in the Wonderfonteinspruit, which was obtained from the Department of Water and Sanitation (2019).

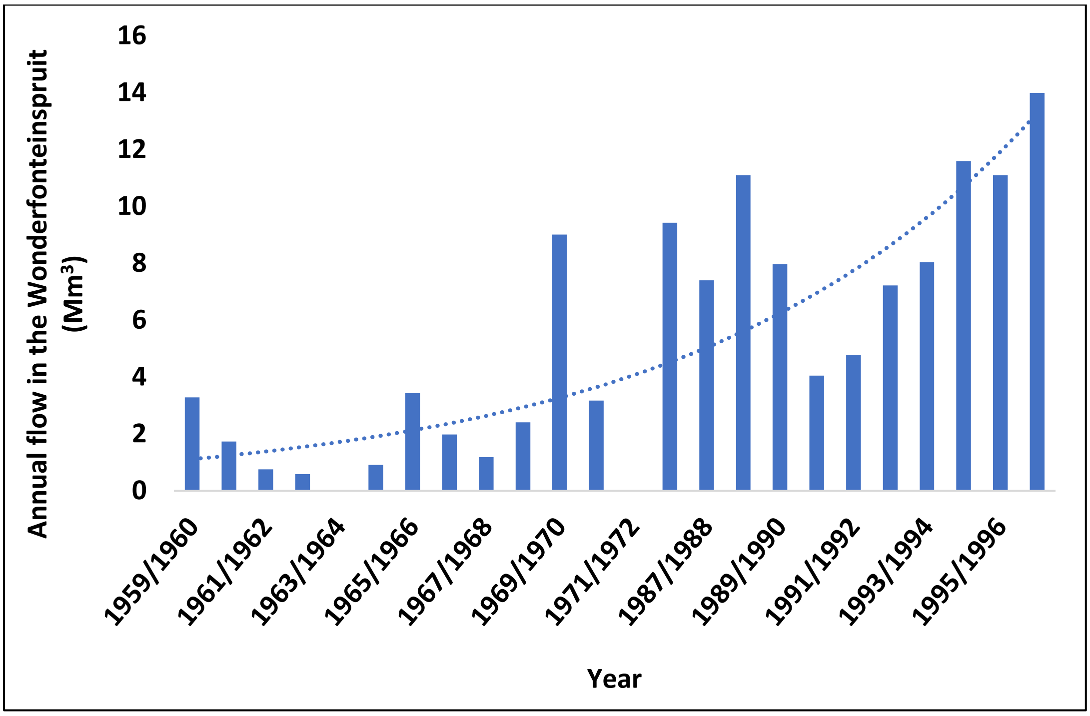


Figure 3-8: Annual flow in the Wonderfonteinspruit, 2 km downstream of the Westonaria Agri-park

As shown in **Figure 3-8**, the annual flow increased from 1960 to 1996. This increase in runoff may be due to the dewatering of the mines, because this monitoring point is within the Venterspost compartment, which has been dewatered. It may also be explained by an increase in rural settlements, or reduction in farming areas, thus resulting in less water being used for irrigation. Average annual flow in the Wonderfonteinspruit between 1959 and 1970 was 1.8 Mm^3 and increased to an average of 8.4 Mm^3 between 1970 and 1996. On average, an additional 6.6 Mm^3 per year therefore became available in that period. The increased flow in the Wonderfonteinspruit would potentially be able to support a monthly production of up to 200 000 tonnes of lettuce in the hydroponic system and 21 290 tonnes and 7 096 tonnes lettuce per month in summer and winter respectively in open fields. However, there is a number of reasons to believe that this potential increase in production would not be realistic, including:

- The flow data was not monitored after 1996 and the chances are that this increase was only temporary;
- Considering the water stresses downstream in the rest of the WMA, it is uncertain whether this water will be allocated to the Agri-park, even if the flow levels are still at this increased level;
- Currently the infrastructure is not available to abstract the water from the river. Given the relatively small production of the Westonaria Agri-park, it may not be economically feasibility to develop the necessary infrastructure; and
- As shown in the next section, the quality of the water in the Wonderfonteinspruit can also complicate the use of the water for irrigation.

3.3.2.3 *Water quality*

The groundwater quality data for the Westonaria Agri-park is relatively good as summarised in **Table 3-8**. Only 5% of the time water quality exceeded acceptable standards in terms of salinity (TDS and EC result), calcium, phosphates and sulphates. The occasional increase in salts and sulphates is possibly due to mining activities in the area. Increases in phosphates could be due to agricultural activities and sewage pollution. The most recent groundwater quality data that could be obtained was sampled in November 2004 and was taken 4 km northwest of the Agri-park. This dataset contained only one result for each derivative, but indicated good water quality (**Table 3-8**).

Data on important derivatives, including heavy metals and radioactivity is not included in the database, however, low sulphate levels and acceptable pH results indicate that the particular site does not seem heavily impacted on by mining activities, even though the site is relatively close to the Venterspost Mine. According to Department of Water Affairs and Forestry (2006) the water quality of all dolomitic compartments in the area is impacted on by mining activities in various degrees, however, the Zuurbekom and Venterspost Compartments were not listed with others in which radioactivity is of particular concern.

Table 3-8: Groundwater quality results for November 2004 taken at 26.253° S: 27.648°E (n=1)

Constituents*	**Result (N=1)**	**Water Quality Standards (DWS)**			
		Target			Unacceptable / Require management
Irrigation Standards					
Electrical Conductivity (mS/m)	8.7	0-40	40-90	90-540	>540
Chloride (mg/L)	2.0	0-100	175	350	500
Fluoride (mg/L)	0.1	0-2	2 to 155		>15
Nitrate (mg/L)	0.04	0-5	5 to 30		>30
pH (pH UNITS)	7.7	6.5-8.4			
Sodium (mg/L)	2.7	0-70	70-115	115-230	>230
Domestic Standards					
Total Dissolved Solids (mg/L)	69.2	0-450	450-1000	1000-2000	>2000
Electrical Conductivity (mS/m)	8.7	0-70	70-150	150-300	300-450

Constituents*	Result (N=1)	Water Quality Standards (DWS)			
		Target			Unacceptable / Require management
Calcium (mg/L)	6.5	0-32	32-80		>80
Fluoride (mg/L)	0.1	0-1	1-1.5	1.5-3.5	>3.5
Magnesium (mg/L)	5.2	0-50	50-70	70-100	>100
Nitrate (mg/L)	0.04	0-6	6-10	10-20	>20
Potassium (mg/L)	1.0	0-50	50-100	100-400	>400
Sodium (mg/L)	2.7	0-100	100-200	600-1000	>1000
Sulphate (mg/L)	2.0	0-200	200-400	400-600	>600
Ecosystems Standards					
Ortho Phosphate (mg/L)	0.02	<0.005 (oligo-trophic)	0.005-0.025 (meso-trophic)	0.025-0.25 (eu-trophic)	>0.25 (hyper-trophic)

The water quality data for the Wonderfonteinspruit (sampled between 1980 and 2019) is summarised in **Table 3-9** and indicate poor quality in terms of salinity (TDS and EC result), calcium, phosphates and sulphates. The median values (50%) for EC, calcium and ortho-phosphate exceeded acceptable irrigation, domestic and ecosystem standards respectively. In the past five years (2014-2019) water quality has further deteriorated, particularly in terms of ortho-phosphate concentrations, with 95% of the samples (5th percentile) reaching hypertrophic conditions.

Table 3-9: Surface water quality results for 1980-2019 taken at 26.289°S: 27.669°E (n=1221)

Constituents*	5^{th} Percentile	Median	95^{th} Percentile	Average	Water Quality Standards (DWS) Target			Unacceptable / Require management
Irrigation								
Electrical Conductivity (mS/m)	73.86	99.9	195.2	111.3	0-40	40-90	90-540	>540
Chloride (mg/L)	31.535	55.519	80.331	55.5	0-100	175	350	500
Fluoride (mg/L)	0.1708	0.321	0.596	0.3	0-2	2 to 155		>15
Nitrate (mg/L)	0.02	0.14	6.4915	1.2	0-5	5 to 30		>30
pH (pH UNITS)	6.41	8.2	8.6796	8.0	6.5-8.4			
Sodium (mg/L)	47.37	83.15	118.72	83.2	0-70	70-115	115-230	>230
Domestic								
Total Dissolved Solids (mg/L)	543.8433	765.2365	1621.05	895.4	0-450	450-1000	1000-2000	>2000
Electrical Conductivity (mS/m)	73.86	99.9	195.2	111.3	0-70	70-150	150-300	300-450
Calcium (mg/L)	70.5	94.6135	321.25	132.6	0-32	32-80		>80
Fluoride (mg/L)	0.1708	0.321	0.596	0.3	0-1	1-1.5	1.5-3.5	>3.5
Magnesium (mg/L)	16.33925	25.189	52.575	28.9	0-50	50-70	70-100	>100
Nitrate (mg/L)	0.02	0.14	6.4915	1.2	0-6	6-10	10-20	>20
Potassium (mg/L)	7.423	10.665	14.5985	10.7	0-50	50-100	100-400	>400
Sodium (mg/L)	47.37	83.15	118.72	83.2	0-100	100-200	600-1000	>1000
Sulphate (mg/L)	151.7854	247.2	1053.7	373.9	0-200	200-400	400-600	>600
Ecosystems								
Ortho Phosphate (mg/L)	0.006	0.054	1.27715	0.3	<0.005 (oligotrophic)	0.005-0.025 (mesotrophic)	0.025-0.25 (eutrophic)	>0.25 (hypertrophic)

3.3.3 Outcomes of feasibility study on irrigating with sewage effluent at Rooiwal

3.3.3.1 *Water and nutrient balance assessment*

The outcomes of the production potential of water and nutrients from the WWTWs, based on water footprinting information used in the WNB, are summarised in **Table 3-10.** Potential agricultural land that can be irrigated with this volume of water is 1477 ha and 375 ha of leafy vegetables in summer and winter respectively, and 512 and 220 ha of root vegetables in summer and winter respectively. This volume of water could therefore supply agricultural land of up to 246 time larger than what is currently cultivated by the Rooiwal Agri-park. Currently, monthly irrigation water requirements for the 5 ha of cultivated land at the Rooiwal Agri-park is approximately 2 283 m^3 in summer and 4 473 m^3 in winter. Potential monthly production that can be achieved with the volume of discharged water from the WWTWs is 57 609 and 14 247 tonnes of leafy vegetables in summer and winter respectively and 36 806 and 15 057 tonnes of root vegetables in summer and winter respectively. Production potential of the volume of water from the WWTWs is notably higher in summer, compared to winter, because the area is a summer rainfall region, receiving no rainfall during winter. The additional rainwater enables higher production during summer compared to winter.

Table 3-10: Water balance for irrigating with effluent from the wastewater treatment works at Rooiwal

		SUMMER	WINTER
Available Water (Monthly Discharge from WWTWs) (m^3)		1 325 000	1 325 000
Monthly Blue Water Requirement Of 6 ha (m^3)		2 283	4 473
Monthly Blue Water Requirement Of 30 ha (m^3)		16 792	32 913
Potential agricultural land that can be irrigated with available blue water (ha)	Leafy vegetables	1 477	375
	Root vegetables	512	220
Potential production with available blue water per growing season (tonnes)	Leafy vegetables	144 022	71 237
	Root vegetables	165 625	82 813
Average monthly production potential with available blue water (tonnes)	Leafy vegetables	57 609	14 247
	Root vegetables	36 806	15 057

3.3.3.1 *Effluent water quality*

The nutrient balance results for sewage effluent using the WNB framework is summarised in **Operating far** above its capacity, the WWTW adjacent to the Rooiwal Agri-park is not a very efficient water treatment plant.

Table 3-12 shows water quality results for the treated effluent quality. The final effluent had high EC that requires management. Suspended solids were relatively low meaning that the water did not need to be filtered before using it for irrigation. Of particular concern is the extremely high nitrate and phosphate concentrations, which are above the general limits applicable to discharge of wastewater. In **Table 3-12,** nitrate and phosphate results are compared to general limits for wastewater, which is relatively poor standard, because it is assumed that the receiving water bodies will dilute the discharged water. However, in sensitive ecosystems special limits for the discharge of wastewater would apply, which are 1.5 mg/L for nitrates and a maximum of 2.5 mg/L for ortho-phosphates. Compared to these special limits, which may be relevant at Rooiwal because of the high concentrations of nutrients in the groundwater, current levels would be unacceptable. High nitrate values can cause excessive vegetative growth and less produce, and may cause clogging of irrigation systems due to algal growth, and these problems must be managed. In conclusion, the final effluent was suitable for irrigation in terms of the measured constituents, but would require careful management.

Table 3-11. Potentially, 938 ha, 2 516 ha and 219 ha of leafy vegetables and 2 532 ha, 2 264 ha and 1 312 ha of root vegetables can be cultivated in summer with the available nitrates, phosphates and potassium, respectively. Therefore, with the available phosphates in the wastewater, the current size of the Agri-park can be expanded up to 419 times. Average monthly production that can potentially be achieved with the available amount of nutrients in the wastewater ranges from 665 tonnes for potassium in winter to 15 699 tonnes for phosphates in summer. Phosphate levels in the wastewater can be used to achieve much higher production, compared to the other nutrients, because crops require relatively lower amounts of phosphates.

Operating far above its capacity, the WWTW adjacent to the Rooiwal Agri-park is not a very efficient water treatment plant.

Table 3-12 shows water quality results for the treated effluent quality. The final effluent had high EC that requires management. Suspended solids were relatively low meaning that the water did not need to be filtered before using it for irrigation. Of particular concern is the extremely high nitrate and phosphate concentrations, which are above the general limits applicable to discharge of wastewater. In **Table 3-12,** nitrate and phosphate results are compared to general limits for wastewater, which is relatively poor standard, because it is assumed that the receiving water bodies will dilute the discharged water. However, in sensitive ecosystems special limits for the discharge of wastewater would apply, which are 1.5 mg/L for nitrates and a maximum of 2.5 mg/L for ortho-phosphates. Compared to these special limits, which may be relevant at Rooiwal because of the high concentrations of nutrients in the groundwater, current levels would be unacceptable. High nitrate values can cause excessive vegetative growth and less produce, and may cause clogging of irrigation systems due to algal growth, and these problems must be managed. In conclusion, the final effluent was suitable for irrigation in terms of the measured constituents, but would require careful management.

Table 3-11: Nutrient balance for irrigating with effluent from the wastewater treatment works at the Rooiwal Agri-park

		Nitrates		Phosphates		Potassium	
		Summer	Winter	Summer	Winter	Summer	Winter
Available nutrients present in water (kg/month)		56 273	56 273	20 127	20 127	17 490	17 490
Nutrient requirements of 6 ha (kg/month)		337	173	49	26	440	223
Nutrient requirements of 30 ha (kg/month)		1 687	865	221	112	2 168	1 087
Potential land that can be fertilized with available nutrients (ha)	Leafy vegetables	938	1 876	2 516	5 032	219	437
	Root vegetables	2 532	3 095	2 264	2 767	1 312	1 603
Production potential of available nutrients per growing season (tonne)	Leafy vegetables	14 631	14 256	39 247	38 241	3 411	3 323
	Root vegetable	40 460	38 491	36 178	34 417	20 959	19 939
Average monthly production potential of available nutrients (tonnes/month)	Leafy vegetables	5 852	2 851	15 699	7 649	1 364	665
	Root vegetable	8 991	6 998	8 040	6 258	4 658	3 625

Table 3-12: Quality of treated sewage effluent used for irrigation at the Rooiwal Agri-park trial

Water Quality Derivative	Standard Maximum Value	Result SAMPLE 1[1]	SAMPLE 2[2]
Boron (mg/L)	0.5*		0.05
Electric conductivity mS/m)	90*	73.5	62.4
pH	6.5-8.4*	7.56	7.79
SAR	2*		2.23
Sodium (mg/L)	70*		65.6
Total dissolved solids (mg/L)	580*		348
Chloride (mg/L)	100**	75.3	64.21

Water Quality Derivative	Standard Maximum Value	Result	
		SAMPLE 1[1]	SAMPLE 2[2]
Fluoride (mg/L)	1**		0
Nitrite + Nitrate (mg/L)	15**	10.2	42.64
Phosphate (mg/L)	10**	9.86	
Calcium (mg/L)	80***		37.2
Magnesium (mg/L)	30***		17.1
Potassium (mg/L)	50***		13.2
Sulphate (mg/L)	200***	70	59.97
Bicarbonate (mg/L)	-		67.71
Carbonate (mg/L)	20		0
Total hardness (mg/L)	-		108.5

*Irrigation water quality standards; **General limit for wastewater quality standards; ***Domestic water quality standards
[1]Data on final effluent obtained from WWTWs (November 2019); [2] Own sample of final effluent analysed by the ARC SCW (May 2020)

3.3.3.2 *Soil moisture*

Soil moisture data taken at two depths (0.25 m and 0.5 m) along a dripper line (EW3) connected to effluent water and at 0.25 m in the dripper line connected to groundwater (GW) is shown in **Figure 3-9**. The sensor installed at GW 1 became disconnected during the end of the growing season and resulted in some data getting lost. In March 2020 a national lockdown was enforced to prevent the spread of the Covid-19 pandemic. During this time the research team were unable to visit the Agri-park and Agri-park farmers had to manage the field with limited sewage water available in the irrigation system, because they did not have the equipment to pump water into the system themselves. However, before the start of the lockdown enough effluent water was pumped into the irrigation system to last a few weeks, if the farmers were careful not to overirrigate at any time. This was explained to the farmers during the last visit before the lockdown.

From the soil moisture sensors, however, it seems as if there was a period of water scarcity most noticeably at 0.25 m depth of EW3. Water was not scarce on the GW, because groundwater never became limited during the lockdown. The farmers were asked to irrigate the control and the treatment at the same time, but from the soil moisture data, it seems as if they continued irrigating GW while there was no effluent water. The soil moisture in EW3 also responded most dramatically to every rainfall event.

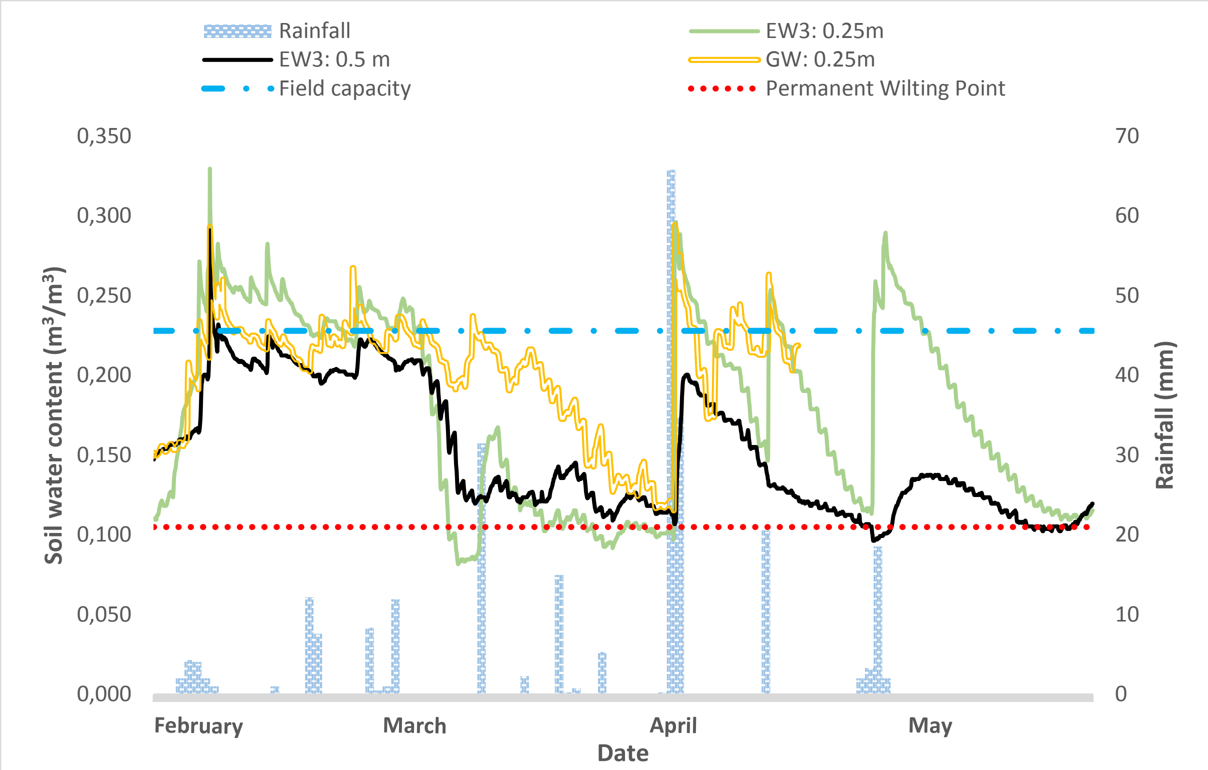


Figure 3-9: Soil moisture measurements at two depths (0.25 and 0.5 m) in EW3 (effluent water) and at 0.25 m in the GW (groundwater) compared to rainfall data for the duration of the growing season (from 3 February 2020 to 22 May 2020) at the Rooiwal Agri-park

3.3.3.3 *Crop quality*

A number of days with good rain and a thick mulch layer covering the soil contributed to a successful production of cabbage despite the lockdown situation and the crops were harvested for analyses. The leaf analyses of the crop samples are shown in **Table 3-13**. Apart from the barium concentrations, there is no notable difference between the crop samples from GW and the three replicates. Barium concentrations are almost double in EW1, EW2 and EW3 compared to GW.

Table 3-13: Cabbage crop sample analysis comparing groundwater irrigated control with three replicates of the sewage effluent irrigated treatment

	GW	EW1	EW2	EW3	UNITS
Metal Analysis					
As	<0.12	<0.12	<0.12	<0.12	mg/kg
Ba	11.15	22.6	19.79	20.49	mg/kg
Cr	2.43	1.76	1.56	2	mg/kg
Cd	<0.2	<0.2	<0.2	<0.2	mg/kg
Co	0.2	0.15	0.17	0.2	mg/kg
Hg	0.25	0.24	0.22	0.27	mg/kg
Ni	5.03	2.34	2.06	2.07	mg/kg
Mo	3.6	3.2	4.32	4.28	mg/kg
V	<0.2	<0.2	<0.2	<0.2	mg/kg
Pb	0.35	0.25	0.2	0.47	mg/kg
Se	<1	<1	<1	<1	mg/kg
Sb	<0.05	<0.05	<0.05	<0.05	mg/kg
	GW	**EW1**	**EW2**	**EW3**	**Units**

Nutrient Analysis					
Moisture	90	88.6	89.2	89.3	%
N	3.4	3	3	2.9	%
K	19087	22599	21452	21908	mg/kg
Ca	21020	16349	18494	20628	mg/kg
Mg	1997	1970	2153	2028	mg/kg
P	3303	3076	2896	2731	mg/kg
Na	6820	3209	4958	5815	mg/kg
Mn	18.6	19.2	16.5	16	mg/kg
Al	65	47.6	66.8	58.6	mg/kg
Fe	85.5	85.1	77.8	88.4	mg/kg
Zn	17.5	19.4	18.8	19.3	mg/kg
B	17	20.3	17.4	15.2	mg/kg
Cu	2.4	2.5	2.4	2.8	mg/kg
S	8214.6	8548.1	8885.3	8311.1	mg/kg
F^-	6712.7	5996.1	7553.2	9711.9	mg/kg
Cl^-	7141.4	9665.7	10492.1	4475.2	mg/kg

3.4 Discussion

3.4.1 Water and Nutrient Balance Framework

The WNB framework has been developed and tested at the Rooiwal and Westonaria Agri-parks. The tool is considered useful to catchment managers within Agri-parks, providing a simple way to conduct water feasibility assessments. The tool requires blue WF data on all crops that are to be planted in the Agri-park, the length of the growth season, current or planned production of each crop and total blue water availability. Even if water is available in the catchment for production, there may be areas and times within the catchment where water is scarcer. For this reason, continuous monitoring of groundwater levels and flow volumes is necessary. In order to get the most reliable results from this tool, WF data must be updated regularly and adapted for different areas. If irrigation water has high levels of nutrients the WNB framework can also be used to estimate production in terms of nutrient availability, in which case, nutrient concentrations in the irrigation water and requirements of the crops are also needed. The value of this work is that the framework has been tested on two Agri-parks, and can now be applied to other Agri-parks in South Africa. If the tool is adopted by Agri-park managers there will be strong motivation to do more careful estimation of the WFs of the crops grown.

3.4.2 Rooiwal water feasibility

In terms of water quantity, current production in the Rooiwal Agri-park is sustainable, compared to total water availability in the Apies River Catchment and increased production can also be considered, if the necessary infrastructure is developed to abstract water from the river. The vegetable crops that are currently produced is considered suitable for the Rooiwal Agri-park, because of the relatively low WFs of vegetables, compared to grains such as wheat and maize and cattle. Based on the fact that feed is sourced from outside the catchment, the WF of the broilers on-site is also relatively low.

However, there is uncertainty about the availability of groundwater underneath the Rooiwal Agri-park. Farmers of the Rooiwal Power Station indicated that water scarcity is their main concern, but it is uncertain whether the reason for this is due to a lack of groundwater, a lack of pumps and other infrastructure or broken borehole pumps. In addition to the obvious importance of maintaining equipment, monitoring of groundwater levels should be done regularly to better understand the impact of abstractions on the local groundwater resource.

Groundwater under the Rooiwal Agri-park is polluted with sewage water from the adjacent WWTWs. Nitrate concentrations are particularly high. The potential negative effects associated with high nitrate concentrations from the borehole water at Rooiwal can be mitigated by 1) ceasing N fertilizer applications, 2) diluting the borehole water with the less N-rich water from the Apies River, 3) utilising the N-rich borehole water during times of vegetative growth and switching to water from the Apies River during times when plant N requirements are low, 4) utilising algicides such as copper sulphate to reduce algae growth within irrigation equipment, and 5) utilising screens or filters to prevent algae from storage tanks entering the irrigation system (Department of Water Affairs and Forestry, 1996). Due to the potential health risks associated with high nitrate concentrations in drinking water the water from the boreholes at Rooiwal should not be used for human consumption or for the washing and processing of produce. Potential effects of high TDS can be mitigated by 1) applying a sufficiently large leaching fraction to prevent salt build-up within the rootzone, 2) switching to salt-tolerant crops such as red beets, asparagus, and members of the squash family, 3) offsetting the reduction in yield by planting annual crops at a higher planting density, 4) converting to a high-frequency irrigation application schedule, and 5) converting towards more water-efficient crops so that irrigation water can be used to supplement rainfall, as opposed to full-scale irrigation (DWAF, 1996). High fluoride concentrations can be mitigated by keeping soil at a neutral to marginally alkaline pH to reduce fluoride solubility (Department of Water Affairs and Forestry, 1996). Borehole water could also be diluted with water from the Apies River, which contains substantially less fluoride.

3.4.3 Westonaria Agri-park

Historically, gold mines had significant impacts on the quantity and quality of water resources in the Wonderfonteinspruit catchment area. Significant increases in agricultural activities at the Westonaria Agri-park, to the extent that the Agri-park model aims, might proof to be unsustainable in terms of water quantity and quality of the ground- and surface water. According to the obtainable data the groundwater available to the Westonaria Agri-park is limited. Considering the water stresses in the Vaal River Water Management Area, it is also reasonable to conclude that surface water will be difficult to obtain. The increase in flows in the Wonderfonteinspruit between 1970 and 1999 might present an opportunity, which can be investigated, but it seems optimistic to assume that this water would still be available and that it could be made accessible to the Agri-park. The gaps in the data, especially for the past ten years is definitely an issue and limits our understanding of the current water availability.

Given the lack of water to Westonaria, cultivating lettuce in hydroponics seems to be the best possibility if the water quality permits, due to the low WF. However, despite the lack of water to the Westonaria Agri-park, the current practice of using municipal water should be strongly discouraged. This practice is a concern, because municipal water is a limited and expensive resource. Irrigating with municipal water is a waste of the high input costs that are required to treat municipal water to drinking water quality standards. And considering the large volumes of water required for irrigation, compared to domestic requirement, this is certainly an unsustainable practice that needs to be addressed.

3.4.4 Irrigation with effluent

There are many strong motivations to develop sewage effluent into irrigation water at the Rooiwal Agri-park, including water scarcity, the large quantities of sewage effluent that could be made available to them and the ecological service the Agri-park could potentially perform by utilising the nutrients that are currently being disposed of. Results on the responses from different role-players are discussed in **Section 4.3.2.** Initial results on crop quality does not indicate any important differences between crops irrigated with groundwater and effluent water, in terms of nutrient and heavy metal content of the crops, but the following must be kept in mind:

- These results were done over a short term and must be followed up by longer term studies;
- Using sewage effluent in a hydroponics system may have different results; and
- It was not possible to measure the impact on crop quality in terms of other risks such as transmission of organic pollutants and micro-organisms, which requires further research.

3.4.5 South African Water Quality Guidelines Decision Support System (SAWQG DSS)

The SAWQG DSS was found to be a useful tool that was simple to use. It accurately assessed the water quality and provided important guidelines for crop, soil and irrigation management at the Rooiwal Agri-park. The tool could not be used successfully for Westonaria, because of limited data, which presents a challenge in the use of the software. In future, the SAWQG DSS can also be linked to the WNB framework, as it automatically calculates what percentage of the crop's N, P and K requirements are being provided by the irrigation water.

3.5 Conclusion

It is therefore concluded that the Westonaria Agri-park is located in water-scarce Vaal River Catchment and available surface water is of poor quality. The Agri-park uses municipal water, which is an unsustainable practice. Catchment water management planning is required, and expansion of the Agri-park is not recommended.

Rooiwal is located in a catchment within the Apies River Catchment, which does have potential water sources available to the Agri-park. Poor monitoring of the local water resources limits the ability to properly plan, supply and allocate water. There is a good possibility of developing sewage effluent from the adjacent wastewater treatment works into a safe irrigation water source. Further research is required to determine and ensure the safety of consuming crops grown with sewage effluent.

The Water and Nutrient Balance Framework was developed to assist Agri-park managers in water management decision making. The tool has been tested on both the Rooiwal and Westonaria Agri-parks and is recommended as a simple and efficient tool to estimate potential production that can be achieved in terms of the quantity and quality of available water.

4 FIELD LEVEL MANAGEMENT OF WATER IN AGRI-PARKS

4.1 Introduction

This section specifically addresses **Aim 3.1** of the project 'To co-design sustainable agricultural practices through active cooperation between small-scale farmers, FPSUs and scientists using principles of sustainable intensification' (**Section 1.2**). The project team interacted with Agri-park farmers to better understand which tools and technologies can improve their water use efficiency and production outcomes. A variety of tools were available and some new tools were developed to improve water use efficiency and improve crop production of Agri-parks. Tools included in the experimentation were selected based on the following principles:

1. The re-use of waste is critically important, not only to establish more sustainable circular economies, but also because Agri-parks particularly target resource poor farmers;
2. Tools must be simple and cost effective; and
3. Farmers must be actively involved in the process of selecting or developing the tools that are presented to them. If farmers do not use a tool; change the tool, not the farmer.

The project team presented several possible solutions to the Rooiwal Agri-park farmers, in response to the problems that they currently experience. These problems and the solutions presented are summarised in **Table 4-1**. The possible solutions and technologies that were proposed to the Agri-park farmers, included the use of effluent water for irrigation, the optimal utilisation of organic waste such as compost or chicken manure, application of mulch material, the use of soil moisture sensors, such as the wetting front detectors (WFD) (Stirzaker, 2003), and chameleon sensors (CS) (Stirzaker, 2014) and the use of social media to access extension services. The question was whether the Agri-park farmers were interested in the tools, what the challenges were in using them and finally if Agri-park farmers actually started to use the tools. If these tools are successfully adopted by the farmers at Rooiwal, farmers from other Agri-parks can be exposed to such technologies through the Agri-parks' support and training units.

Table 4-1: Problems experienced by Rooiwal Agri-park farmers and the technological solutions presented in response

Problems Experienced by Rooiwal Agri-Park Farmers	Technological Solutions Presented in Response to these Problems
Water scarcity and sewage pollution	Using sewage effluent for irrigation
Inefficient irrigation	Soil moisture sensors
Weed pressure	Mulching
Low production and high input costs	Substituting fertilizers with chicken manure
Lack of extension services	Social media platforms

4.2 Materials and Methods

After visiting various Agri-parks, the Rooiwal Agri-park was selected to be the primary study area where trials and experiments were done. Rooiwal was considered the most suitable research area for a number of reasons:

- The initial trial at Shoshanguve were destroyed, thus the team made the decision to continue research at Rooiwal;
- The size of Rooiwal Agri-park and diversity of produce is relatively much higher than other Agri-parks;
- The proximity to the WWTW provided the opportunity to obtain effluent water for the feasibility study on irrigation with effluent water;

- The broiler farm at Rooiwal provided the opportunity to investigate the use of chicken manure in vegetable farming; and
- The City of Tshwane (CoT) and the farmers at Rooiwal were cooperative and assisted the team with the research trials.

4.2.1 Stakeholder engagement in Agri-parks / FPSUs

The project team engaged with the Agri-park farmers to better understand the current challenges on their farms, to identify existing tools and technologies that could support them and also to work with them to co-develop new tools that could assist them to improve production and water use efficiency. The stakeholder engagement process included following activities:

- Interaction with the CoT:
  - Obtain permission to conduct research (**Appendix 8**);
  - The CoT extension officer joined certain site visits and the Focus Group Meeting;
  - To discuss the feasibility study on irrigation with effluent water; and
  - Interactions with the WWTW to discuss their challenges and possible cooperation.
- Interactions with Rooiwal Agri-park farmers:
  - On-site meetings with the farmers;
  - Training of the farmers;
  - Implementation of tools, technologies or practices chosen by the farmers;
  - On-going liaison, monitoring and guiding of the participating farmers; and
  - Interviews, both informally and during the Focus Group Meeting to discuss their perceptions and ideas.
- Interactions with farmers from other Agri-parks:
  - Soil moisture trial at Soshanguve Agri-park; and
  - Farmers' Demonstration Day for Johannesburg farmers at Westonaria Agri-park.

4.2.2 Rooiwal Agri-park: Responses to irrigating with sewage effluent

The responses of different role-players, including Agri-park farmers, the CoT and the managers at the WWTW at Rooiwal, to irrigating with sewage effluent was determined during interviews and through the feasibility study at the Rooiwal Agri-park. Comments and statements as well as commitment and cooperation during the study were recorded.

4.2.3 Rooiwal Agri-park: Development and application of the Vundisa Manure Application Tool (VMAT)

At the Rooiwal Agri-park there is a potential opportunity for vegetable farmers to use the chicken manure from their neighbour. Using chicken manure for crop production, has the benefits of reducing chemical fertilizer needs, reducing water pollution of leached nutrients, improving soil health and crop production. Improved crop production also translates to more efficient water use. Farmers at Rooiwal have previously used chicken manure and some had a few objections to the practice. It seems as if the main problem is a lack of understanding on how to apply the manure. The need was identified for the Vundisa Manure Application Tool (VMAT), which provides the output of a recommendation on the number of wheelbarrows or shovels of chicken manure to apply to a certain area of different crops.

In this approach we determined the quantity and quality of chicken manure produced at the Rooiwal Agri-park to better understand the potential savings that could be achieved by using these organic waste products. Chicken manure samples were taken at the broiler farm at Rooiwal Agri-park on 5th December 2019 to determine the nutrient content and the possible benefit of using it as fertilizer. The chicken manure samples were dry and mixed with sawdust. Samples were immediately stored in a cool bag with ice.

The samples were taken to the Agricultural Research Council – Soil Climate and Water (ARC-SCW) soil analytical laboratory for analysis. Air-drying, milling and mixing, for better homogeneity, was done as part of preparation before analysing the nutrient content levels. The chicken manure samples were treated in three ways before being analysed namely: wet, air-dried and machine dried. The pH, electric conductivity, moisture, ash and nutrient analysis was conducted. Details such as percentage of total solids, moisture lost and C/N ratio were included as part of the package offered by the ARC-SCW. Chicken manure affects the structure and enhances the water holding capacity of the soil, therefore elements such as moisture and total solids are important. Organic matter, ash along with the other nutrients indicate how much the manure could supplement the soil. It was important to take the following aspects into consideration:

- Many replicates of manure samples should be used;
- Chicken manure samples have to be fully composted so that measurement results are more accurately associated with nutrients available to plants; and
- The rate of chicken manure decomposition depends on the climate of the area, soil structure, soil aeration, the composition of the manure, specifically C/N ratio and finally the method of the manure application (Eghball et al., 2002).

4.2.3.1 *Nitrogen analysis*

Nitrogen was determined by first using a Thermo Scientific Flash 2000 Elemental Analyzer in a dry oxidation process called Dumas method (ARC-SCW 2020). Samples that weighed 9-13 mg were poured into tin containers that were ignited at 950°C to generate carbon dioxide, nitrogen gas and oxides of nitrogen. The oxides are filtered by using silver cobalt oxide and a column of copper. Water vapour is removed and N_2 and CO_2 were separated by gas chromatography detected by a thermal conductivity detector. A software called 'Eager experience' controls, calibrates and computed the N concentrations (Soil and Plant Analysis Council, 2000).

4.2.3.2 *Phosphorus and potassium analysis*

The Inductively Coupled Plasma Optical Emission Spectrometric, which is a multi-element instrument was used to analyse P and K simultaneously. Each element was measured at one or two appropriate emission wavelengths, chosen for high sensitivity and lack of spectral interference. The wavelengths used were 766.491 nm (& 769.897nm) for K and 213.618 nm for P (Soil and Plant Analysis Council, 2000). The results are found in the appendices and are measured in g/kg.

Standard equations were applied to the N, P and K data from the laboratory analysis to determine the amount of nutrients available for crop production at Rooiwal (Alberta Agriculture and Food, 2015). **Table 4-2** summarised the equations that were used in the VMAT to estimate the available nutrient content of manure.

Table 4-2: Equations used in the VMAT tool

Nutrient	Equation
Nitrogen (N)	Organic N = Total N – NH_4-N
	Available Organic N (Year 1) = Organic N * 0.25
	Retained NH_4-N = NH_4-N * Retention factor (given figure)
	Estimated Crop available N = Available Organic N + Retained NH_4-N
Phosphorous (P)	Estimated Crop available N = Total P * 0.7
Potassium (K)	Estimated Crop available K = Total K * 0.9

4.2.3.3 *Soil analysis*

Soil samples were collected at Rooiwal Agri-park on 21 November 2019 from the section of the farm where vegetables are currently being cultivated. The recommended depth at which soil samples for vegetable crops should be collected is 15-30 cm. Five soil samples were taken at random spots across the length of the field to obtain an idea of the nutrient levels from near to the water tanks, past the sewage manhole and to the end of the field. The samples were analysed separately, because we had reason to believe they were different.

The soil samples were analysed for the presence of N, P, K, Ca (Calcium), Mg (Magnesium), Na (Sodium), and Organic matter (Total N & P). Further, pH, exchangeable acidity, resistance and particle size were analysed. Soil test results and other information was used to determine how much fertiliser must be applied to the soil to meet the standard fertiliser recommendation for leafy and root crops in order to reach the desired yield. These recommendations follow the standard method of calculation for fertilizer application rates from measured soil analysis results (Soil and Plant Analysis Council, 2000).

4.2.3.4 *Development of the VMAT*

The VMAT is a simple spreadsheet, which uses relevant equations to estimate application rate and presents it in terms that small-scale farmers can typically understand. It was developed with the intention to sustainably make use of farm waste to improve production outcomes and improve water utilization at the Agri-parks. The VMAT assumes that N, P and K nutrients are available at 25, 70 and 90% levels, respectively. An assumption that farmers want the optimum yield for their crop is made so the target yields align to the recommended N, P and K requirements from each crop. The N, P and K requirements were obtained from Manson et al. (2011) and are constant values. The tool also assumes measurement units of g/kg, mg/kg and kg/ha.

In order for the farmers to be able to easily obtain a recommendation for their own field, the equations are programmed into VMAT. Soil results for N, P and K should be entered into the manure calculator spreadsheet. **Equation 4-1** was used to translate nitrogen from percentage to an amount present in the soil. Nutrient levels are measured in mg/kg which should be converted to kg/ha by multiplying the nutrient with bulk density (BD), effective soil depth (ESD) and 10 as a conversion factor (**Equation 4-2**).

$$N\ (mg.kg^{-1}) = Total\ N\ (\%) \times 10000$$

Equation 4-1

$$N\ (kg.ha^{-1}) = N(mg.kg^{-1}) \times BD\ (g.cm^{-3}) \times ESD\ (m) \times 10$$

Equation 4-2

Fertiliser recommendations for leafy and root crops were gleaned from literature. Cabbage, lettuce, kale and cauliflower were used as examples of leafy vegetable crops. For root crops: carrot, parsnip, beetroot and radish were used as examples. The average N, P and K recommendations for each group of vegetables was used for the tool (Scotland's Rural College, 2013).

Manure is applied on the basis of the critical nutrient, i.e. the element or nutrient most lacking in the soil, or that requiring the highest application to reach the target crop yield. This is the nutrient that is most inadequate in the soil. When manure is applied on this basis the concentration of the remaining elements that will be applied is then calculated. Phosphorus is converted to phosphates by multiplying available concentration by 2.3. Potassium on the other hand is converted to P_2O_5 by multiplying available potassium by 1.2 (Alberta Agriculture and Food, 2015) .

The equations are available to determine the N that will be available for plant growth and development through the season. Organic N is the difference between total N and ammonium N. Decomposition of manure happens over a time period of a couple of years, so it is of paramount importance to estimate the proportion N that will be available in the first, second and third cropping years. The retained ammonium N is calculated and added to available organic N.

Variables considered to determine the N, P and K application rate were target yield and crop type. The limiting factors were levels of existing nutrients in the soil (namely P), pH and electric conductivity. These are the factors that potentially limit the frequency of application as crops are sensitive to them, so unfavourable levels could stunt growth. The outputs of VMAT are application frequency, N, P and K required and finally the amount of manure typically needed to satisfy the vegetable crop requirement. Nutrients that will be made available in the soil over the next years were also considered. Another input is the amount of additional nutrients needed to be added to the soil in order to fulfil the nutrient requirement the crop needs for the current cropping season.

The VMAT was built in Excel to do fertilizer recommendation calculations, by entering the above equations in fixed cells. Then a column is used for the insertion of the measured amounts obtained from the manure analysis for the current location. The resulting answers from the equation then gives specific generated values for fertilizer and manure requirements. The Excel spreadsheet is then designed to be user-friendly for the potential clients and extension workers. The tool comprises of two parts, one is a farmer tool, and provides information on exactly the amount of chicken manure to apply to different crops in terms of the number of wheelbarrows or shovels. The second part is for Agri-park managers, and provides information on the size of a farm that can be supported with the available chicken manure, in terms of nutrient content.

4.2.4 Rooiwal and Soshanguve Agri-parks: Soil moisture sensors

Irrigation scheduling tools were introduced to farmers at the Rooiwal and Soshanguve Agri-parks, involving on-site training and liaison. A trial was initiated at Soshanguve Agri-park to test soil moisture sensors, which involved the installation of Wetting Front Detectors (WFD) and Chameleon sensors (CS), training and ongoing monitoring and guiding of the farmer, Ms Dorah Mando. A CS was installed at Rooiwal early in 2019 and the farmers received training on how to use it.

4.2.5 Rooiwal Agri-park: Mulching

During several conversations the practice of mulching was discussed informally with the Rooiwal Agri-park farmers. Mulching was also a topic discussed at the Focus Group Meeting on 25 February 2020 (**Section 4.2.7**). Mulch material was applied to the cabbage seedlings at Rooiwal (**Section 3.2.3**), which investigated the potential to irrigate with sewage effluent. The thoughts and feedback of the farmers with regards to the use of mulch material were recorded.

4.2.6 Online learning programme

In order to investigate the potential of Facebook as a platform to host e-learning programmes, a learning programme on the fundamentals of weed science was created. The topic was selected due to the influence of weed management on all aspects of production, and its importance in the context of small-scale farmers in sub-Saharan Africa.

The learning programme consisted of 14 ‘chapters’, with each ‘chapter’ comprising of a Facebook post focusing on a different topic of weed science. ‘Chapters’ were posted daily on the Ingesta: Farming for the Future Facebook page. Each post contained no more than 1500 words, and was published with supporting diagrams, figures, and pictures where applicable. Participants were required to complete a five-question multiple choice test at the end of each ‘chapter’, as well as a 30 mark multiple choice test at the end of the learning programme. Tests were hosted through Google Forms, and marked using the automated marking function.

Due to the small number of farmers currently within the CoT Agri-parks, it was decided that the learning programme would be open to the public to better understand the reach potential of social media. In order to promote the learning programme, as well as making the information contained in the 'chapters' as widely available as possible, the posts were shared into a number of Facebook groups that catered for small-scale farmers in sub-Saharan Africa. A total of 21 suitable groups were identified based on a combination of the group's activity, previous experience sharing Ingesta posts into the group, and permission for the Ingesta page administrators to post within the group as the Ingesta page itself.

Page and post data from the 14 days of the learning programme, as well as 28 days prior and following this period, were downloaded through the Ingesta page's 'Insight's' interface 28 days after the publication of the final chapter of the learning programme. Post data was also manually collected from the Post Details interface for each chapter post for comparison. 'Like', 'love', and 'wow' reactions were considered to be positive, while 'angry' and 'laugh' reactions were considered to be negative. Where necessary, significance was determined through t-testing.

4.2.7 Rooiwal Agri-park: Focus Group Meeting

After research was done on several technologies, all of which have been presented, discussed or implemented at Rooiwal during the first two years, a focus group meeting was arranged on 25 February 2020 to obtain feedback from the farmers (**Figure 4-1**). The aim of the meeting was to better understand how they feel about the information that was provided and what problems they had with these technologies.

Figure 4-1: A: Discussion on soil moisture sensors; B. Mr Hay showing the farmers how thick a mulch layer should be to prevent weeds from growing; C Farmer indicating that she likes the tensiometer; D Farmers filling in a draft version of the decision support tool on using chicken manure

The Focus Group Meeting was attended by the project team, a social scientist (Dr Attie van Niekerk from the Nova Institute), four farmers representing all groups farming at Rooiwal and a representative from the CoT. The following technologies that were investigated during the research project were discussed in four sessions:

- Effluent water for irrigation;
- Chicken manure for crop production;
- Soil moisture sensors; and
- Mulching.

4.2.8 Westonaria Agri-park: Farmers' Demonstration Day

4.2.8.1 *Attendance and agenda*

A Farmers' Demonstration Day was held on 20 February 2019 at the Westonaria Agri-park. The Westonaria Agri-park belongs to the Gauteng Department of Agriculture and Rural Development (GDARD), who assisted with the arrangements and preparations. All costs for the day were covered by WRC project funds, including meals and transport of the farmers. The WRC donated a folder and writing pad for each farmer. Fifty farmers from five different Gauteng Agri-parks namely Merafong, (10 people), Tarlton (8 people), Eikenhof (15 people), Slovoville (2 people) and Westonaria (15 people) attended the day (**Appendix 5**). The Farmers' Demonstration Day was also attended by 16 extension officers and government officials from GDARD and the Department of Agriculture, Forestry and Fisheries (DAFF).

During the Farmers' Demonstration Day each farmer attended four training sessions, which covered the following topics:

- Irrigation, presented by Prof Sue Walker from the ARC-SCW;
- Fertilization, presented by Prof Michael van der Laan from the University of Pretoria (UP);
- Agricultural technology (including a demonstration of the CS, WFD and the Ingesta Facebook page); presented by Mr Richard Hay from UP. Three pairs of WFD were given to farmers that showed the most interest during the demonstrations; and
- Pest and weed management, presented by Mr Sanele Dlamini from UP.

Presentations were also given by Ms Elize Lundall-Magnuson from the ARC – Plant Health and Protection on beekeeping and by Mr Obed Phahlane from the ARC-SCW on AgriCloud mobile App for planting rainfed crops.

4.2.8.2 *Questionnaire and data analysis*

Team members assisted farmers to complete a questionnaire to obtain necessary data. The questionnaire included questions on personal information, family history and background, current farm management and challenges experienced. Thirty farmers completed a questionnaire at the Farmers' Demonstration Day. The data from the completed questionnaires was compared with data collected by the ARC (2014) in a *status quo* analysis on selected beneficiaries of agricultural projects adopted by the Agri-park initiative. None of these projects investigated by the ARC are officially listed as Agri-parks, they are existing agricultural projects in some of the poorest communities in South Africa, but since they have been adopted by and benefited from the Agri-parks initiative we refer to them as Agri-parks. These Agri-parks included the following districts with sample sizes in brackets:

- Limpopo Province:
    - Sekhukune (69);
    - Waterberg (57);
    - Mopani (56);

    - Capricorn (50); and
    - Vhembe (52).
- Eastern Cape Province:
    - Sarah Baartman (49);
    - Alfred Nzo (48);
    - OR Tambo (56); and
    - Amathole (37).
- Mpumalanga Province:
    - Ehlanzeni North (56); and
    - Ehlanzeni South (54).
- KwaZulu-Natal Province:
    - Zululand (50);
    - UMzinyathi (33);
    - UMkhanyakude (60); and
    - Harry Gwala (56).

Our data from the Farmers' Demonstration Day was collected in 2019, which is 5 years after the *status quo* assessment done by the ARC (2014), and over time things could have changed. However, the data that was compared is dependent on less dynamic drivers such as access to water sources, availability of support, knowledge, capital and land, politics and distance to cities and services. It was therefore assumed that the 5 years difference in time when our data was collected compared to the ARC data, would not significantly impact the measured results.

4.2.8.3 *Telephonic follow-up with participants*

Participants received training on using Facebook to access extension services and gain information and advice on problems that they experience on their farms. Telephonic interviews were conducted to follow up on how many of these farmers actually started to use Facebook or other online sources. The participants who provided their contact numbers were telephonically interviewed between 10 and 20 July 2020 to gauge whether they found the training useful, what additional training they felt they needed, and whether it may be possible to provide some training over the internet. Of the 19 participants who provided a cell phone number, a total of nine could be reached.

The three participants who received WFDs at the FDD were also contacted in January 2020. The following questions were asked:

- Did you install the WFD in your fields?
- Are your still using the WFD?
- Do you find the WFD simple to use?
- Do you find the WFD to be useful and did it change the way you irrigate? and
- Have you experienced any challenges with using the WFD?

4.3 Results

4.3.1 Persona of Rooiwal farmers

On 21 November 2019 the project team visited the Rooiwal Agri-Park. There we met two farmers, a husband and wife working on their open fields (**Figure 4-2**). The husband, Takalani Mutavhatsindi, volunteered to talk to us, but did not remember the other team members from previous visits in 2018. After reminding him about the project it seemed as if a fog had been removed from his eyes, his face suddenly lit up and broke into a smile. He told the team how happy he was with the CS that we installed in one of his fields and how the WRC program had helped them. He led the team to the CS and recalled a time when they did not have access to any technology to measure soil water. The CS, however, was disconnected at the time and one wire was broken due to sun damage. According to Takalani, his wife, Tshifiwa Mutavhatsindi, works with him on the farm and records the soil moisture measurements in a diary. He continued to show us the spinach he grows and mentioned that he had received an order of a 1000 bundle of spinach from a local retailer. As his own spinach was not looking healthy, he had resolved that he would buy the required spinach from an associate farmer in order to supply the retailer. We noticed that the spinach plants were overcrowded, indicating that it had not been harvested for a couple of weeks. Further, they had lesions and holes in the older leaves, and the young spinach plants appeared stunted with a lack of chlorophyll production in the leaves. Takalani had some explanation for the poor condition of the plants. He recalled the time when he heard a buzzing sound from a distant side of the Agri-park, so he rushed to check and found many beetles he could not identify. The beetles damaged the entire field, leaving the spinach leaves with many large holes. Therefore, his crop was not able to be marketed and he had become despondent. This showed a gap in the knowledge of the farmer about pests and diseases that could occur on his crops. It also showed that he does not have any back-up support from the extension staff who he could called when such troubles occur.

By this time Takalani had warmed up to our team and took us to the part of his farm where they grow food for themselves. Plants like okra, squash and nectarines were growing there. He then began to quiz the project team on the different crops, to see if we knew the variety of crops him and his family consumed. We think he was pleasantly surprised that between us as a team we knew most of the crops and fruit trees that he was producing. However, it again became obvious that although there was a large variety of vegetable and fruit trees grown for his own family's consumption, he did not have support to upscale these and produce them even for the local surrounding informal market. If there had been support and weekly visits to discuss the various crops, then he could have been able to produce a good supply of vegetables and fruit from the existing crops. He would need assistance in planning a dedicated fertilization program together with a spray program for the pest and diseases likely to infect those specific crops. He showed signs that he is keen to learn more about the agronomic practices to be able to produce more vegetables. However, there is always a lack of funding for the input costs and transport to any nearby market.

Figure 4-2: Tshifiwa (wife) and Takalani (husband) on their farm in the Rooiwal Agri-park with their harvested Swiss chard crop

Takalani is a small-framed gentle man who easily volunteers information and likes learning. His Tshivenda name translates to 'be happy' and is quite fitting, as he possesses a very jovial spirit. Takalani loves working on the farm, seeing the results of his work but beyond that, he is religious and loves the natural environment.

He said: 'I like trees and grass, we have to conserve nature'. He feels very proud of the Baobab tree that he brought to Pretoria from Venda, which now grows at his house.

His wife, Tshifiwa, is a very knowledgeable, intelligent and composed. A minute with her can often feel like a lecture from a Crop Science textbook. She works alongside Takalani and the other farmers in the park and does most of the work that requires administration. Takalani said that he previously had partners, but they left the farm, because they were always fighting. He, Takalani, does not care about who the boss is, as long as they all work hard. But he is now happy, because his wife works hard and they want to do the same thing; they both want to farm.

'Food, food food' Takalani beams proudly at his harvested produce. 'This is what I do, I feed people, we are feeding the world'. He is very committed to his job, and really regards it as a calling more than a means to make money. He said that other people strike and do not go to work, but he does not strike, because he owns his farm and, therefore, he takes responsibility for it. He also said that 'if you want to farm, you have to be committed to your work'.

In the past few months, the farmers had experienced many setbacks due to pests, extreme weather (including winds and heavy rainstorms) and unavailability of water. He speaks about how their lack of infrastructure makes them more vulnerable to the effects of rainstorms. There has recently been a storm that caused their nets to collapse on their growing spinach and pepper. He displays concern when talking about the recent happenings but is clearly glad he has a rich harvest of pepper.

4.3.2 Rooiwal Agri-park: Responses to irrigating with sewage effluent

4.3.2.1 *Initial responses*

During the initial conversations with the Agri-park farmers (mainly the Mutavhatsindis family) and the manager of the WWTW it was found that most people are comfortable with the idea of irrigating with the available sewage effluent. The current manager of the Rooiwal WWTW has experience in irrigation with effluent water, after producing various vegetable crops, including lettuce and pumpkins, successfully at Sasol where he also worked at a WWTW, and he strongly supports the idea. The Mutavhatsindis family is willing to use the effluent. For Agri-park farmers the biggest concern is whether the CoT would give permission for them to use the effluent.

The team also held a meeting with the CoT on 17 December 2019 to determine if they would allow the farmers to use effluent water. The CoT indicated that they are very interested in the concept and that the team can go ahead with a feasibility study based on the existing permission letter, received in 2018. The CoT also indicated that small-scale farmers from Winterveld have previously looked into the possibility of using sewage effluent for irrigation, but they did not have the necessary knowledge and experience to do it. Therefore, lessons learned at Rooiwal can also benefit other Agri-park farmers and the community from Winterveld. The CoT did, however, warn that it could be a potential liability and the concept must first be approved by their legal department, before it can be taken to scale.

4.3.2.2 *Responses during the preparation of the trial*

Tshifiwa and Takalani Mutavhatsindi were very positive when the team first mentioned the use of effluent water. During the preparations of the feasibility study (**Section 3.2.3**), however, the commitment of the farmers was even more impressive. The farmers responded more positively and cooperated with more commitment compared to any of the other technologies that were presented to them. They worked very hard to assist the team to install the irrigation for the trial, to prepare the land and to plant the seedlings. During an interview they indicated that they work hard, because they need the water. They hoped the research will one day indicate that the crop is healthy to consume and that the CoT will give them permission to use the effluent water. Some of the relevant remarks that were made during the informal discussion while preparing for the land for the feasibility study include:

- Remarks on their current water challenges:
  - ‘We have been suffering for many years’ (Takalani);
  - ‘We are crying for water’ (Takalani);
  - ‘We need that effluent water badly, look at our crops, it is dry’ (Tshifiwa); and
  - ‘That farmers down the Apies River, they use that water from the river. But that water is polluted and it should not be used.’ (Takalani).
- Positive remarks on the effluent water
  - That effluent water is good water, there is nothing wrong with that water; and
  - The effluent water it is good, it is only really ‘human manure’.
- Religious remarks on using effluent water:
  - The Lord will show us the way; and
  - We must pray to get permission to use effluent water from the WWTW.
- Remarks made by officials from the Rooiwal WWTWs
  - The effluent is very good for irrigation, crops grown with effluent water are big and healthy; and
  - You will not have any problems using this water, many of the farmers in this area are using our water for their crops.

It is therefore clear that the farmers and the workers at the WWTWs are very positive about the idea of using sewage effluent for irrigation. The safety of consuming crops grown with sewage effluent is indeed a very important subject for future research, especially concerning crop uptake and potential risks of organic pollution, elevated levels of nitrates and micro-organisms in sewage water. What this research does proof, however, is that from a social perspective, there seems to be no resistance to the use of sewage effluent. Every other tool or technology that were presented to the farmers were either received with mild interest, sometimes with a few objections or completely rejected, poorly implemented and not well maintained. The re-use of sewage effluent, on the other hand, is accepted with enthusiasm and commitment.

4.3.2.3 *Responses during the Focus Group Meeting regarding irrigation with effluent*

During the Focus Group Meeting, Dr Betsie le Roux from the University of Pretoria gave a short introduction to the current research on how effluent water can safely be used for irrigation. Dr le Roux asked the participants to discuss three questions:

- What are the general problems you experience on the farm?
- Do you have a problem with irrigating with sewage effluent? Do you think it is gross/unhealthy?
- Takalani and his wife worked hard to help us with our research, what do you expect from our project team?

From the discussions it was clear that the lack of water is a big problem for the farmers. One farmer said: ‘You see, the climate changed, on warm days you find that the water is scarce. Sometimes, the plants do not grow, you can think the soil is tired, you give fertilizer, but the problem is not the soil, it is the sun. Also, there are conflicts between the groups of farmers working here’. Another farmer said: ‘If you do not rotate the crops, the soil becomes less productive. I find that I am losing the productivity on my soil’.

The farmers indicated that they have no problem using effluent water for irrigation, because commercial farms and smallholdings in the area are using that water for production. The Apies River and groundwater is full of sewage and other farmers are already using it. It is just the perception that is a problem. The representative from the CoT said that they can give this water to the farmers, if they want to use it. But their concern is that people may stop buying the products if they know that it is produced with sewage effluent. It is important to determine how the local market will feel about the practice. This has been identified as a topic for future research.

As far as their expectations are concerned, the farmers indicated that they hope that through the research they can get access to water and that the water can produce crops that are safe to eat. The representative from the CoT told them that it may take a long time for this water to become available, because the research must first be done and results made available.

4.3.3 Rooiwal Agri-park: Vundisa Manure Application Tool

4.3.3.1 *Farmers' responses to using chicken manure*

Rooiwal farmers are not allowed to keep free-range chickens, because of the broiler farm on-site. The CoT had advised against this since it poses a health threat to the broilers. They sometimes use chicken manure from the broiler farm, and compost on their crops. However, they limit their use of it or otherwise use it in conjunction with store-bought chemical fertiliser. Takalani claimed that using manure did not yield as much produce as fertilizer. Further, he said that crops fertilised with manure took much longer to grow. His wife, Tshifiwa, claimed that when manure is applied to the soil it blocks infiltration, preventing the crop from accessing water.

-.....'sometimes crops can suffer and die, when we use of manure because they are not getting water'

Another farmer (Ethel) claimed that when fertilizer is applied, the stems of crops become stronger much quicker, once they have been transplanted. She also spoke about disadvantages she attributes to using too much fertiliser. She claimed that when one uses fertiliser unnecessarily, the crops produced are bitter or just have a different taste. There were farmers at Rooiwal who indicated they were not able to afford fertilizer and used chicken manure as an alternative. One of them, Joyce, made positive remarks about chicken manure.

Joyce:

- 'I use chicken manure, because I know it works and I see the results'

As shown in **Appendix 6** the air-dried sample of chicken manure taken from the compost heap (CH) results indicate a pH of 8.53 and 8.98 while the air-dried sample of the sawdust (SD) manure is 8.14. Ash content was measured to be 80.8 and 69.1% for the CH samples and 15.1% for the SD sample. Ash found in chicken manure contains elements such as chlorine, K, Na, P, etc. Organic matter measured at 898.8 and 891,7 g/kg for CH sample and 915 g/kg. Total C measured at 9.0 and 16.6% for the CH sample and 38% for SD sample. The result for total N was 1.11 and 1.62% for CH and 3.15% for SD sample.

During the Focus Group Meeting on 25 February 2020, Ms Zibuyile Dlamini from the ARC-SCW gave a presentation on the benefits of using chicken manure instead of inorganic fertilizers. She then introduced a draft version of a simple decision support tool that she was developing to assist farmers on how much manure is required for crop production. The farmers completed the flow chart with their information and seemed interested in the tool.

4.3.3.2 *Outcomes of the VMAT tool*

The average soil test measurements for the samples from Rooiwal Agri-park for N, P and K were 0.07%, 133.2 and 80.6 mg/kg respectively. The average bulk density was 1.2 g/cm^3 and effective soil depth 0.2 m. Manure results indicate that N as NH_4-N, P and K measured 31.5, 1.05, 10.9 and 28.9 g/kg respectively. The details of the Excel calculation spreadsheet is shown in **Figure 4-3**.

Based on field observations during the course of the project, it was estimated that about 5.4 ha out of 6 ha (90%) of land is used to produce a leafy vegetable crop, including Swiss chard, on Rooiwal Agri-park. It was also estimated that root crops are produced on 0.6 ha of the 6 ha. The broiler farm produces a volume of 10 800 kg chicken manure, from 4 broiler houses per month. Therefore, the total volume of N, P and K produced is 340.2 kg, 117.72 kg and 312.12 kg per month (**Figure 4-4**). The elements N, P and K currently absorbed by leafy vegetables at Rooiwal is 1 350, 108 and 1 296 kg respectively, while root crops use up to 90, 15 and 114 g during one whole crop growth cycle. These amounts are then used in a calculation for the potential productivity of the Rooiwal Agri-park per season.

The VMAT indicated that currently there is 13 times more P in the manure compared to how much the leafy vegetable crop on the farm requires, assuming four annual crop cycles. The root crops have a lower nutrient demand as they, on average, use less N, P and K. Nitrogen and K levels in the manure are 45 and 32 times larger than what root vegetable crops currently use in one year. Had there been a shortage of nutrients, the manure would be able to fertilize 3 times more land than currently under vegetable production at Rooiwal to support leafy crops, assuming manure application is done on the basis of N. The nitrates in the manure from the broiler houses on the Rooiwal Agri-park can therefore fertilize 16 ha of the total of 30 ha of available land. Fertilization using manure would enable at least 27 ha of land to be productive for root vegetables, in terms of the N content. The excess could also be sold in bags to local nearby farmers to generate some income and boost productivity of the surrounding area.

Soil results for the Rooiwal Agri-park indicate that there is already an abundance of nutrients, especially nitrates. This is probably due to the high levels in the groundwater which is used for irrigation as well as an effluent leak that occurred in 2018. Nitrogen concentrations were higher than both the other nutrients which was anticipated from a knowledge of the conditions at the site. The VMAT calculator, showed that no additional nutrients should be added to the soil in order to reach target nutrient requirements for vegetable production. Farmers can however, use the VMAT to get an indication of the level of excess nutrients that are present. They should make use of practices that reduce the existing P and N load. One of the management strategies is deliberate leaching of nutrients, which unfortunately requires a large volume of water. To reduce P levels, crops can be rotated with high P demanding vegetables (Sheffield R et al., 2008). We are aware that high concentrations of nitrates in the soil could have a negative effect on root crops during the later crop stages. Farmers should be observant to check for this impact and make necessary management plans to counter this effect.

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MANURE TEST RESULTS

AVAILABLE NUTRIENTS FROM SOLID CHICKEN MANURE IN ONE YEAR

NITROGEN (g/kg)

Total N (%)	Ammonia NH4-N	Organic N	Available Organic N	Retained NH4-N	Crop available N
31.5	1.05	30.45	7.6	0.91	8.5

PHOSPHORUS *(g/kg)* / POTASSIUM *(g/kg)*

Measured P	Crop available P	Measured K	Crop available K
10.9	7.6	28.89	26.0

SOIL TEST RESULTS

Total N (%)	N (Nitrogen) *(mg/kg)*	P (Phosphorus) *(mg/kg)*	K (Potassium) *(mg/kg)*	Bulk Density *(kg/l)*	Soil Depth *(m)*
0.07	700	133.2	80.64	1.2	0.15

Total N as a percentage multiplied by 10000 gives value in mg/kg

N (Nitrogen) *(kg/ha)*	P (Phosphorus) *(kg/ha)*	K (Potassium) *(kg/ha)*
1260	239.8	145.2

Crop type	Target yield *(kg/ha)*
Leafy crops	10000- 40000
Root crops	10000- 40000

ESTIMATING FERTILISER REQUIREMENT *(kg/ha)*

Crop type	N (Nitrogen)	P (Phosphorus)	K (Potassium)
Leafy crops	250	20	105
Root crops	150	25	85

ADDITIONAL NUTRIENTS REQUIRED TO SATISFY FERTILISER REQUIREMENT *(kg/ha)*

Crop type	N (Nitrogen)	P (Phosphorus)	K (Potassium)
Leafy crops	-1010.0	-219.8	-40.2
Root crops	-1110.0	-214.8	-60.2

Negative results indicate adequate nutrients in the soil and no additional fertilizer is required

MANURE APPLICATION RATE *(tons/ha)*

Manure applied based on the N requirement

Crop type	Manure applied for N	P_2O_5 applied	K_2O applied
Leafy crops	0	0	0
Root crops	0	0	0

	P_2O_5 balance	K_2O balance
Leafy crops	0	0
Root crops	0	0

A positive P2O5/K2O balance result indicates an under-application.

A negative balance indicates an over-application of P2O5/K2O and additional P/K fertilizer may be required.

CALCULATING MANURE APPLICATION RATE *(tons/ha)*

Manure applied based on the P and K requirement

Application rate= Reference nutrient recommendation / Reference manure nutrient concentration

Crop type	N (Nitrogen)	P (Phosphorus)	K (Potassium)
Leafy crops	Manure applied to satisfy	0	0
Root crops	P or K requirement	0	0
	N (Nitrogen) applied P based		
Leafy crops	0		0
Root crops	0		0
	N (Nitrogen) applied K based		
Leafy crops	0	0	
Root crops	0	0	

Manure is applied based on the element with the positive figure, indicating quantinty of manure that shoud be applied to satisfy that requirement

TRANSLATION TO LAYMAN'S TERMS

Quantification of manure applied using farm tools (shovels and wheelbarrow

1 Shovel = 5kg

1 Wheelbarrows = 60 kg

Crop type	Shovels	Wheelbarrows
	Application on the basis of N	
Leafy crops	0.0	0.0
Root crops	0.0	0.0
	Application on the basis of P	
Leafy crops	0	0
Root crops	0	0
	Application on the basis of K	
Leafy crops	0	0
Root crops	0	0

Numbers that are negative (meaning there is no need to apply manure on that basis) are floored to zero

The spreadsheet indicates the total amount of manure that should be applied to reach the target yield

Figure 4-3: Vundisa Manure Application Tool Excel spreadsheet

Nutrients required by leafy veg (g/ha/growing season		**Nutrients required by root veg (g/ha/growing seaso**	
Nitrogen	250000	Nitrogen	150000
Phosphorus	20000	Phosphorus	25000
Potassium	240000	Potassium	190000
Leafy veg produced at Rooiwal (ha)	5.4	Root veg produced at Rooiwal (ha)	0.6
Annual crop area of leafy veg (4 harvests)(ha)	21.6	Annual crop area of root veg (ha)	1.2
Total nutrients used by leafy veg at Rooiwal (g)		**Total nutrients used by root veg at Rooiwal (g)**	
Nitrates	1350000	Nitrates	90000
Phosphates	108000	Phosphates	15000
Potassium	1296000	Potassium	114000
Total nutrients used by leafy veg at Rooiwal (kg/ha)		**Total nutrients used by root veg at Rooiwal (kg/ha)**	
Nitrates	250	Nitrates	150
Phosphates	20	Phosphates	25
Potassium	240	Potassium	190
Nutrients availability: requirement ratio		**Nutrients availability: requirement ratio**	
Nitrates	3.0	Nitrates	45.4
Phosphates	13.1	Phosphates	94.2
Potassium	2.9	Potassium	32.9
Potential leafy veg crop area ito N (ha)	16.3	Potential root veg crop area ito N (ha)	27.2

Figure 4-4: Vundisa Manure Application Tool spreadsheet for calculation of potential vegetable production from broiler chicken houses manure

4.3.4 Rooiwal and Soshanguve Agri-park: Soil moisture sensors

Ms Mando from the Soshanguve Agri-park was initially very impressed by the chameleon sensors (CS) and the Fullstop Wetting Front Detectors (WFD) as it was clear that she was over-irrigating, even though she struggled to get enough water. However, one month into the trial a miscommunication between Ms Mando and a contractor resulted in the research field being ploughed over. All WFDs, CS, capacitance sensors, and data loggers were destroyed. The tractor also broke much of the shade-net structure, as seen in **Figure 4-5**. Data from the record book showed that since the installation of the WFDs and CS arrays Ms Mando had reduced irrigation time by between 30 and 50% compared to the irrigation schedule used in the field prior to the installation of the tools. However, due to the destruction of the equipment no water balance could be calculated to quantify water savings. In consultation with Ms Mando regarding her experience with the WFDs and CSs, she expressed that her experience was positive and that she felt that these tools were a benefit to her production system. Ms Mando stated explicitly that she felt these tools should be provided to farmers as part of the Agri-parks support.

Figure 4-5: Damage at the Soshanguve Agri-park test site 12/12/2018

After the damage that was done at Soshanguve, the idea was to move the trial to Rooiwal, but that could not be done, because the of the sewage leaks that were there at the time and the famers that participated, the Mutavhatsindi family, had no plans to plant another crop in the foreseeable future. The one CS that was installed at Rooiwal remained there, however, it was never used and was always disconnected during subsequent site visits. The field in which it was installed was also left fallow in 2020, but the CS was not moved to the new fields. Nonetheless, the farmer, Takalani Mutavhatsindi, indicated that he was very impressed by the tool, and the reason for the poor use of the technology is currently uncertain.

During the Focus Group Meeting, Mr Richard Hay presented three different tools that measure soil moisture, including the WFDs, CS and the tensiometer. Takalani Mutavhatsindi said that he prefers the CS, which he knows because it was installed on his fields. He likes it because of its simplicity to interpret. He also said it helps him to schedule irrigation. Ethel, an old lady who farms on her own, said that she likes the tensiometer, because 'you can see there is water in it; it works like a plant, but it is talking to you'. She does not like these appliances that you take out of the soil, put into a computer and then the computer is telling you how much water is in the soil.

4.3.5 Rooiwal Agri-park: Mulching

Rooiwal has a particularly high weed pressure, which the farmers are often unable to control. During the course of the project, a field of spinach had to be abandoned because of weeds outgrowing the crops. Apart from weeds, mulching can also reduce evaporative water losses, saving scarce water resources. The farmers assisted with the application of mulch to the cabbage fields (**Section 3.2.3**) and even gave their expert opinion on how to apply mulch. They demonstrated that a thick layer of mulch must be placed under each cabbage seedling and the leaves of the seedlings should be above the mulch material. However, despite the fact that they know how to apply mulch, they do not use it in their own fields. At one point during the feasibility study, the team was unable to visit the farm for two weeks. After the two weeks, weeds that were not there during the previous visit have almost taken over the cabbage field (**Figure 4-6**). Some cabbages were completely covered by weeds and these were smaller than those that were still growing above the weeds. The weeds were removed by hand and more mulch material was added under each plant. The farmers diligently applied water to the trial, but they did not do anything about the weeds. This seems to the normal practice at Rooiwal.

Figure 4-6: Weed growth on the cabbage field at Rooiwal after two weeks

Mulching was also discussed during the Focus Group Meeting at Rooiwal on 25 February 2020. The farmers said that they know about mulching and they agree that it is beneficial, because the soil underneath the mulch is always cool and moist. They have tried it, but they stopped the practice, because they experienced several problems including:

- The seeds brought with the mulch material causes more weeds to grow;
- The mulch material around them is not always available throughout the year;
- The size of the fields is too large for them to apply the mulch material;
- The maggots eat the mulch material and take it below the ground. Then after a few weeks you have to put down more mulch; and
- It does not bring them money.

One lady, Ethel, indicated that she cleans all crop residues from her fields, because that is the way she learned to do it. She said: 'You have to clean your fields before planting'. This same woman, however, started applying mulch to her fields soon after the Focus Group Meeting, and she was impressed by the immediate positive effect it had on weeds and soil moisture (**Figure 4-7**). In response to the farmers' problem to apply mulch material to large fields, a WRC reference group member indicated that it is often more productive to farm on smaller, but more manageable fields where mulch can be applied and managed, than to farm on larger fields, which may result in poor production.

Figure 4-7: Rooiwal farmer, Ethel, showing the mulch layer she applied to her fields after learning about it at the project's focus group meeting

4.3.6 Online learning programme

Terminology in this section is used as is in the data files downloaded from the Ingesta page's Insight's portal. Definitions were adapted for clarity and brevity, and provided in **Appendix 0.** Response to the learning programme had a dramatic effect on the page's Likes, daily Page Engaged Users, and daily Total Reach, with the bulk of the activity occurring during the 14-day period of the learning programme. This period is indicated by the third and fourth vertical lines in **Figure 4-8**, which denote the publishing of the first and fourteenth chapters of the programme. The second to thirteenth chapter posts are the only posts in the 70-day period not indicated with vertical lines, for the sake of figure clarity. Between the 28 days prior to the announcement of the learning programme and 28 days after the publishing of the final chapter, the page amassed 2045 Likes, almost tripling its Lifetime Total Likes. This was the highest activity level in the life history of the Ingesta page.

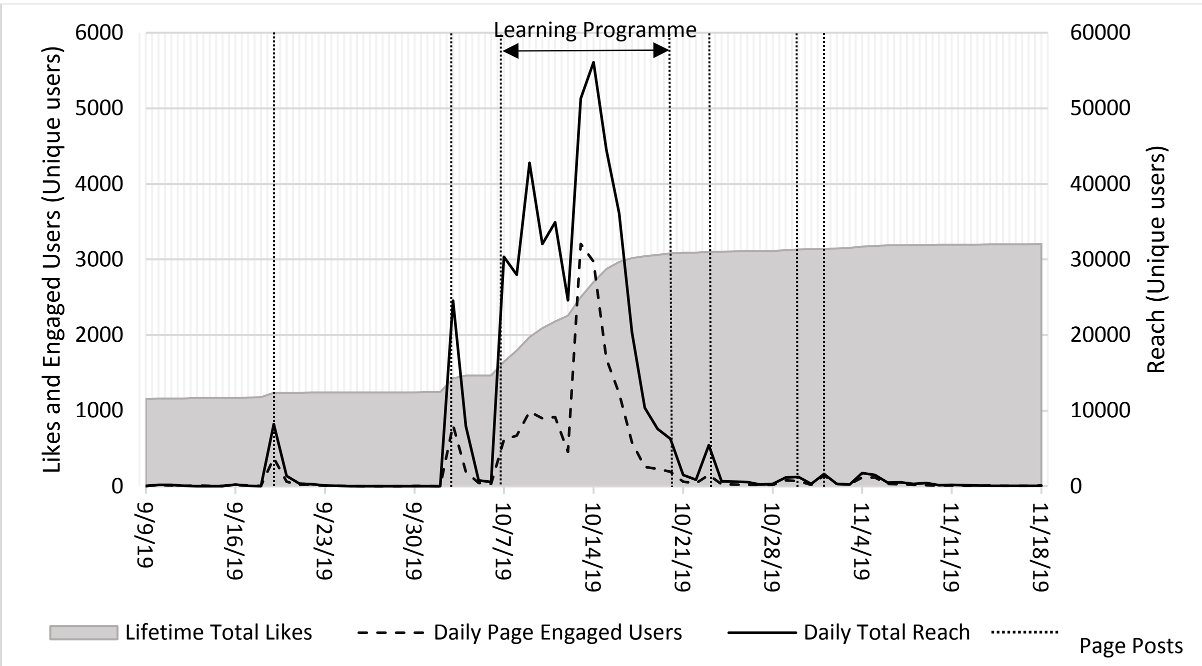

Figure 4-8: Cumulative likes, engaged users, and viral reach of the Ingesta Page preceding, during, and following the learning programme

In terms of page Reach, the specifics of what Facebook constituents as 'reaching' a user are unknown. It is likely that this is a measure of the number of unique users on whose timeline the algorithm has loaded information relating to the page, without a minimum threshold of how long the information needed to remain visible to the user. At page-level, Reach data is provided as Total, Organic, Viral, and Paid Reach. It logically follows that Total Reach is a function of the three, however due to the privacy of Facebook's algorithms it could not be confirmed. As no paid posts were used during this period, daily page and post Paid Reach were consistently zero. The sum of daily page Organic and Viral Reach was, however, not equal to daily page Total Reach indicating an overlap between page Organic and Viral Reach in some areas. Post-level data does not include a Viral Reach component indicating that the user activities that contribute to page Viral Reach do not pertain to posts, although it is unknown what these activities are. Mean daily page Organic Reach was found to be 96.23% of mean daily page Total Reach, while mean daily page Viral Reach was found to be 28.32% of mean daily page Total Reach and 29.86% of mean daily page Organic Reach over the 70-day period. Statistical analysis revealed that there was no significant difference (p = 0.49) between daily page Total and Organic Reach; however, this relationship may only be true in the context of this study and bears no indication on Facebook's algorithms.

The initial spike in daily page Engaged Users is attributed to an initial poll on user interest in enrolling in a free online learning programme, denoted by the first vertical line in **Figure 4-8**. The poll had a Total Reach of 585 unique users, of which 338 voted and 332 expressed interest. The second spike in daily page Engaged Users and Viral Reach is attributed to the post announcing the learning programme, denoted by the second vertical line in **Figure 4-8**. The post contained a link to a Google form through which 223 individuals, of which 174 were from South Africa representing all nine provinces, enrolled for the learning programme (**Figure 4-8**). Despite only sharing the learning programme posts into groups specifically focused on agriculture in SSA, eight individuals living outside of the region enrolled, indicating the presence of international members even within region-specific groups.

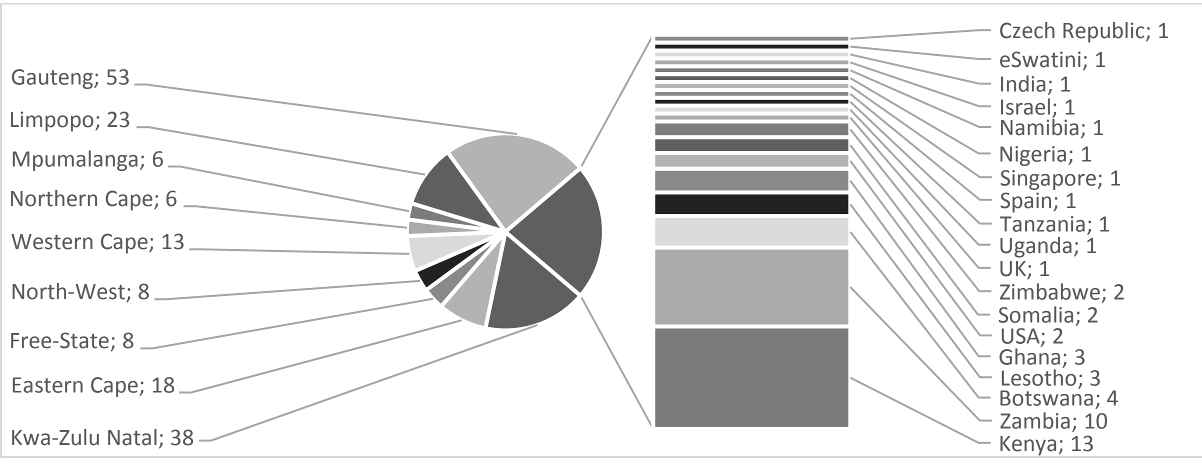

Figure 4-9: Location of individuals who enrolled in the learning programme

Initially 223 individuals enrolled for the learning programme, of which 173 were from South Africa. The remaining 50 individuals were largely from countries in sub-Saharan Africa including Botswana, eSwatini, Ghana, Kenya, Lesotho, Namibia, and Zimbabwe (**Figure 4-9**). However, there was a sharp decline in participation with only 78 individuals completing the first test and 37 individuals completing the final test (**Figure 4-10**). Only 34 individuals successfully completed the full programme, of which 25 were South African.

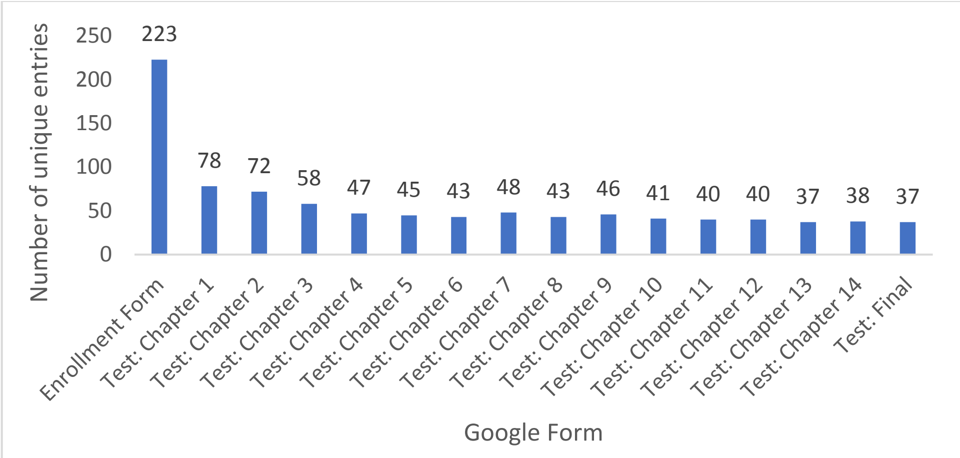

Figure 4-10: Number of unique entries for each Google Form

Of the 34 individuals that completed the programme 17 were already farming, with only four having at least partial ownership of the land they farmed. The remaining 13 either farmed on communal land (9), rented land (3), or worked on a farm (1). The majority (9) farmed an area less than 1 hectare in size, while six farmed an area between 1 and 5 ha, one an area between 5 and 10 ha, and one an area greater than 100 ha. Almost all indicated that they grew vegetables. Fourteen indicated they had no formal agricultural training, with the remainder having received an evenly spread variety of training from Agrisetas and other short courses to holding Bachelor degrees in agricultural sciences. All individuals indicated that their reasoning for signing up for the course was to advance their own knowledge and skills to either have the necessary skills to become a farmer, or to be a more efficient farmer if they were already farming.

The majority of the participants who completed the programme accessed the programme via mobile devices, with 75% accessing the programme solely or mostly through a mobile phone or tablet (**Figure 4-11 A**). In terms of the content, 94% of the final participants found the programme either easy or very easy to understand (**Figure 4-11 B)** and 91% indicating that the length of the chapters was just long enough (**Figure 4-11 C**). The most popular option for further development was a chapter published every day with a total of five chapters or less or between 10 and 15 chapters, securing 10 votes each (**Figure 4-12**).

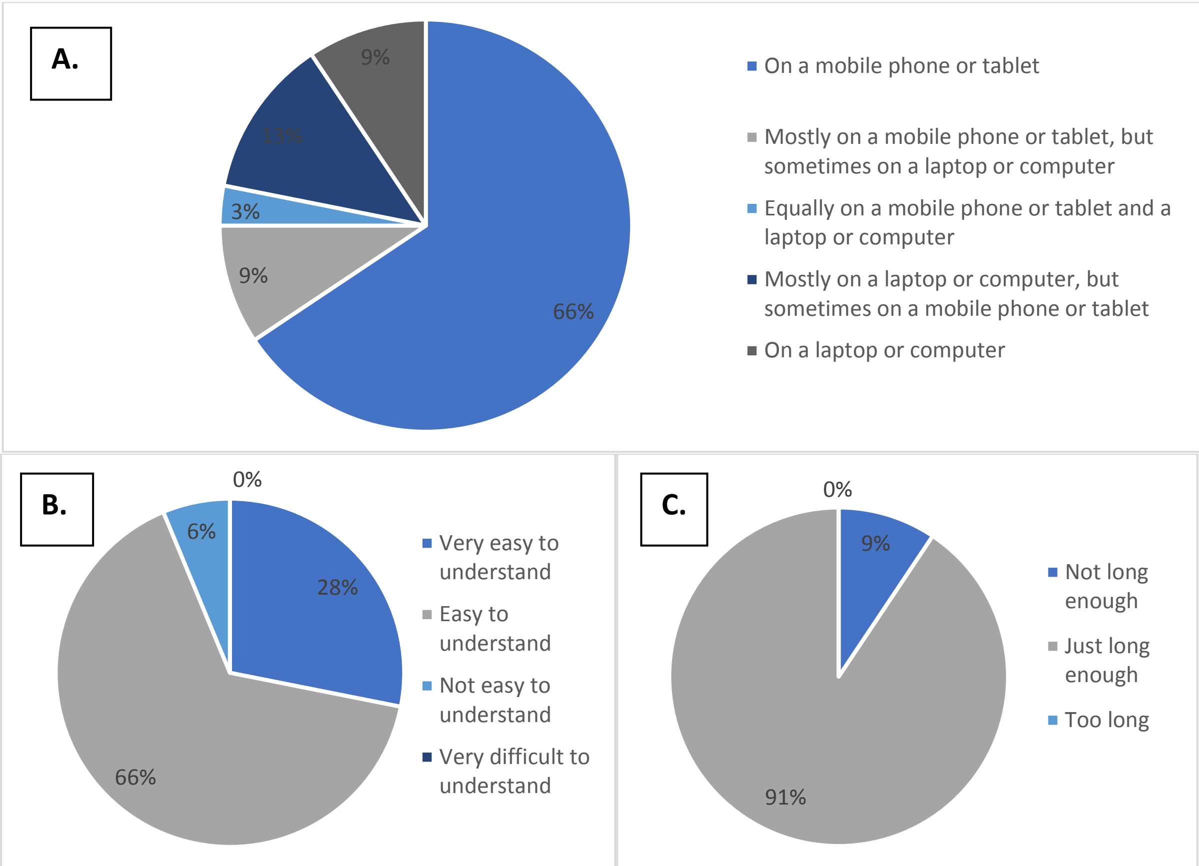

Figure 4-11: Feedback from participants who completed the online learning program: A: Device through which final participants accessed the learning programme. B Final participants' opinion on ease of understanding of the learning programme's content and C: Final participants' opinion on the length of the learning programme's chapters

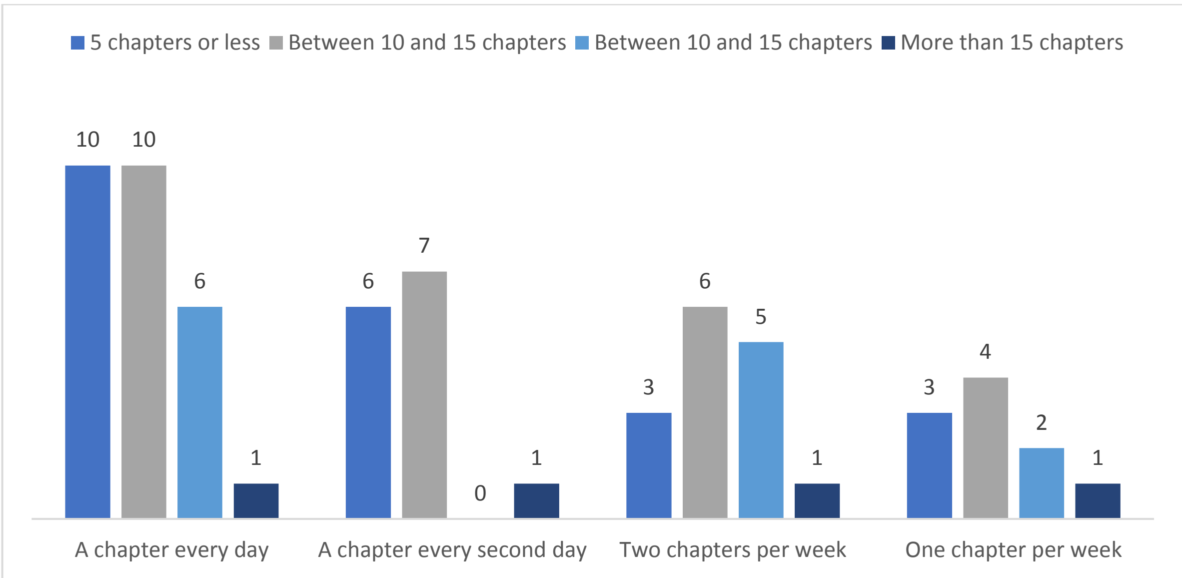

Figure 4-12: Responses to the question: 'If we develop more learning programmes, how long should they be and how often should we publish the chapters?'

Two of the final participants indicated that they had troubles accessing the posts, of which one cited the reason being that they did not receive notifications when the posts were published. However, another participant stated in their answer that they had followed the steps to turn page notifications on and had received them. Eight of the participants explicitly stated that they found the process to be easy, with two stating that they found the use of Facebook to be well organised. No participants indicated they had difficulties accessing the Google Form tests, with eight positively commenting on the ease of use and one commenting on the efficiency of the automated marking reports.

Two participants reported experiencing difficulties viewing the pictures. One participant, who accessed the learning programme solely through a mobile device, indicated that he found it difficult to reference the relevant picture between the long text. The other participant, who also accessed the learning programme solely through a mobile device, indicated that when they had a test open, if they went back to reference a picture in the chapter, they would have to restart the test. All other participants stated that they found the process of viewing the images to be simple.

One participant indicated that they did not find it easy to read the information in the picture captions, however the cited reason was that they were "not used to working with herbicides". All other participants indicated that they did find this process easy, with 21 expressing additional positive comments relating to the pictures and the captions. Such comments included that they found the captions to be clear, well-explained, "in simple to understand English", and "more insightful as they highlighted information that one has would have missed if it was just a picture with no caption". Two participants who solely used a mobile device to access the programme did comment that they had to zoom in to read the text in some images, although both indicated that overall, they found the process to be easy.

All participants indicated that they had learnt information that they felt would better help them manage weeds in their fields, with 17 expressing additional positive comments. Comments included that they felt the learning programme was well summarised and would "be very beneficial for farmers to practice for sustainability within the agricultural industry", were able to "[pick] up a lot of information on weed management in just a short time", and that the information they had acquired was already being incorporated into their management decisions.

Participants gave a wide variety of responses on what topic they would want to see in a future learning programme covering all aspects of agricultural production, however it must be highlighted that the most common response type (Five participants) related to irrigation management and efficiency.

4.3.7 Westonaria Agri-park: Farmers' Demonstration Day

4.3.7.1 *Telephone interviews with participants of the farmers day*

Of the three farmers who have received WFD at the Farmers' Demonstration Day, only one could be contacted for feedback. The other farmers were unavailable on their telephones and email addresses and one them stopped working at the Agri-park shortly after the Farmers' Demonstration Day. The farmer who was contacted produces Swiss chard. He indicated that he uses his WFD, and that it helped him reduce the amount of irrigation water applied and that it saved him money. He did not test for nitrates, but he feels that irrigating less reduces the amount of compost that he has to apply. However, the depths at which he has installed the meters (estimated 1 m and 80 cm), is too deep for Swiss chard, and more water savings could probably be possible. He was then told to install the detectors at approximately 30 cm and 50 cm depth, and to stop irrigation when the wetting front reaches 30 cm. This farmer appreciated the information and showed a good understanding of how the tool works.

A summary of information from the telephonic interviews to determine their use of social media is provided in **Table 4-3**. Training around irrigation and soil water was identified as being useful to most of the participants, likely indicating challenges and uncertainties with managing water in the Agri-parks. The majority indicated a need for training on general agricultural topics (as opposed to specialised ones), motivating that there is still an urgent need for training on the basics of growing a crop for these Agri-park farmers.

Only four out of nine participants indicated that they could connect to the internet with their own digital device, and only three out of nine indicated that they make use of Facebook. The ages of people using social media or internet sources was 26, 32, 52 and 73. The ages of participants who do not use social media or other internet sources ranged from 30 to 65 years. Two participants had internet access, but do not use social media.

Table 4-3: Summary of information from the telephonic interviews

Farmer	Age	Agri-park	Previous training found useful	Training needed	Source of information	Use social media			Device to connect to internet
						Facebook	Twitter	Internet	
1	30	Tarlton	How to irrigate	Plant propagation	Agri-park training	No	No	No	No
2	32	-	Measuring soil water	Soil correction	Agri-park training	Yes	No	Yes	-
3	65	Merafong	Soil management	Planting vegetables	Officers from Randfontein	No	No	No	Yes
4	32	Westonaria	Crop irrigation	-	Fellow Agri-park farmer and father	No	No	No	No
5	48	Doornkop/ Soweto	Bee-keeping and fertilisation	How to cultivate spinach	Self	No	No	No	Yes
6	26	Tender expired	Crop irrigation	Crop rotation	Municipality workshop	Yes	Yes	Yes[1]	Yes
7	73	Eikenhof	"Did not finish"	General farming topics	Discussion in the tunnel	Yes	No	Yes	Yes
8	32	Tarlton	No	General farming topics	Nowhere	No	No	No	No
9	52	Open field next to Khutshong	When to plant	Open field farming	Online, books, study groups	No	No	Yes[2]	No[3]

- = Could not or would not say, 1 = uses Farmer's Weekly page, 2 = uses Google, 3 = reliant on someone else's device to connect to internet

4.3.7.2 *Personal information on Agri-park farmers*

The following sections shows the data that we have collected during the Farmers' Demonstration Day in February 2019, compared with the data on similar production units from the (Agricultural Research Council, 2014). Of the farmers that completed the questionnaire, 62% were male and 38% were female (See Gauteng West Rand data in **Figure 4-13**). Most Agri-parks that were evaluated by the Agricultural Research Council (2014) had notably more males than females, while the Agri-parks in KwaZulu-Natal mostly had more females **(Figure 4-13**). As shown in **Figure 4-14**, most of the farmers that attended the Farmers' Demonstration Day (West Rand, Gauteng) were between 18 and 35 years of age, making it the Agri-park with the most farmers within the youngest age group, as compared to ARC data. The age categories used for West Rand data in **Figure 4-14** were selected to correspond with the available ARC data. It is interesting to note that in 10 out of 16 Agri-Parks, the numbers of farmers over 61 years of age exceeded farmers in the younger age group, 18 to 35. It would be interesting to observe the long-term trend in this data, because it might be that the younger generation is not interested in farming, or it could be that people generally start to farm at a later age, or only if other employment opportunities are not available.

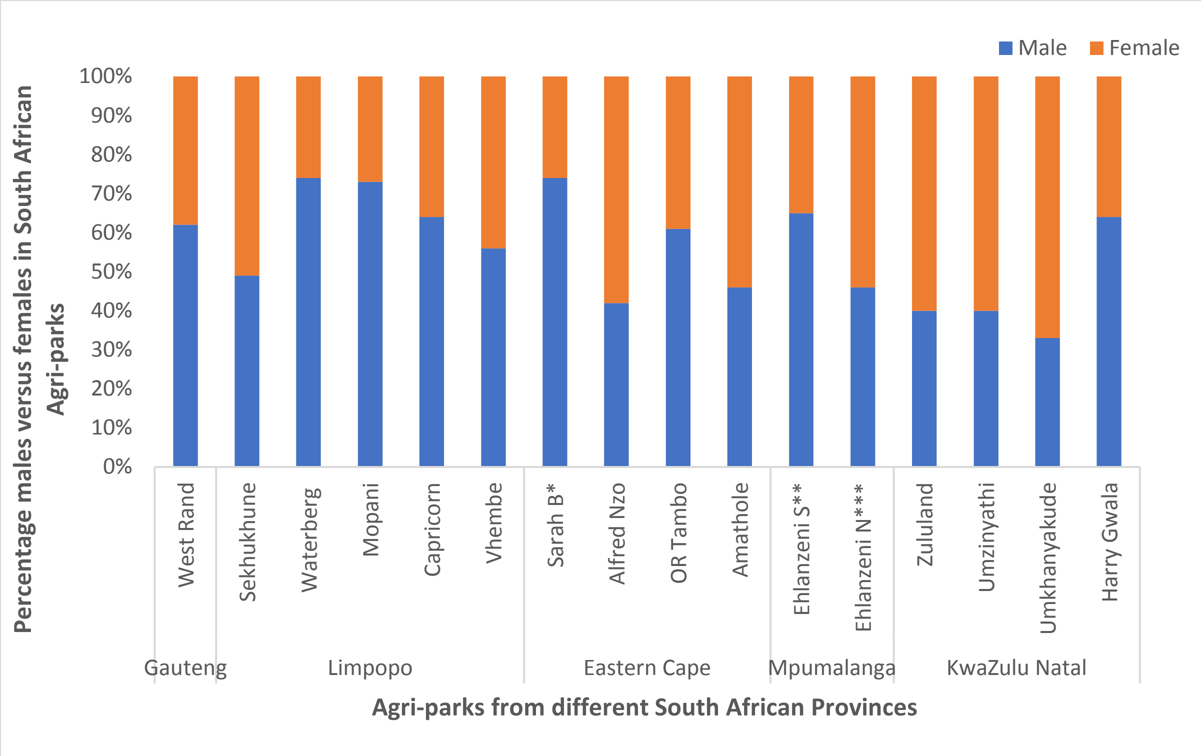

Figure 4-13: Gender balance between males and female farmers at South African Agri-parks[1]

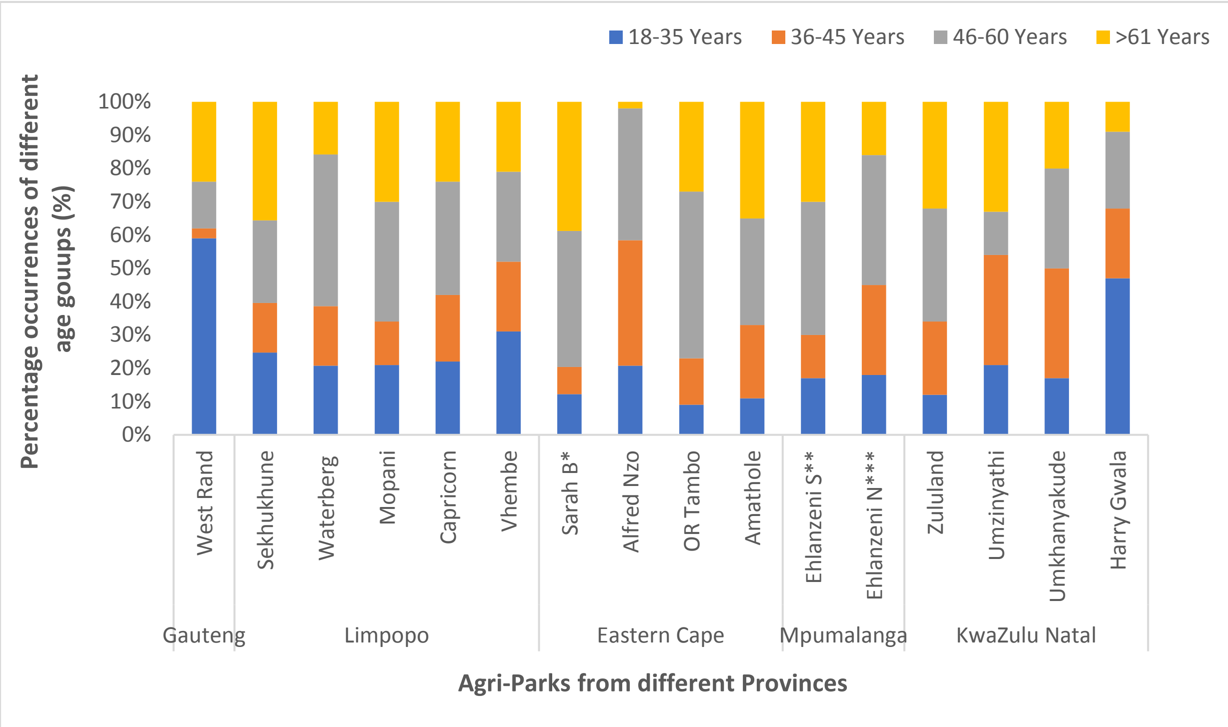

Figure 4-14: Percentages of Agri-park farmers that fall within different age groups

[1] West Rand (Gauteng) data was collected at the Farmers' Demonstration Day as part of this project, data for all the other Agri-parks were taken from Agricultural Research Council (2014)

*Sarah Baartman; ** Ehlanzeni South; *** Ehlanzeni North

As shown in

Figure 4-15 the majority of farmers (70%) attending the Farmers' Demonstration Day have less than 5 years of agricultural experience, while 53% have less than ten years of education (**Figure 4-16**). Few farmers (10%) indicated that they farm alone, while 51% said they farm with other family members.

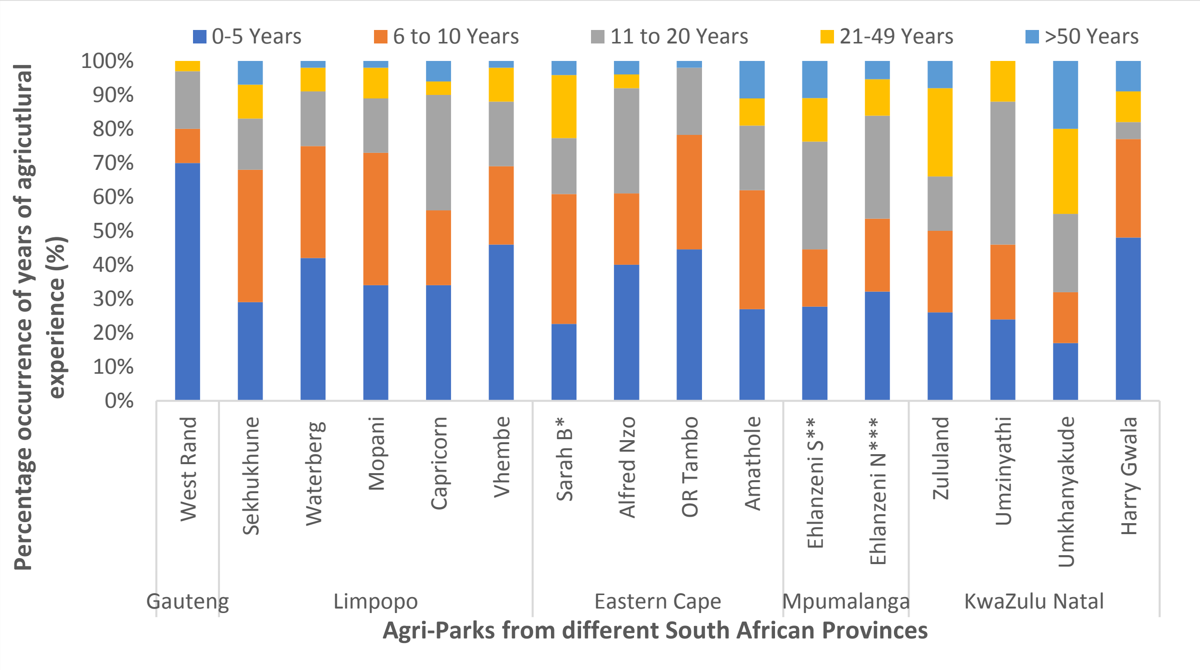

Figure 4-15: Number of years of agricultural experience of the Agri-park farmers[2]

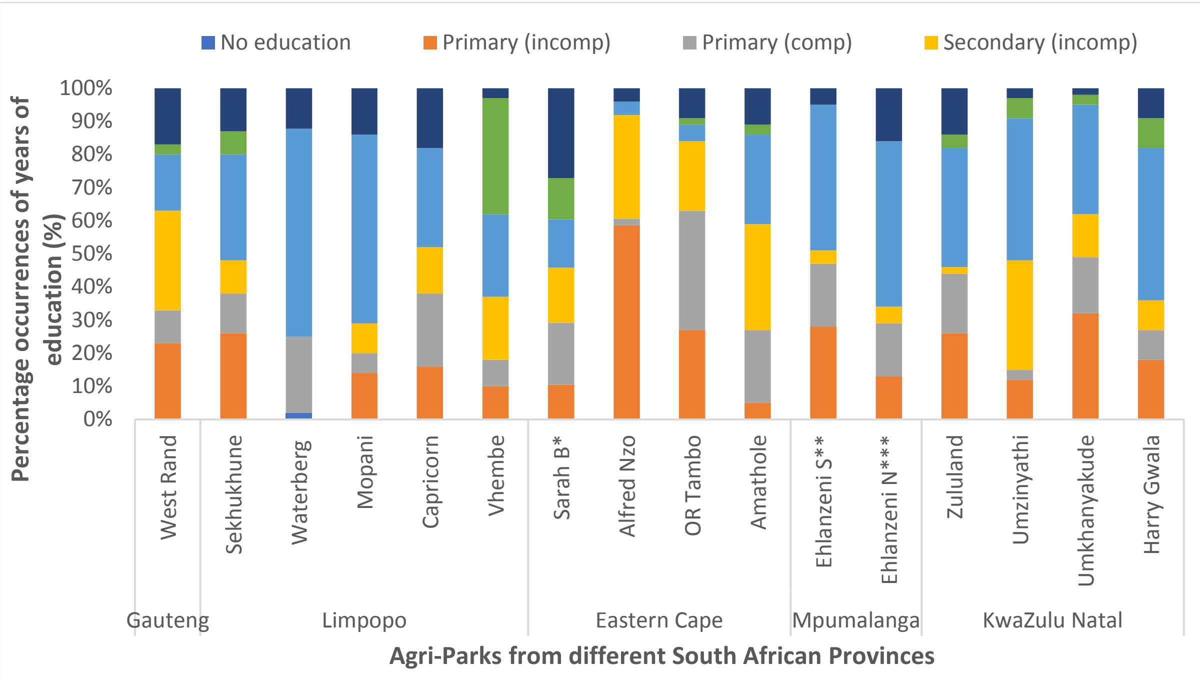

Figure 4-16: Number of years of education of the Agri-park farmers[2]

[2] West Rand (Gauteng) data was collected at the Farmers' Demonstration Day as part of this project, data for all the other Agri-parks were taken from Agricultural Research Council (2014)
*Sarah Baartman; ** Ehlanzeni South; *** Ehlanzeni North

4.3.7.3 *Current production on Agri-parks*

Figure 4-17 indicates the crops that are produced by West Rand Agri-park farmers. This section is not compared with ARC data, because the West Rand farmers were only vegetable farmers, whereas the farmers in the ARC data also farmed with fruit crops. Tomatoes, peppers (mainly green peppers) and Swiss chard is most commonly produced. This is most likely because of the high market demands for these crops. Most farmers were unable to say how much they produce, but 85% indicated that they sell 'almost all' (21%) or 'nearly everything' (64%) of their produce. Seventy percent were happy with their current production level.

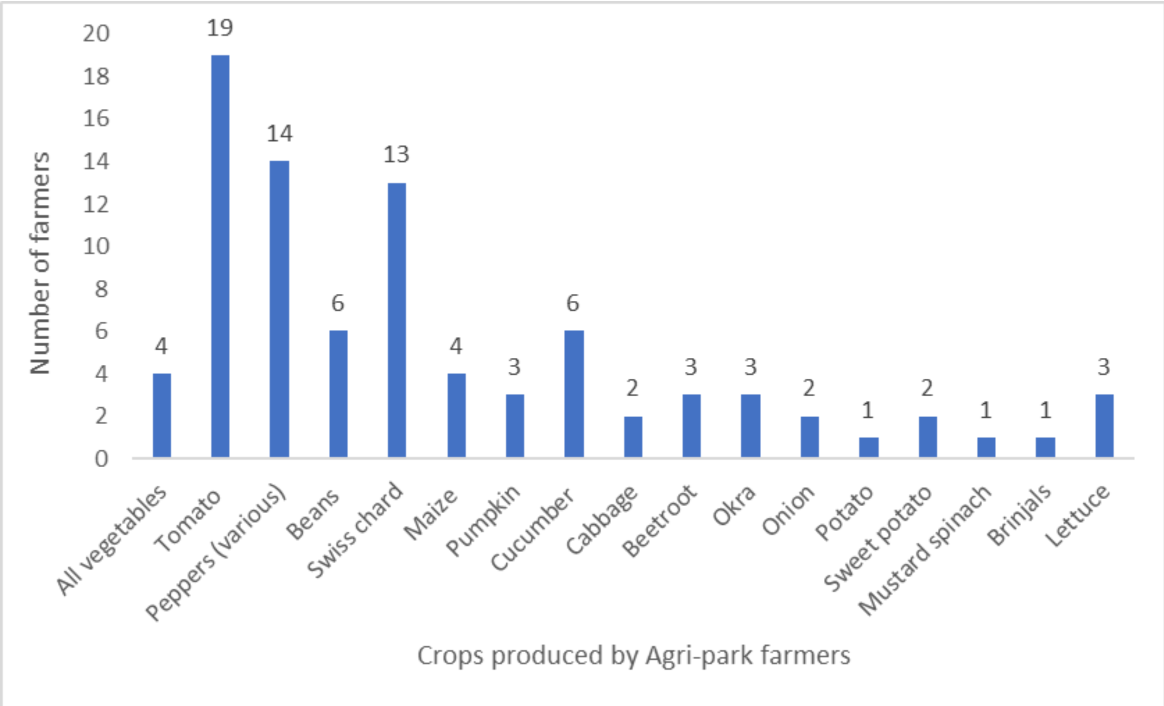

Figure 4-17: Crops that are produced by West Rand Agri-park farmers. Data was collected at the Farmers' Demonstration Day as part of this project.

4.3.7.4 *General agricultural practices*

The majority of Agri-park farmers use drip irrigation (82%), and most use groundwater (76%) (**Figure 4-18**). Generally, Agri-parks in Eastern Cape, Mpumalanga and KwaZulu-Natal irrigate with water from rivers, while water used in Gauteng and Limpopo is from groundwater through boreholes. These trends are probably driven by the available water resources, as Gauteng and Limpopo are drier with small, often ephemeral rivers. At the Farmers' Demonstration Day, 7% of farmers indicated that they use municipal water for irrigation. Out of the 15 Agri-parks assessed by the ARC, six used municipal water to a certain extent. At the Sarah Baartman and Ehlanzeni North Agri-parks, 18% and 16% of farmers, respectively, indicated that they use municipal water.

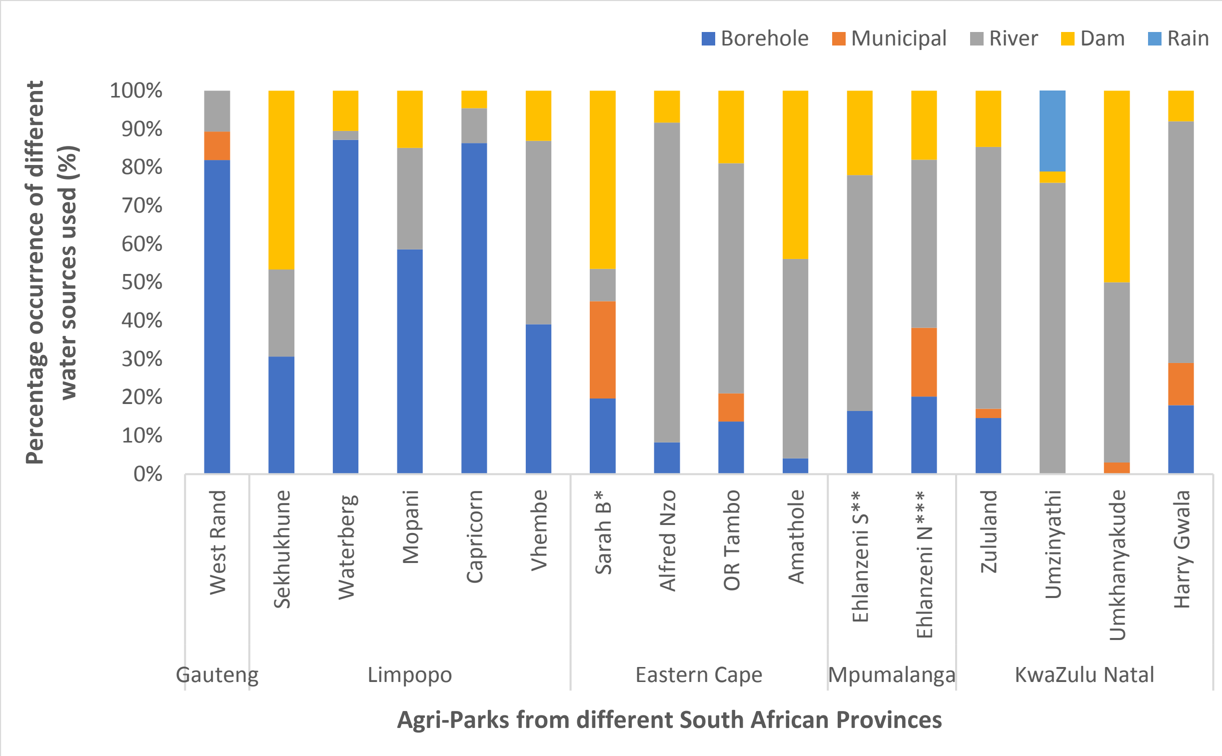

Figure 4-18: Water sources utilized by Agri-park farmers[3]

All farmers apply fertilizers, but the majority use compost and manure (35%) or a combination of compost and manure with chemical fertilizers (35%), while 24% use chemical fertilizers only and 6% did not specify which fertilizers they use. Of the West Rand Agri-parks farmers who were interviewed, 78% used pesticides and 22% do not use pesticides. The majority of the farmers spend 8 hours (56%) or more (30%) per day working on their farms. Almost all farmers (93%) practice crop rotation and 85% leave land fallow at times, 52% leave crop residues on the soil surface after harvest. Most farmer weed their fields manually (71%) while 13% do a combination of manual and chemical weeding. Only 61% of the farmers use tractors on their farms **(Figure 4-19)**.

4.3.7.5 *Technologies available to Agri-park farmers*

At the Farmers' Demonstration Day, 53% and 91% indicated that they use tractors and irrigation systems, respectively (shown as West Rand in **Figure 4-19**). The Alfred Nzo Agri-park reported 91% of farmers using tractors and irrigation systems. Most of the other Agri-parks have less than 50% farmers that uses tractors, and only a few farmers that use irrigation systems.

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[3] West Rand (Gauteng) data was collected at the Farmers' Demonstration Day as part of this project, data for all the other Agri-parks were taken from Agricultural Research Council (2014)
*Sarah Baartman; ** Ehlanzeni South; *** Ehlanzeni North

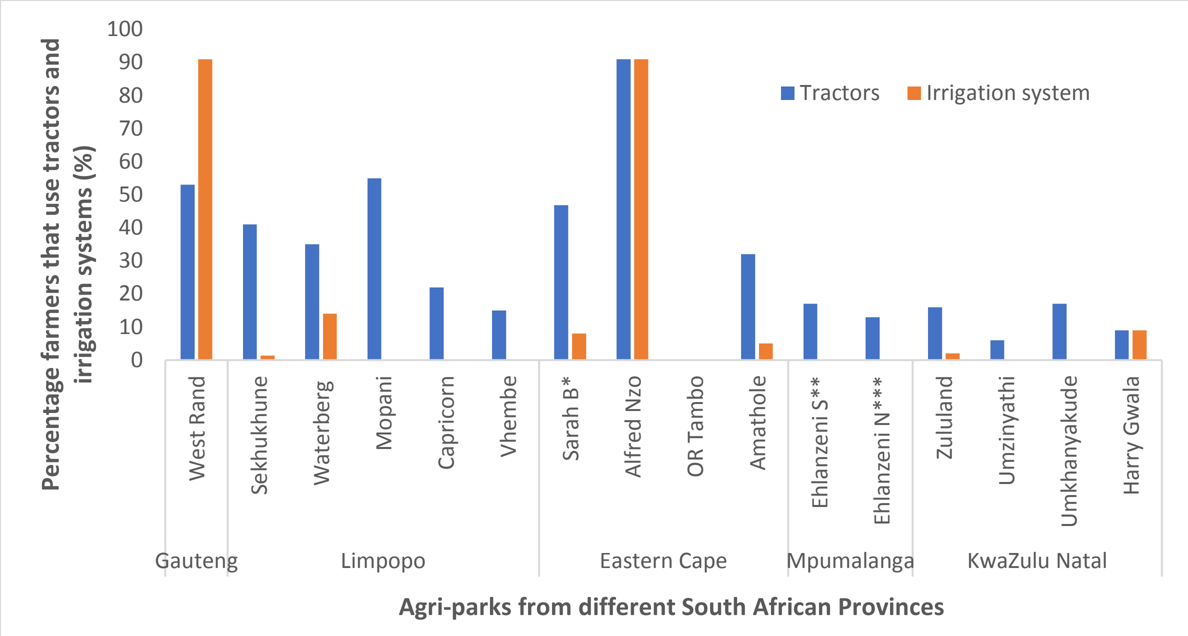

Figure 4-19: Percentage Agri-park farmers that use tractors and irrigation systems[4]

4.3.7.6 *Markets accessed by Agri-park farmers*

Figure 4-20 shows the different kinds of markets accessed by the farmers that attended the Farmers' Demonstration Day (West Rand) as well as the other Agri-parks, as reported by the ARC (2014). Almost 50% of farmers in West Rand sell produce to the formal market, with only 21% using the informal market. This is in contrast to most other Agri-parks, where the informal market is very important, with seven Agri-parks selling more than 90% of produce at the informal market. Future research could focus on obtaining data from these informal markets, such as their challenges, packaging and general waste management, and percentage food waste. The Alfred Nzo Agri-park in the Eastern Cape sells 94% of produce to the formal market, which is interesting, because this municipality is not close to major cities. At Ehlanzeni North in Mpumalanga 63% of farmers indicated that they cannot access any markets (shown under category 'Other'). The West Rand is a highly populated area of Gauteng, with easy access to formal markets. The other Provinces are further away from major cities and lack the infrastructure to distribute their produce, which explains why they sell their produce mainly at informal markets.

[4] West Rand (Gauteng) data was collected at the Farmers' Demonstration Day as part of this project, data for all the other Agri-parks were taken from Agricultural Research Council (2014)
*Sarah Baartman; ** Ehlanzeni South; *** Ehlanzeni North

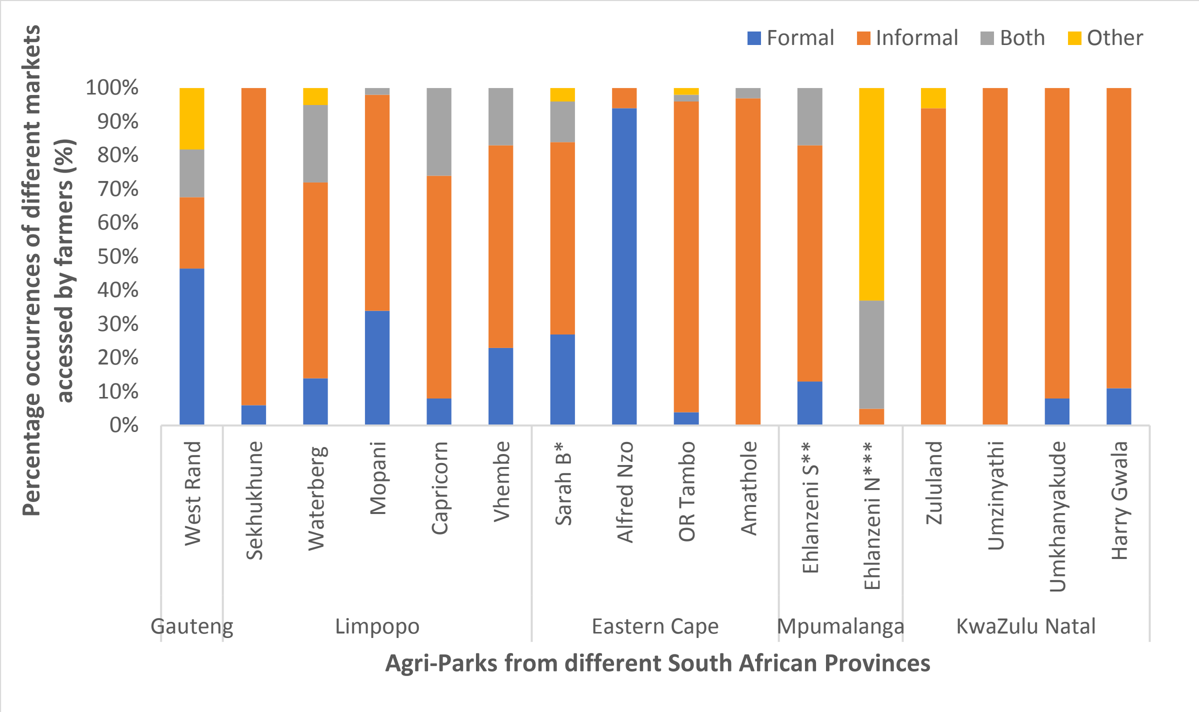

Figure 4-20: Different markets accessed by Agri-park farmers[5]

4.3.7.7 *Typical problems experienced by Agri-park farmers*

The farmers were also asked what problems they typically experience on their farms. A number of farmers indicated that they experience problems with water, with 20% indicating a lack of water, 13% indicated problems with water infrastructure and 7% indicated that water quality at their farms is poor. Twenty seven percent indicated that a lack of markets is a concern. High prices and a lack of electricity or load shedding was a problem also mentioned by 27% of the farmers. Heat or a lack of cooling systems were reported by 17% of the farmers and 7% indicated that they struggle with produce that rot. Other problems that were mentioned included space and land (13%), pests or weeds (17%) and labour (10%).

4.4 Discussion

The Agri-park farmers in Gauteng was found to be experienced and hard-working with much potential. They do, however, struggle with difficult problems that limit their ability to increase the scale of their production, and in many cases lead to productive losses. An Agri-park that functions according to the original model, would certainly contribute greatly to the development of emerging farmers. Although many different technologies exist, people do not easily accept them. The major question that was asked in this chapter was which technologies would be most acceptable to the Agri-park farmers.

4.4.1 Using sewage effluent for irrigation

One of the most important results from the feasibility study on using sewage effluent for irrigation is the positive attitudes of the Agri-park farmers and the managers at the WWTWs. Solutions are seldom accepted with enthusiasm, and the amount of effort that was done by both the farmers and the

[5] West Rand (Gauteng) data was collected at the Farmers' Demonstration Day as part of this project, data for all the other Agri-parks were taken from Agricultural Research Council (2014)
*Sarah Baartman; ** Ehlanzeni South; *** Ehlanzeni North

managers at the WWTWs indicates their commitment and the potential to successfully establish a practice of irrigating with effluent.

Despite the concerns about the risks involved, the research to develop sewage water for irrigation is necessary, because globally farmers are already irrigating with effluent. Also, current levels of sewage pollution in the environment could result in the same risks even when crops are being irrigation from natural water resources. It is therefore recommended that the management of risks associated with irrigation with sewage effluent is addressed in future research.

4.4.2 Vundisa Manure Application Tool

The VMAT is considered to be a valuable tool that can be presented to Agri-park farmers. The benefits of using chicken manure in vegetable production could also motivate other Agri-parks to combine the production of poultry with vegetable crops. By substituting chemical fertilizers with chicken manure, will not only save costs, but could also reduce impacts on water quality due to leaching of nutrients. The tool has now been tested on the Rooiwal Agri-park and is user-friendly and informative. The results of the VMAT can be communicated directly to the Agri-park farmers, but support from extension officers and the laboratory facilities of the proposed Agri-hubs would be required for implementation.

4.4.3 Soil moisture sensors

Measuring soil moisture to schedule irrigation and prevent under or over-irrigation is an important tool that can potentially make an important contribution towards the sustainable water use and management in Agri-parks. Most of the participating Agri-park farmers have also recognised the importance of these tools. However, it seems as if the tools are not properly taken up in their usual farming practices. At Soshanguve several tools were installed, but everything was destroyed by a contractor. At Rooiwal a CS were installed, but they never used it, and also did not move it to their new fields. The reason for the lack of using, maintaining and caring for the tools is still not well understood and requires further investigation.

4.4.4 Mulching

The application of mulch material is not just important to suppress weeds, but also to conserve water. Mulching is therefore also an important strategy for emerging farmers to become more resilient to climate change impacts. Furthermore, the practice can be low-cost if mulch material is available, and requires very little skills. Most Agri-park farmers know the value of mulching and how to apply it. However, some farmers are having problems that are preventing the use of mulch material, and particularly important is the amount of labour needed to apply and maintain a mulch layer. Agri-parks could have extension officers that can understand the challenges of the farmers with regards to mulching and that can work with them to overcome those challenges. The size of the farm must also be manageable, because smaller, more manageable farms could be more productive than larger less manageable farms.

4.4.5 Online learning programme

Overall, the learning programme was considered a success, with a number of lessons learnt for improving the system going forward. Facebook's publishing tools interface for page administrators is simple to utilise, and allows posts to be scheduled for automated posting in advance. This reduced the workload by not requiring the research group to manually post learning programme chapters every day. However, the only way to add captions to scheduled posts is to save and schedule the post, and then edit the post. It is unclear why Facebook only allows captions to be added to images in the post editing interface.

The use of Google Forms, and in particular the automated marking function, also reduced the work load by automatically collection data into Google Sheets spreadsheets. One lesson learnt for future learning programmes is that some form of unique identification, such as an identity number, passport number, or assigned student number would assist in tracking student's participation. This is because although participants were asked to provide their full name as part of every form, some only provided a first name. Although there were no duplicate names in this particular cohort, this was flagged as a potential problem going forward.

Given the length of the learning programme, it was anticipated that there would be a large difference between the number of individuals that started the programme and the number that successfully completed the programme. The difference between the number of individuals that completed the test for Chapter 1 and those that completed the final test was less than anticipated, however the difference between the number of individuals that completed the enrolment form and those that completed the test for Chapter 1 was surprisingly high. The decision not to email applicants, but rather conduct all general communications through the Ingesta Facebook page, was deliberate to assess if it was possible to run such a learning programme solely through a social media platform. The specifics of social media algorithms are complex, every-changing, and closely guarded by the corporations themselves, however it is common knowledge that these algorithms do influence what individual users see on their timeline when scrolling. Options such as manually setting notifications for specific pages' updates do exist, which would ensure participants are reminded of the content without requiring administrative action by the learning programme hosts. However, based on the feedback from participants who successfully completed the learning programme indicates that these participants actively waited in anticipation for the daily release of the chapters, and so it is possible that this difference between enrolment and completion numbers may be more largely influenced by individual ability and commitment to completing a self-study learning programme. This opens up further research opportunities for education and agricultural extension specialists, as more research into this is necessary if these types of learning programmes are to be optimised. A second unexpected phenomenon was the number of individuals who only completed either one or a few of the tests, but did not continue with the learning programme.

4.5 Conclusion

Although various tools are available to assist Agri-park farmers to improve the water use efficiency, user-acceptance is the main unsolved problem. User-friendly technologies must be developed, with a complete understanding of the intended users, in this case the Agri-park farmers. The best way to achieve this is to co-develop technologies together with the Agri-park farmers. Training is not sufficient to ensure successful transfer of the tools, the necessary daily farming practices are to be developed in which the given tools can be used. Future research should therefore include the co-development of user-friendly tools and the necessary farming practices in which the tools will be used.

After working alongside the farmers during this project, it has been observed that the possibility of irrigation with sewage effluent is considered the most desirable option of all the tools that were presented to them. Future research is now needed to determine ways to manage the possible risks and to co-develop the best practice of irrigating with sewage effluent.

5 OUTLOOK ON AGRI-PARKS IN SOUTH AFRICA

5.1 *Status Quo* of South African Agri-Parks

The Agri-parks concept could potentially address numerous problems in the country. Firstly, Agri-parks could play an important role in revitalising agriculture, to produce food for the growing population. Secondly, Agri-park could support emerging farmers and uplift previously disadvantaged communities. If communities in rural areas are able to farm profitably, fewer people would need to migrate to urban areas for employment opportunities. Therefore, if Agri-parks are successful, the initiative can also help to prevent rural-urban migration and the consequences thereof. Thirdly, the way the model integrates catchment-scale management with local-scale management structures, could become a key mechanism to address many unsustainable practices in agriculture. For example, farmers within the Agri-park could become part of a larger support system with access to technologies and laboratories, etc., but still maintain a smaller and more manageable farm on which they can practice a more sustainable form of agriculture. Also, water planning and management can be done on a catchment-scale, and enforced on a local-scale within a functioning Agri-park.

In their current form, the Gauteng Agri-parks do not resemble what is described in the model by Department of Rural Development and Land Reform (2016), and there appears to be a disconnect between national, provincial, and local municipal governance. The CoT and GDARD officials have routinely insisted that Rooiwal, Soshanguve, Westonaria and the other sites in Gauteng are Agri-parks. However, these sites are more akin to the production units that fall within the Farmer Production Support Units (FPSUs) that would supply the Agri-hubs within an Agri-park Catchment Area. This results in various problems. The first problem is that Agri-parks resembling production units do not have the impact of revitalising agriculture and uplifting rural poor people according to the expectations that was created. Secondly, the potential of integrating farmer-scale management with catchment-scale management through Agri-parks is impossible in this situation, because all the Agri-park management is now focussing on a few small units. The supporting structures that would have been provided by the Agri-hub, such as finances, infrastructure, laboratories, etc. only make sense if the Agri-parks are at a much larger scale. Thirdly, the distance between current FPSUs (for example Rooiwal, Soshanguve, innovation hub in Pretoria) makes it impossible to manage them as one Agri-park from a water resource perspective, because they fall within different catchments. Other issues include transport distances, poor integration between units and the selection of farmers resulting in the exclusion of surrounding people.

Therefore, much work is needed to develop Agri-parks that will resemble the model described by the Department of Rural Development and Land Reform (2016). The aim of this research was to assist Agri-park managers and farmers towards achieving this goal, particularly in terms of their water use and management. During this project, the team has experimented with various tools and ideas that can improve water resource management in Agri-parks, as discussed in this report. However, user acceptance is the main unsolved problem in many similar projects in many parts of the world. Education of and demonstrations to end-users to use the given technology seldom succeed. It is important to understand that not all people will be able to or interested in using all these tools. If one tool is well received by people in one location, it will not necessarily be accepted by people in another location. Cultures, socio-economic status, age and personal preferences can all have an impact on how technologies are received. The particular conditions of the local environment and water resources will also play an important role in the success of a technology or tool in a particular location. An Agri-park manager will have to engage with the farmers to better understand their needs and requirements, before deciding which technologies to implement.

5.2 Water Management at Gauteng Agri-Parks

Catchment water management is a complex process and requires inputs from various water specialists and cooperation between stakeholders. Like most complex systems, water management involves integration of management on different scales, i.e. catchment- and farm-scale, as well as interaction and cooperation between farmers in a catchment. The Agri-park concept could potentially be an ideal place to manage water resources on the catchment level, because the Agri-hub would operate at the catchment level, while the FPSUs could facilitate interactions with individual farmers. It is therefore unfortunate that the Agri-parks are not yet developing according to this multi-scale model that has been proposed originally.

Currently, water management at the Rooiwal, Westonaria, Soshanguve and other Agri-parks in Gauteng, is not up to standard. A monitoring program must be implemented, various role-players, managers, farmers and other landowners must become more integrated, etc. For example, water management at Rooiwal should aim to solve current problems at the WWTWs that cause water pollution and improve the water quality of the area, and to develop irrigation water sources from sewage effluent for current and future agriculture. Farmers must be supported to use water more efficiently and to maximise production. At various Agri-parks the team has found that farmers are over-irrigating and the use of municipal water for irrigation is also common. With better support and involvement farmers could become more responsible with their water use.

5.3 Catchment Water Management in Agri-Parks

5.3.1 Development of water resources from wastewater

This study has shown that there is a significant opportunity to develop a new water resource from treated sewage effluent. The volume of effluent water available at Rooiwal can become a steady resource of water and nutrients that could support a very productive farming community. By growing food with this water, the crops will also improve the water quality of the discharged effluent and reduce the current impacts on the local water resources.

Of all the technologies and solutions that were introduced at the Rooiwal Agri-park, farmers were most enthusiastic about the idea of using sewage effluent for irrigation. It highlights the observation of van Niekerk (2020) that 'a pre-requisite for end-user acceptance is that the technology must become part of the the daily practices of the existing system'. Irrigation is an existing practice at Rooiwal, and as long as the wastewater can be used within the current irrigation system, user-acceptance is expected to be successful. The farmers' positive attitudes towards using sewage effluent also highlights the desperation of the farmers to access more water, and it may also show a more relaxed attitude towards water quality and potential risks that the effluent water may pose. The following comment from someone at Rooiwal is proof of this more relaxed attitude: "The effluent water, it is good, it is only really 'human manure'". However, it is currently not recommended that Agri-parks start irrigating with sewage effluent, before the necessary research is done to ensure the safety of this practice. The 'human manure' in urban areas, like Pretoria, is unfortunately not completely natural, and due to current living standards, there are many risks that must receive attention in future research studies, such as:

- Risk of transmission of disease-causing organisms, such as Covid-19, from the water to the crop;
- Risk of crop uptake and accumulation of organic pollutants that may be present in the wastewater; and

- Risk of crop uptake and accumulation of nitrates, which could occur in high concentrations in the water.

5.3.2 Water and Nutrient Balance Framework

The water footprint (WF) framework was developed by le Roux et al. (2017) and is a useful and simplified method to determine production limits in terms of water availability. This framework was now incorporated into an Excel-based tool, called the Water and Nutrient Balance Framework (WNB) that determines the water and nutrient balance for an Agri-park (**Appendix 0**). The framework has been tested on the Rooiwal Agri-park and can assist Agri-park planners and managers to determine the maximum production potential and crop fields that can be irrigated with the available volume of blue water. If the WNB framework is successfully adopted by Agri-parks, future research can be motivated to obtain more accurate, site-specific WF data for various crops to further improve the accuracy of the outcomes.

5.4 Decision Support Tool for Using Chicken Manure

The Vundisa Manure Application Tool (VMAT) was developed to assist Agri-park farmers to apply the correct amount of chicken manure to their crops. The tool is interactive and user-friendly and requires soil and chicken manure analyses results as inputs. According to the original planning, the Agri-hub would include laboratories where soils analyses can be done to assist farmers in using the VMAT. A user can enter the required data and obtain a recommendation for chicken manure application rate quantified as the number of wheelbarrows and shovels that is most useful for emerging small-scale farmers.

There are similar manure application rate calculators in existence, however, they are web-based and present the potential challenge of a financial cost, since that requires internet connection and availability of mobile data. Other tools like the “Alberta Agriculture and Food” calculator require the user to make their own calculations such as to work out the basis for manure application (Alberta Agriculture and Food, 2015) . This manure tool is unique and novel compared to other calculators as it determines crop nutrient use and quantifies the potential value broiler manure can add to an Agri-park vegetable production unit.

Applying the VMAT tool to the Rooiwal Agri-park has shown that it could potentially be a useful tool for Agri-parks in general. Other Agri-park farmers across the country can benefit from using VMAT, if they choose to integrate chicken broiler raising operations with vegetable cultivation. If there is a market for free-range chickens, the vegetable waste can also be used to supplement vitamins and fibre required for chicken feeds. It must, however, be noted that vegetable waste does not contain the necessary protein and fat contents that chicken feed requires. Integration of vegetable cultivation with free range chicken farms can have the following benefits:

- Waste products can be utilized, reducing costs to both chicken and vegetable farmers;
- Less resource inputs (including chemical fertilizers and chicken feed) are required, making the system more sustainable;
- Soil structure and health can be improved over the long term;
- The slower release of nutrients from the chicken manure would result in reduced leaching and water pollution; and
- Potential increased production can result in better use of water resources.

5.5 Social Media

The overwhelming positive response from participants who successfully completed the learning programme indicates that there is a desire for these types of learning programmes within wider society. In the context of the Agri-parks, the completion of this learning programme by individuals from the different countries and eight different South African provinces shows potential that such learning programmes could be created for all 45 Agri-parks and run from one central office. This could potentially make providing regular learning opportunities for Agri-parks farmers economically viable for the programme in its current form. If the Agri-parks are to become economically viable models of sustainable, socially uplifting agriculture there needs to be greater support given to the farmers already within the system. The farmers at Rooiwal and Soshanguve have routinely expressed interest in uplifting themselves, but have stated that it is difficult to attend what few courses are on offer. Hosting virtual learning programmes through social media allows farmers to work through the course material in their own time, giving them greater flexibility. Equipping farmers with greater knowledge will enable them to make more informed decisions.

In the context of the Agri-parks initiative, social media may be the solution to a number of challenges as well as have the potential to add value to efforts towards meeting the aims of the programme in the future. However, from working with the Ingesta Facebook page it is clear that, while social media presents a number of unique opportunities for coordination and information dissemination, there is no universal approach. In its current form the CoT Agri-park consists only of four FPSUs with a limited number of farmers, with little of the proposed supportive infrastructure and systems meant to enable small-scale farmers in place. However, this could be an opportunity to relook at the Agri-parks model, and pioneer the incorporation of social media into agri-development.

5.5.1 Farmer level

Although the Agri-parks model aims to consolidate small-scale farmers, it is unclear whether this will be in the form of a traditional cooperative approach or with each farmer acting in their own interest but utilising shared processing and distribution networks within the Agri-park. Currently the CoT FPSUs host a mix of individual farmers and small cooperatives who function as separate entities from one another. In this context, individual farmers and small cooperatives could benefit from using social media to access new markets.

On several occasions, the Mutavhatsindis of the Rooiwal FPSU have been forced to leave produce to rot in the field after contracts with suppliers fell through and they were unable to find buyers. This had dire consequences for their income stream. Ms Dorah Mando of the Soshanguve FPSU experienced similar constraints with finding buyers in the past, however since the project team became involved, Ms Mando has started using social media to advertise her produce and started building a relationship with the local community (**Figure 5-1**). Originally, Ms Mando was supplying local retailers and informal traders within the community, but has since moved towards selling mixed produce boxes and ready-to-cook vegetable packs directly to consumers. This has allowed Ms Mando to increase the diversity of crops she grows, and increase revenue. The success of Ms Mando can and should be a lesson for other Agri-park farmers. The Covid-19 pandemic and the national lockdown motivated changes in consumer behaviour, as many people started buying online. These behavioural changes are expected to become more permanent.

Figure 5-1: Examples of social media posts created by Ms Mando

Expanding on what Ms Mando has already achieved, creating online brands for individual farmers and smaller cooperatives within the Agri-parks could be an avenue to connect them with wealthier consumers who are looking to actively support smaller enterprises as a form of personal social contribution. One of the aims of the Agri-parks programme is to focus on the production of high-value and niche crops. Currently the majority of the CoT Agri-park farmers focus on the production of common vegetables such as Swiss chard, tomatoes, cabbage, and bell peppers, with the only crop of relatively high value produced being the herbs at Rooiwal. Creation of online brands, built around uplifting small-scale farmers, could be vital in the marketing of the wealthier consumers whose support would make the cultivation of niche and high-value crops economically viable and sustainable.

5.5.2 Farmer Production Support Unit level

If the intention of the Agri-parks programme is to pool small-scale farmers together into a single cooperative within the FPSUs, then such cooperatives would benefit from creating online brands as mentioned above. Given the fast-paced nature and rapid turnover of social media content, it will likely be easier for cooperatives with a larger number of farmers growing a diverse range of crops to consistently create the social media content to build their online brand. This could potentially give these cooperatives a competitive edge over individual farmers in the area, although further work is needed in this regard. To meet the aim of providing “local logistics support such as delivery of farming inputs, primary produce collection, and postharvest transportation to local markets”, social media functions such as private FPSU-specific Facebook groups could potentially be used as coordination forums as is the case in communities across the world. Such virtual forums provide the opportunity for relatively data-lite real-time virtual communication across a wide range of devices, and certainly require further investigation for incorporation into the Agri-parks model.

However, it is in extension support and training where the research group envisions social media’s greatest impact to the Agri-parks programme. In its current form, the Tshwane Agri-park is likely too small to appoint a dedicated extension offer. If the Tshwane Agri-park is an accurate reflection of the majority of the country’s Agri-parks, as it appears is the case, a radical approach to rural extension and advisory services is needed to support the small-scale farmers while the remainder of the Agri-parks’ supportive infrastructure is established. Social media has the potential to connect Agri-parks farmers from across the country to extension officers in real-time, making it possible to have a small team of extension officers assigned to Agri-parks farmers at a national or provincial level rather than at a district municipality level.

6 CONCLUSIONS

The Agri-parks model represents a multi-scale system that could potentially make an important contribution to supporting emerging farmers, revitalising agriculture and addressing future food production. This project aimed to assist in the development of Agri-parks by developing a framework for planning integrated water resources management and by investigating tools and solutions to the numerous problems that emerging farmers currently experience. Three innovations were developed through this research:

- **The Water and Nutrient Balance Framework** to assist Agri-park planners or catchment managers with integrated water resource management planning. The framework requires input values including volume of available blue water (streamflow or groundwater) and water quality data. It combines water accounting using a water footprint approach, the SAWQG Decision Support System (DSS) funded by the WRC, and simple crop macro-nutrient accounting. It also requires crop information (length of the growing season, size of the farm, yields per hectare, water use of the crop as well as the macronutrient (N, P and K) requirements). The tool gives information on the potential size of the Agri-park and potential production. The framework was applied using Rooiwal and Westonaria as case-studies, and is simple enough to be used by a wide range of stakeholders
- **Vundisa Manure Application Tool (VMAT)** to give farmers an indication of the amount of chicken manure in terms of the number of shovels or wheelbarrows, which they have to apply to substitute fertilizers. The tool requires inputs on the N, P and K content in the available chicken manure and in the soil. It also requires bulk density and soil depth as well as fertilizer requirements of the crops.
- **A social media platform** was developed and tested to supply Agri-park farmers with extension services and training. The Ingesta Facebook Page was used to provide an online learning program on weed science.

The quantity and quality of available water is a problem at all Gauteng Agri-parks, which requires catchment-scale water management. The water quality of the groundwater at Rooiwal is poor due to sewage pollution from the adjacent WWTWs. Water quality at Westonaria is impacted on by mining activities. Both Agri-parks may possibly access some additional water from the nearby rivers, but this would depend on a number of things, including whether the water will actually be allocated to them, the investments to develop the infrastructure will be made available, and whether the water quality will permit cultivation.

Other options, such as irrigation with sewage effluent should be considered and is a possibility that Rooiwal Agri-park farmers have shown much interest in. Using mulch material and soil moisture sensors are existing solutions that are currently not well adopted. Further interactions with the Agri-park farmers are necessary to understand how these technologies and the VMAT could be made more attractive to them. Agri-park farmers will also benefit from better support and extension services. The use of social media can be considered for this purpose, if extension services are not available.

The existing Agri-parks studied in this project are not what was proposed in the original concept, and the initiative to roll out more Agri-parks in South Africa appears to have lost momentum. Through the research it became clear that the current Agri-park farmers have the potential to become successful commercial farmers, but they have challenges that are currently restricting their production potential.

The following recommendations are given on the development of Agri-parks:

- Feasibility studies should be done prior to the implementation of the Agri-park and monitoring and management plans must be developed. Suitable water sources should be developed and water use licences must be obtained.
- Monitoring is very important to determine the long-term effect of agricultural production on the water quality and quantity. It is recommended that continuous water quality monitoring should be done at all Agri-parks. Regular monitoring of groundwater levels is also required to assess the long-term impacts of abstraction for agricultural production on the aquifer.
- Farmers and extension officers should receive training on good agronomic practises and available tools and technologies. Through continued interactions between extension officers and farmers, the most suitable tools and technologies should be developed or selected. The following tools are recommended for use in Agri-parks:
    - Water and Nutrient Balance Framework (**Appendix 1**)
    - South African Water Quality Guidelines Decision Support System
    - Vundisa Manure Application Tool (**Appendix 2**)
    - Social media training platforms (**Appendix 7**)
- Developing sustainable resources from waste should be a high priority, for economic and ecological gains. Integrated systems, such as combining animal and crop production provide opportunities to re-use waste products. It is highly recommended that Agri-parks seek to establish such integrated systems.

Recommendations on future research:

- Using sewage effluent for irrigation presents possible health risks. Organic pollutants is an important risk to consider when using sewage effluent, which is currently not well understood. Helmecke et al. (2020) said that numerous organic pollutants could potentially be found in sewage effluent, and it is still unknown whether these are taken up and accumulated in the edible portions of the crops. Information on the transmission of envelop type viruses like Covid-19 through water is limited. Therefore, despite the potential benefits of reusing sewage water, there are some important risks that requires further research.
- Future research is needed to co-develop user-friendly tools with the Agri-park farmers and to develop daily farming practices for the use of existing tools, such as soil moisture sensors, social media, VMAT, etc.
- The VMAT can be further developed to include other crops, other than leafy and root vegetables, and to include important micro-nutrients such as zinc and copper.

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APPENDICES

Appendix 1: Water and Nutrient Balance Framework – Excel spreadsheet

Guidelines for WNB

Description: This tool was created to be used by Agri-park and other catchment managers. The purpose of the tool is to determine potential production of leafy and root vegetables in terms of the availability of water and the concentrations of nutrients in the receiving water. If the available water is at a good quality, the amount of nutrients will not be sufficient to produce crops, therefore the nutrient balance was built in mostly for situations where wastewater is used or natural water bodies have been polluted to contain high nutrient concentrations

A user can choose to compare water and nutrient balance results for different crops and for different farms.

User guidelines: The cells in the input sheets of the WNB framework is colour coded, making it a user-friendly tool:

- Data must be added into Pink cells
- Green cells contain automatic formulae
- Grey cells include general information.

Step 1: To get a water balance for the farm, enter the following data in the Farm 1 and/or Farm 2 worksheets:

- Available blue water (m^3/month): This can be sourced from streamflow data, CoT, DWS documents, groundwater levels, etc.;
- Crop field sizes (hectares) for up to two different crops
- Duration of the growing season (months)
- Average yields in summer and winter (tonnes/hectares)
- Blue water requirement (in m^3/ha) and blue WF of the crop (in m^3/tonnes)

Step 2: To get a nutrient balance for the farm, enter the following data in the Farm 1 and/or Farm 2 worksheets:

- Available blue water (m^3/month): This can be sourced from streamflow data, CoT, DWS documents, groundwater levels, etc.;
- Macro-nutrient (N, P and K) concentrations in the irrigation water;
- Macro-nutrient application requirements (this is an output of the SAWQG DSS, or standard fertilizer guidelines can be used)
- Crop field sizes (hectares) for up to two different crops
- Duration of the growing season (months)
- Average yields in summer and winter (tonnes/hectares)

Step 3: Find the water and nutrient balance results under the 'Balance Sheet'

Appendix 2: Vundisa Manure Application Tool (VMAT) – Excel spreadsheet

Guidelines for VMAT

1) Farmer tool

Description: Uses soil, manure analysis results and fertiliser recommendation to calculate manure application rates. It calculates how many shovels and wheelbarrows of manure can be applied per hectare to reach the target yield

Step 1
Soil analysis

Conduct soil tests for Total Nitrogen, Phosphorus, Potassium and Bulk density. The recommended depth at which soil samples can be collected is 15-30 cm. Soil test information is used to determine how much fertiliser must be applied to the soil to meet the standard fertiliser recommendation for leafy and root crops in order to reach the desired yield. Soil results for Nitrogen, Phosphorus and Potassium should be entered into the spread sheet. An equation was used to translate Nitrogen from percentage to a figure with the unit mg/kg.

$$N = Total\ N * 10000$$

Add data in pink cells

SOIL TEST RESULTS					
Total N (%)	N (Nitrogen) *(mg/kg)*	P (Phosphorus) *(mg/kg)*	K (Potassium) *(mg/kg)*	Bulk Density *(kg/l)*	Soil Depth *(m)*
	0				

Nutrient levels are measured in mg/kg which should be converted to kg/ha by multiplying the nutrient with bulk density, effective soil depth and 10.

$$N\ (kg/ha) = N\ (mg/kg) * BD * ESD * 10$$

Fixed formula in olive cells

N (Nitrogen) *(kg/ha)*	P (Phosphorus) *(kg/ha)*	K (Potassium) *(kg/ha)*
0.0	0.0	0.0

Micronutrients like Calcium, Manganese and Sodium are important to measure as well as pH and Electrical conductivity. Soil particle size analysis helps categorize it into sand, silt or clay and gives indication of electrical conductivity/salt levels in the soil. However, the VMAT only considers the macronutrients that are needed in large quantities by crops and these are often the emphasis in synthetic fertiliser.

Step 2
Manure analysis

Chicken manure is analysed for the concentration of Total Nitrogen, Ammonia Nitrogen, Phosphorus and Potassium. Total Nitrogen is reduced to estimated crop available Nitrogen by using the following calculations:

Organic N = Total N – NH_4- N
Available Organic N (Year 1) = Organic N * 0.25
Retained NH_4- N = NH_4- N * Retention factor (given figure)
Estimated Crop Available N = Available Organic N + Retained NH4-N

It is estimated that 25% of organic Nitrogen becomes available within the first year of application. Organic Nitrogen is the difference in total Nitrogen and Ammonia Nitrogen which are measured in the lab. Ammonia Nitrogen is prone to decline at an estimated rate of 23%. Therefore the retained Ammonia Nitrogen is calculated to be added to Available Organic N.

Estimated Crop Available N = Total P * 0.7

Estimated Crop Available K = Total K * 0.9

Crop available Phosphorus is estimated to be 70% of the measured Phosphorus. Most (90%) of the Potassium becomes available on the first year of application.

				Add data in pink cells	
				Fixed formula in olive cells	
Total N (%)	Ammonia NH4-N	Organic N	Available Organic N	Retained NH4-N	Crop available N
		0	0,0	0,00	0,0
	Measured P	Crop available P	Measured K	Crop available K	
		0,0		0,0	

Step 3

Fertiliser recommendation

General fertiliser recommendations were given for leafy and root crops. The fertiliser recommendations figures are subtracted from the measured soil nutrients that are presented in kg/ha.

Add data in pink cells

ESTIMATING FERTILISER REQUIREMENT *(kg/ha)*			
Crop type	N	P	K
Leafy crops			
Root crops			

The fertiliser requirement for each element is subtracted from the soil test result of that element to gauge how many additional nutrients are needed. If numbers are negative, meaning there is abundant concentration of that nutrient whether Nitrogen, Phosphorus or Potassium, than figures appears as zero on the spread sheet. This indicates to the user that no additional input of that nutrient is needed to satisfy the crop nutrient requirement.

Fixed formula in olive cells

ADDITIONAL NUTRIENTS REQUIRED TO SATISFY FERTILISER REQUIREMENT *(kg/ha)*			
Crop type	N (Nitrogen)	P (Phosphorus)	K (Potassium)
Leafy crops	0,0	0,0	0,0
Root crops	0,0	0,0	0,0

Additional nutrients required to meet the fertiliser recommendations divided by crop available nutrients. At this point the basis for fertiliser application must be determined.

Determine basis for application rate calculation

Manure is applied on the basis of the critical nutrient, i.e. the one required the most to reach the target crop yield. This is the nutrient that is most inadequate in the soil. When manure is applied on the basis of for example Nitrogen, the figure concentration of the other elements that will be applied is calculated. Phosphorus is converted to phosphates by multiplying available concentration by 2.3. Potassium on the other hand is converted to by multiplying available potassium by 1.20.

$$P_2O_5=P*2.29$$

$$K_2O=K*1.20$$

The excess of P_2O_5 and K_2O is generated by subtraction for both leafy and root crops. Positive P_2O_5 and K_2O balance imply an under-application of the nutrients and a likelihood of accumulation overtime if mitigation procedures are not put in place. Negative result indicates an over-application of P_2O_5 and K_2O additional P and K fertilizer may be required. The part of the manure calculator below indicates equations used to determine application rate on the basis of Nitrogen (a) Phosphorus and Potassium (b). This shows adherence to the equation for application rate.

$$\text{Application rate} = \frac{\text{Reference nutrient recommendation}}{\text{Reference manure nutrient concentration}}$$

a)

Fixed formula in olive cells

CALCULATING MANURE APPLICATION RATE *(tons/ha)*			
Crop type	Manure applied for N	P_2O_5 applied	K_2O applied
Leafy crops	0	0	0
Root crops	0	0	0
		P_2O_5 balance	K_2O balance
Leafy crops		0	0
Root crops		0	0

b)

Crop type		N	P	K
Leafy crops	Manure applied to satisfy		0	0
Root crops	P or K requirement		0	0
	N applied P based			
Leafy crops		0		0
Root crops		0		0
	N applied K based			
Leafy crops		0	0	
Root crops		0	0	

The concentration of the other two elements if manure is applied based on one element are calculated by multiplication. Application rate can be based on either N, P or K depending on which element is needed most. The largest number under manure application rate indicates the critical element and the amount of manure that should applied to satisfy the nutrient requirement. Shovels and wheelbarrow are used to quantify the manure used and are estimated to hold 5 kg and 60 kg respectively.

Manure application rate in green cells

Shovels	**Wheelbarrows**
Application on the basis of N	
0.0	0.0
0.0	0.0
Application on the basis of P	
0.0	0.0
0.0	0.0
Application on the basis of K	
0.0	0.0
0.0	0.0

The basis of the application is indicated by which figure is larger in the previous image. For example if the figure under 'application on the basis of P' is the largest for crop type leafy or root, that amount of shovels/wheelbarrows will have to be applied. In other words the user must apply manure on the basis of P. The number of shovels or wheelbarrows of manure per hactare should be applied based on the element most needed. This is indicated by the highest positive number. Negative numbers are floored to 0 if there is no need for application.

2) Catchment tool

Description: It calculates the potential yield the total amount of manure can produce on a farm. It quantifies the positive impact the input from the broiler farm and farm waste could have on vegetable cropping systems.

Column 1

The first piece of information required is manure test results. Nitrogen, Phosphorus and Potassium results in g/kg are required.

	Add data in pink cells
Nitrogen	
Phosphorus	
Potassium	

The user can give an estimate for volume chicken manure generated at their farm per month measured in kilograms. A formula ten estimates how much manure would be generated in a year by multiplying figure by 12.

	Add data in pink cells *Fixed formula in olive cells*
Volume chicken manure generated at Rooiwal per month (kg)	10800
Volume of chicken manure generated at Rooiwal per year (kg)	129600

A pre-set formula to on the tool helps determine total Nitrogen, Phosphorus and Potassium individualy

	Fixed formula in olive cells
Total nutrients coming from Rooiwal chicken houses (g)	
Nitrates	0
Phosphates	0
Potassium	0
Total nutrients coming from Rooiwal chicken houses per year (g)	
Nitrates	0
Phosphates	0
Potassium	0

Column 2 and 3

The user needs to enter the Nitrogen, Phosphorus and Potassium requirement for leafy and root crop in g/ha.

	Add data in pink cells
Nutrients required by leafy veg: growing season (g/ha)	
Nitrogen	
Phosphorus	
Potassium	

	Add data in pink cells
Nutrients required by root veg: growing season (g/ha)	
Nitrogen	
Phosphorus	
Potassium	

The user also needs to know the estimate of crops in kilograms per hectares that is produced in the target farm (where manure will be applied). It is assumed that there are four harvests of that crop in a year.

	Add data in pink cells
	Fixed formula in olive cells
Leafy veg produced at Rooiwal (ha)	
Annual crop area of leafy veg (ha)	0

	Add data in pink cells
	Fixed formula in olive cells
Root veg produced at Rooiwal (ha)	
Annual crop area of root veg (ha)	0

The tool then calculates the 'total nutrients used by crop in grams' by using figures using nutrients required by crop in grams per hectare and crop produced at farm.

	Fixed formula in olive cells
Total nutrients used by leafy veg at Rooiwal (g)	
Nitrates	0
Phosphates	0
Potassium	0

	Fixed formula in olive cells
Total nutrients used by root veg at Rooiwal (g)	
Nitrates	0
Phosphates	0
Potassium	0

The final result gives user an estimation of how much land in hetres can be fertilised by the nutrients supplied by the manure available at Rooiwal Agripark. A user can enter figures for

Fixed formula in olive cells	
Nutrients availability: requirement ratio	
Nitrates	0.0
Phosphates	0.0
Potassium	0.0
Potential leafy veg crop area ito N (ha)	0.0

Fixed formula in olive cells	
Nutrients availability: requirement ratio	
Nitrates	0.0
Phosphates	0.0
Potassium	0.0
Potential root veg crop area ito N (ha)	0.0

Appendix 3: Capacity Building

Capacity building was a key component of this research and included training of Agri-park farmers, Government officials and postgraduate students.

Training of Agri-Park Farmers

Tshwane Agri-parks:

Since the beginning of the project, the Rooiwal Agri-park farmers have been participating in the project activities, which included on-site training on soil moisture sensors, mulching practices and substituting fertilizers with chicken manure. The farmers became actively involved with the irrigation with sewage effluent trial, through which they are also learning about the potential risks of the practice, such as infections with pathogens and heavy metals. At the end of the project, the team hopes to gain a better understanding of these risks and how to manage them, which will be communicated to the farmers. During a Focus Group Meeting, the team further engaged with the farmers to discuss the above-mentioned technologies that are available to improve their production outputs.

The team also engaged with Ms Dorah Mando from the Soshanguve Agri-park. Ms Mando received training on the installation and use of soil moisture sensors.

West Rand Agri-parks:

Fifty Agri-park farmers from 5 different Agri-parks in Johannesburg were invited to a Farmers Demonstration Day on 20 February 2019. These farmers received training on the use of soil moisture sensors, weed and pest management, irrigation scheduling, application of fertilizers, bee-keeping and Agri-Cloud.

Online Learning Programme on Weed Science

In order to investigate the potential of Facebook as a platform to host e-learning programmes for Agri-park farmers, a learning programme on the fundamentals of weed science was created. A total of 34 individuals successfully completed the full programme, of which 25 were South African. All participants indicated that they had learnt information that they felt would better help them manage weeds in their fields.

Future Dissemination Activities:

A dissemination package, consisting of a manual with all the tools that was tested and developed during this research, and all the software that was developed, will be distributed to Rooiwal and other Agri-parks. The manual and software will be presented to farmers during future dissemination activities.

Training of Government Officials

The City of Tshwane official, Ms Egnes Shiba, is responsible for providing support to the Tshwane Agri-park farmers. Ms Shiba participated and assisted the team with the research, she attended many of the site visits and the Focus Group Meeting, where farmers received information and training. She also received formal training on the WNB balance tool in March 2021, which could assist her with future planning and management of water in the Tshwane Agri-park.

Training of Post-Graduate Students

Mr Richard Hay (MSc (Agric) Agronomy Student)

Mr Hay has now completed his field trial for the project and collected all the necessary data for his research. During the year, Mr Hay participated in one Agripark Farmer Day and gave a TEDX@UP talk on technology transfer to small-scale farmers. Mr Hay was recognised for his research on this project by being chosen as one of the NEWS24 Hundred Young Mandela's of the Future. Mr Hay is currently writing-up his MSc dissertation.

Mr Hay contributed sections of this report relating to sustainable intensification and small-scale irrigation (**Section 2.3.2.3** and **Section 2.4.2.3**), social media as a tool for extension services (**Section 2.4.2.1**, **Section 4.2.6**, **Section 4.3.6**, **Section 4.4.5** and **Section 5.5**), SAWQG DSS (**Section 2.4.1.2** and **Section 3.3.1.2**), mulching (**Section 2.4.2.2**) and soil moisture sensors (**Section 4.2.4, Section 4.3.4** and **Section 4.4.3**).

ABSTRACT

The City of Tshwane Agri-parks initiative as a case study for the sustainable intensification of smallholder agriculture in South Africa

BY: RICHARD LEE HAY

Submitted in partial fulfilment of the requirements for the degree MSc Agric Agronomy in the Department of Plant and Soil Sciences, University of Pretoria

Over the next decade, sub-Saharan Africa (SSA) is predicted to experience the largest relative population increase of any subcontinent. The region is already greatly impoverished and the least food secure in the world, with 58.7% of the population classified as at least moderately food insecure. Smallholder farmers are the foundation of SSA's agricultural sector, producing the majority of the region's grains and legumes, and almost all of the tuberous and root crops. However, the Green Revolution that resulted in dramatic increases in yields across most of the globe is largely considered to have failed in SSA, and yield gaps in the region remain some of the largest in the world. Sustainable Intensification (SI) has been proposed as the most appropriate means to increase production of smallholder farmers in a way that is both environmentally sustainable and appropriate for the context and complexities of smallholder agriculture in SSA. Numerous examples of SI initiatives across SSA, such as complex cropping systems, small-scale irrigation schemes, and the use of improved germplasm, have demonstrated the potential for increasing yields, reducing the environmental impact of agriculture, and improving the livelihood of smallholder farmers. However, a number of socioeconomic factors still limit widespread adoption. One initiative that aims to overcome these challenges and intensify smallholder agriculture through state-funded development is the Agri-parks programme, which aims to provide farmers with financial and institutional support for a period of ten years, while developing linkages across the agricultural supply chain to ensure long-term economic viability. On paper, the Agri-parks initiative appears to be a model, scalable SI programme. However, five years since the launch of the Agri-parks programme, various challenges and delays as well as a disconnect between provincial and national governmental departments has resulted in significant delays in the programme's timeline. The Agri-park in the City of Tshwane (CoT) was found to be limited in size and functionality, with much of the infrastructure originating from previous projects on the sites and in various states of disrepair. None the less that Agri-parks programme still holds potential to become a flagship SI programme, if it is developed to the extent the original model describes. One of the major limiting factors of small-scale irrigation schemes in SSA is the relatively high costs of equipment, which are economically out of reach for most smallholder farmers. Examples from elsewhere in the world have shown that, given the right institutional and financial support,

smallholder farmers can greatly benefit from investment into irrigation technologies. In recent years a number of tools, such as the Wetting Front Detector and the Chameleon sensor, have been developed specifically to help smallholder farmers better manage their irrigation water resources. These tools formed part of the research projects technology transfer through field trials at the Soshanguve and Rooiwal Farmer Production Support Units (FPSUs); however, uncontrolled circumstances disrupted the field trials at both sites but illustrated the daily struggles faced by the farmers at these sites. In order to replicate the conditions at the CoT Agri-park FPSUs in a more controlled environment, a trial to investigate the impacts of different mulching treatments and weeding practices on weed emergence and pressure was conducted. The trial revealed that mulching treatments weeding had a significant effect on the total weed biomass ($p = 0.0009$) and that weeding had a significant effect on weed pressure ($p = 0.0001$) and weed species richness ($p = 0.0000031$). However, consultation with the farmers of the Rooiwal FPSU revealed that mulching was not an appropriate strategy for them as they felt the mulch made it more difficult to weed the field. Weed pressure on the site was high, but farmers were hesitant to use chemical control measures. This illustrated the importance of providing comprehensive agricultural extension, to ensure farmers have access to knowledge of scientific best practices on which to base their management decisions. The current limited size of the Agri-parks mean it is unlikely to be viable to appoint a dedicated extension officer to the CoT Agri-park, but social media has the potential to connect a number of Agri-parks to a single extension officer instead. In order to explore the viability of social media as a platform for hosting e-learning programmes, a 14 'chapter' learning programme on the fundamentals of weed science was run through the Ingesta: Farming for the Future Facebook page. Thirty-four individuals from six different countries, as well as eight of South Africa's provinces, successfully completed the learning programme. Feedback from the learning programme was overwhelmingly positive, with 90% of the final participants finding the programme to be at least 'easy to understand' and 91% indicating the length of the chapters was 'just long enough'. All final participants indicated that they had learnt information that they felt would better help them manage weeds in their fields, with 17 expressing additional positive comments. As a result, the pilot study was considered a success xiv and social media proven to be a viable platform to provide access to agricultural science learning material for smallholder farmers in SSA. Although there is insufficient evidence to support that the CoT Agri-park can currently be considered an example of SI, the initiative does still have the potential to be if there is a coordinated approach to develop the Agri-park as the original model describes, and the incorporation of various tools and technologies will enhance support to smallholder farmers.

Mr Gareth Glasspool (BSc (Hons) Environmental Soil Science)

Mr Glasspool has now successfully completed his honours degree at the University of Pretoria. The title of his research report was 'Development and application of a micro-lysimeter to estimate nitrogen mineralisation in agricultural soils'. From his work, a low-cost technique to estimate the mineralisation of nitrogen from soil organic matter in small-scale farmers' fields has been tested, and shows excellent promise. Mr Glasspool has now been appointed by a commercial agriculture company in Nelspruit. He also contributed to the project by assisting with a mulching trial to better understand the potential of mulching to improve water use efficiency and reduce weed pressure.

ABSTRACT

Development and application of a micro-lysimeter to estimate nitrogen mineralisation in agricultural soils

By: GARETH NORMAN GLASSPOOL

Submitted in partial fulfilment of the requirements for the degree BSc (Hons) Environmental Soil Science In the Department of Plant and Soil Science, University of Pretoria

There is a massive challenge in measuring nitrogen (N) mineralisation in the soil, and currently no standard in-field measurement protocol exists. The development of such a protocol, that is facilitated by a cost-effective design as well as validated with modelling, could enhance N management, reducing the loss of N fertility in soils. The purpose of this study was to estimate the N-mineralisation dynamics in the soil as a function of accurate leaching measurements with a cost-effective micro-lysimeter that are being applied all over the world. The micro-lysimeters used in the study were successfully built and tested at the University of Pretoria. The design for the micro-lysimeter has been shown to successfully obtain and quantify leaching loads. A major advantage of the proposed micro-lysimeter is the capacity for both measuring the concentration of nitrate (NO_3^-) from the soil and the flux of drainage in the soil. The input of water into the system can be determined as well as the output which collects in the micro-lysimeter. Drainage from simulated water events was collected to quantify the load of N leached in kg ha^{-1} from the soil for both systems. The usefulness of data collected to parametrise the crop model Agricultural Production System sIMulator (APSIM) was assessed. The model was calibrated using parameters from a previous study completed on the Experimental Farm as well as measured data collected from the study. Results attained from the study highlight the need increased data collection to improve the accuracy of the APSIM model as a poor calibration was attained. This study however displays the potential viability of using micro-lysimeters to quantify N mineralisation parameters in agricultural soils.

Miss Jean Annandale (BSc (Hons) Crop Science)

Miss Annandale has also successfully completed her honours degree at the University of Pretoria. She also assisted with the mulching trial for this project. The title of Miss Annandale's research report was 'Comparison of SPAD and electrode measurements of nitrate in wheat (Triticum aestivum) and Swiss chard (Beta vulgaris) crops'. Her research contributed to improve understanding of measurements that can be made on crops to inform improved nitrogen fertiliser management. Miss Annandale is currently looking for an employment opportunity.

ABSTRACT

Comparison of spad and electrode measurements of nitrogen (NO_3^-) in wheat (*Triticum aestivum*) and Swiss chard (*Beta vulgaris*) crops

By: JEAN ANNANDALE

Submitted in partial fulfilment of the requirements for the degree BSc Agric Hons in Crop Science at the Department of Plant and Soil Sciences, University of Pretoria

The agricultural industry is paramount in ensuring food security and as a means of income to millions of people across the world. From subsistence farmers to large-scale companies, all play a meaningful role in providing food to an ever-growing population. But many practices are currently considered unsustainable and detrimental to the environment. Biodiversity is being lost rapidly, and soils are becoming compromised. Proper and efficient management of fertilisers could reduce unwanted losses of the environment and input costs. Monitoring the nitrogen (N) content of a crop, especially as technology continually advances, may allow more precise applications of fertiliser N. A variety of techniques could be used, e.g. dry analysis of plant leaves, nitrate (NO_3^-) strips or electrodes using the sap, but the most efficient and accurate manner has not been determined. Finding a reliable anti-invasive method in monitoring N status would be ideal. Previously, the potential of the SPAD meter has been tested in macadamia and rice with promising results. The goal of this study was to find the best method (in terms of accuracy and ease-of-use) between a SPAD meter and nitrate electrode, and whether a significant relationship can be drawn between the readings from each tool as well as total leaf N. A pot trial was conducted for Swiss chard (*Beta vulgaris* L.) measurements where the soil was leached, and N addition was varied at 0 mg/ml, 5 mg/l and 10 mg/l. The data obtained from the pot trial yielded no significant results, and may have been influence by the presence of a powdery mildew fungus. Wheat (*Triticum aestivum*) was also studied in the long-term wheat trial at the Experimental Farm on the Hillcrest Campus of the University of Pretoria. Results presented very poor correlations between SPAD and NO_3^- electrode measurements being observed in most cases. It was concluded that the SPAD meter would be easier to use as an in-field testing method than the electrode, but further calibration work is still required to establish thresholds. The NO_3^- electrode is possibly a more accurate measure as it uses a homogenous mixture of leaves to obtain the plant sap.

Miss Zibuyile Dlamini

Miss Dlamini is an intern at the Agricultural Research Council. Under supervision of Prof Sue Walker, she is conducting a study on the use of chicken manure as a substitute for fertilizers. Miss Dlamini interacts with farmers at the Rooiwal Agri-park and gave a presentation on a decision support tool for using chicken manure at the Focus Group Meeting at Rooiwal. Farmers responded very positively to the tool. Miss developed the user-friendly Vundisa Manure Application Tool (VMAT) that can guide farmers on the amount of chicken manure to apply to their fields. Ms Dlamini contributed the sections of this report relating to the VMAT (**Section 2.4.2.1, Section 2.4.3, Section 4.3.3, Section 4.4.2** and **Section 5.4**).

Appendix 4: Research Outputs

Publications

Book Chapter: le Roux, B, Howard, M. The problem of nutrient accumulation in the South African water system: Towards a complementary approach in sustainable food production. Submitted for review.

Conferences:

- Network on Irrigation Research and Extension for Small-Scale Agriculture (NIRESA) conference: Theme: Agri-parks (19 & 20 June 2019)
- WRC conference on Women in Water and Science and the impact of Covid-19: Presentation by Le Roux, B. Improving water management in Rooiwal Agri-park: Towards a model for uplifting rural communities and revitalizing agriculture.

Appendix 5: Attendance at farmers information days

Table 0-1: Names and contact details of Johannesburg Agri-parks farmers that attended the Farmers' day in February 2019

Name of farmer	Telephone number	E-mail address
Eikenhof Agri-park		
Gakeboife Morake	074 634 2166	morakegakeboife@gmail.com
Gloria Mafajane	073 289 8391	-
Jacobeth Marakiya	078 160 8705	-
Jim Mashu	072 951 1180	-
Lilian Kamohi	073 978 2141	-
Mabei Dikobee	083 544 7611	-
Nohithando Mbengo	078 091 1190	-
Paulus Mashele	078 538 4103	-
Petrus Modikwe	063 431 5751	-
Phetole Raseropo	-	-
Sibongile Mbantha	-	-
Sibusiso Mashele	073 069 9675	Sibusisomashele@gmail.com
Tankiso Sematla	072 683 5805	-
Teboho Sematla	072 683 5805	-
Motuba Mahoko	071 006 6379	-
Merafong flora Agri-park		
Johannes Macaruxela	076 511 1422	-
Lydia Nhlapo	078 617 2192	Lydianhlapo30@gmail.com
Mpho Selebogo	071 444 2150	-
Napo Mashaba	-	-
Peggy Mamome	072 224 6989	Peggy.mamone57@gmial.com
Phemelo Rammutla	072 906 0324	phemr@yahoo.com
Stephen Lepedi	084 696 5076	-
William Letlhoike	072 590 3226	-
Gaaringtoni Koqo	060 389 5993	-
Melumzi Matinize	073 323 8923	matinisemelumzi@gmail.com
Slovoville Agri-park		
Sinqobile / Victoria Moyo	-	-
V. Lethiwe Hlongwane	076 353 5933	-
Tarlton Agri-park		
Awelani Mulaudzi	064 600 4115	-
Cozy Mahilo	076 478 9120	-
Irene Munyai	078 314 9406	-
Tshwarelo Malatji	064 613 3186	-
Moxolo Mgindi	078 005 4615	-
Petronel Mulaudzi	081 826 3616	-
Thandiswa Dlelinataka	073 677 2486	-
Thebe Johannes	063 433 3965	-

Westonaria Agri-park		
Fabian Letsholo	072 624 8646	-
Judae Leisholo	076 124 0704	Ntlhalefeng.lekholo@gmail.com
Malizole Sillau	073 227 5251	-
Mondisa Mbuzi	073 458 4249	-
Mpho Mosiea	073 718 1415	-
Paul Mantshonyane	071 994 4956	-
Angel Tswayi	078 501 6008	-
Elias Rammala	078 263 0728	rammalaelisa@gmail.com
Mogale Maleka	074 477 3123	malekamogale@gmail.com
Monde Dlikilili	073 258 1920	-
Tumelo Pule	082 078 931	Tumelo.bndct@gmail.com
Belsarri Mavingo	064 622 8008	-
Kefuwe Mapane	076 219 0384	-
Bhsen Zvina	-	-
Zwelijikile Tsibiyani	060 447 6453	-

Appendix 6: Data

Data relevant to the irrigation with effluent feasibility study at Rooiwal

Arcadia weather data for January to May 2020

STATION NAME	Latitude	Longitude	Altitude
PRETORIA – ARCADIA	-25.73857	28.20733	1400

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	1	1	30.2	18.11	83.8	35.95	16.67	2.04	3.81	3.79	12.37	-24	0	1.8
2020	1	2	31.22	18.43	76.3	30.75	26.08	1.27	0	5.68	14.7	-24	0	1.57
2020	1	3	33.16	18.57	72.23	29.36	28.11	1.88	0	6.31	14.93	-24	0	1.52
2020	1	4	32.27	17.76	79.57	31.12	26.25	2.41	0.25	5.58	13.86	-24	0	1.51
2020	1	5	30.55	17.42	79.93	30.8	25.66	1.78	0	5.67	14.35	-23	0	1.52
2020	1	6	33.87	19.87	70.41	22.53	28.04	1.56	6.6	6.25	15.7	-24	0	1.51
2020	1	7	30.92	19.81	70.31	25.05	26.52	1.83	0	6.13	14.83	-24	0	1.4
2020	1	8	27.57	20.81	57.34	39.98	12.85	1.34	50.8	3.27	13.86	-24	0	1.42
2020	1	9	27.94	16.94	93.21	49.59	11.8	0.87	0	2.5	12.54	-23	0	1.89
2020	1	10	26.29	19.64	82.54	50.12	14.27	1.7	0	3.17	12.31	-24	0	1.81
2020	1	11	24.68	18.01	84.99	54.31	11.02	1.21	0	2.49	11.12	-24	0	1.66
2020	1	12	29.19	17.75	88.04	36.85	21.64	1.16	1.27	4.73	12.64	-24	0	1.67
2020	1	13	29.6	16.34	92.82	37.77	20.5	1.41	7.37	4.45	12.16	-22.5	0	1.7
2020	1	14	28.98	16.18	78.04	32.72	21.02	1.19	0	4.4	11.59	-20.5	0	1.47
2020	1	15	29.56	17.35	78.65	25.84	26.76	1.32	0	5.64	13.45	-23.5	0	1.37
2020	1	16	29.64	17.76	69.1	17.09	28.83	1.49	0	6.13	13.92	-23.5	0	1.17
2020	1	17	30.09	18.25	68.67	31.56	22.63	1.28	0.51	4.74	14.35	-24	0	1.4

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	1	18	24.69	18.34	91.61	41.66	7.5	0.65	12.19	1.66	11.24	-24	0	1.78
2020	1	19	27.96	18.2	91.03	45.6	17.14	1.58	0	3.68	11.94	-24	0	1.75
2020	1	20	27.67	16.55	72.64	40.5	21.82	1.92	0	4.48	11.42	-20.5	0	1.45
2020	1	21	27.66	17.1	76.81	43.82	17.21	1.5	0	3.79	11.28	-22	0	1.61
2020	1	22	29.49	18.72	86.41	36.21	20.87	1.84	0	4.68	13.68	-24	0	1.69
2020	1	23	30.75	17.82	83.17	30.63	23.14	1.51	8.13	5.25	13.58	-24	0	1.58
2020	1	24	22.88	16.47	92.84	59.66	9.48	1.41	21.08	2.07	9.51	-20	0	1.7
2020	1	25	25.3	15.49	94.88	47.72	17.8	1.77	2.79	3.56	9.86	-18.5	0	1.64
2020	1	26	29.22	17.31	88.41	40.49	25.38	1.42	0.51	5.32	13.36	-23	0	1.7
2020	1	27	32.64	18.28	74.95	19.43	27.13	1.38	0	6.08	14.85	-24	0	1.44
2020	1	28	26.62	16.02	88.42	38.11	18.36	1.68	0	3.88	10.51	-20	0	1.55
2020	1	29	30.56	17.25	83.08	32.11	25.54	1.19	0	5.47	13.76	-23	0	1.55
2020	1	30	30.2	18.68	70.12	33.97	25.27	1.96	0	5.7	14.42	-24	0	1.45
2020	1	31	30.13	16.69	76.52	18.93	27.99	1.65	0	5.91	13.64	-22.5	0	1.18
2020	1	**Average**	29.08	17.8	80.54	35.81	21.07	1.52	3.72	4.59	12.96	-23.02	0	1.56
2020	1	**Total**	901.51	551.92	2,496.85	1,110.24	653.31	47.19	115.32	142.44	401.74	-713.5	0	48.45
2020	1	**Highest**	33.87	20.81	94.88	59.66	28.83	2.41	50.8	6.31	15.7	-18.5	0	1.89
2020	1	**Lowest**	22.88	15.49	57.34	17.09	7.5	0.65	0	1.66	9.51	-24	0	1.17

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	2	1	34.37	18.5	58.14	18.78	23.83	1.18	0	5.52	15.7	-24	0	1.21
2020	2	2	31.88	19.26	72.83	22.63	26.3	1.14	0	5.89	15.45	-24	0	1.43
2020	2	3	31.77	17.7	65.58	17.2	27.59	0.96	0	5.9	14.48	-24	0	1.13
2020	2	4	31.06	18.79	58.35	22.77	24.98	1.18	0	5.39	14.92	-24	0	1.19

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	2	5	31.89	19.99	58.86	24.11	22.47	1.27	0	5.13	15.72	-24	0	1.29
2020	2	6	31.49	19.61	73.61	31	21.49	1.78	2.03	4.85	13.94	-24	0	1.58
2020	2	7	29.46	19.22	76.17	32.92	24.93	1.82	4.32	5.48	13.44	-24	0	1.62
2020	2	8	21.98	17.28	93.12	62.74	5.82	1.41	4.06	1.28	9.25	-23.5	0	1.88
2020	2	9	29.26	17.46	93.11	39.23	20.63	1.47	2.03	4.32	11.92	-22.5	0	1.75
2020	2	10	29.81	17.34	88.74	34.69	21.33	1.8	1.02	4.61	12.08	-23.5	0	1.68
2020	2	11	24.95	16.28	73.72	46.7	20.12	2.48	0	4.17	9.96	-20	0	1.44
2020	2	12	25.82	15.52	86.11	45.05	17.36	2.32	0	3.74	9.94	-19.5	0	1.45
2020	2	13	27.97	16.52	90.06	41.64	19.5	1.47	0	4.15	11.87	-20.5	0	1.61
2020	2	14	31.2	18.12	77.93	27.95	22.33	1.04	0	4.97	14.81	-24	0	1.51
2020	2	15	31.44	18.83	77.21	25.78	24.9	0.95	0	5.33	14.99	-24	0	1.47
2020	2	16	35.45	18.84	74.63	29.16	24.31	0.99	0	5.01	14.38	-24	0	1.42
2020	2	17	31.72	18.03	80.82	31.18	20.72	0.96	1.02	4.5	14.79	-24	0	1.55
2020	2	18	29.82	20.3	70.57	34.73	19.59	1.54	0	4.49	14.8	-24	0	1.56
2020	2	19	30.61	19.43	74.49	31.63	20.78	1.41	0	4.54	14.06	-24	0	1.59
2020	2	20	29.6	19.27	76.16	35.15	20.44	1.44	0	4.61	14.65	-24	0	1.59
2020	2	21	30.13	18.37	90.12	37.83	12.71	1.41	12.19	3.05	13.19	-24	0	1.77
2020	2	22	28.92	18.9	91.85	44.57	13.93	1.72	7.62	3.2	11.62	-24	0	1.95
2020	2	23	25.01	16.37	83.46	43.01	15.62	2.26	0	3.52	10.86	-22.5	0	1.56
2020	2	24	28.45	14.29	72.85	26.33	23.66	2	0	4.82	10.18	-16	0	1.24
2020	2	25	28.35	16.01	88.27	28.91	23.86	1.06	0	4.8	11.22	-20	0	1.35
2020	2	26	30.56	15.24	72.88	27.37	23.04	1.08	0	5.01	12.76	-21	0	1.27
2020	2	27	30.56	17.19	73.55	25.47	23.05	1.15	0	5.07	14.34	-23	0	1.32
2020	2	28	29.67	17.5	76.89	33.22	16.65	1.93	8.38	3.84	12.28	-23	0	1.54
2020	2	29	23.44	14.1	88.83	44.08	12.47	1.78	0.51	2.61	8.14	-15	0	1.31
2020	2	30	--	--	--	--	--	--	--	--	--	--	--	--
2020	2	31	--	--	--	--	--	--	--	--	--	--	--	--

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	2	**Average**	29.54	17.73	77.89	33.3	20.5	1.48	1.49	4.48	12.96	- 22.55	0	1.49
2020	2	**Total**	856.65	514.26	2,258.88	965.81	594.41	43.03	43.18	129.78	375.73	-654	0	43.27
2020	2	**Highest**	35.45	20.3	93.12	62.74	27.59	2.48	12.19	5.9	15.72	-15	0	1.95
2020	2	**Lowest**	21.98	14.1	58.14	17.2	5.82	0.95	0	1.28	8.14	-24	0	1.13

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	3	1	21.99	14.57	80.25	49.69	9.29	0.73	1.02	1.98	7.67	-13	0	1.37
2020	3	2	18.28	14.92	94.5	77.13	2.56	0.65	11.94	0.67	6.16	-8	0	1.62
2020	3	3	26.2	13.14	90.94	35.95	18.52	1.13	0	3.71	8.56	-14	0	1.4
2020	3	4	28.56	15.75	84.87	22.25	24.71	1.24	0	4.96	11.44	-20	0	1.21
2020	3	5	29.62	15.78	64.71	24.39	22.1	0.9	0	4.58	12.46	-21	0	1.15
2020	3	6	28.41	16.16	67.8	19.59	24.59	1.18	0	4.95	11.84	-22	0	1.07
2020	3	7	27.43	14.07	73.35	23.93	23.45	1.12	0	4.64	10.6	-17	0	1.08
2020	3	8	29.47	16.25	69.74	22.77	20.09	0.82	0	4.15	12.3	-21.5	0	1.21
2020	3	9	31.48	15.96	66	23.02	22.2	0.83	0	4.59	13.06	-22	0	1.15
2020	3	10	30.04	16.4	69.4	29.37	22.3	1.14	0	4.73	13.07	-22	0	1.27
2020	3	11	31.79	18.04	69.93	26.36	20.79	1.15	0	4.56	13.97	-24	0	1.34
2020	3	12	27.7	16.08	91.52	33.41	17.33	1.93	31.5	3.86	12.46	-23	0	1.42
2020	3	13	22.87	14.59	93.52	48.42	8.05	1.58	0	1.8	8.59	-18	0	1.47
2020	3	14	29.45	15.75	79.48	25.56	22.56	1.31	0	4.75	12.55	-20.5	0	1.39
2020	3	15	31.64	17.04	67.13	19.39	21.53	1.58	0	4.89	14.14	-23.5	0	1.11
2020	3	16	29.08	17.25	82.65	35.05	16.41	1.37	0	3.47	12.06	-22.5	0	1.53
2020	3	17	22.36	14.55	92.74	49.92	9.46	2.42	2.29	2.38	8.15	-15.5	0	1.33
2020	3	18	26.57	15.17	94.56	41.03	15.73	1.16	0	3.23	9.82	-18	0	1.53
2020	3	19	30.01	15.53	83.54	25.63	20.16	1.09	0	4.31	12.91	-20	0	1.32
2020	3	20	29.83	17.43	76.7	27.36	21.93	1.18	0	4.57	13.26	-23.5	0	1.41

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	3	21	31.84	15.89	92.83	23.41	20.17	1.22	14.99	4.43	12.44	-21	0	1.38
2020	3	22	24.87	16.13	91.1	41.34	9.33	1.01	0.25	1.98	8.95	-18.5	0	1.51
2020	3	23	27.45	16.53	76.59	32.88	19.33	1.71	0.76	3.98	10.72	-19	0	1.37
2020	3	24	29.38	15.25	81.54	29.01	21.09	1.13	0	4.44	12.04	-18.5	0	1.35
2020	3	25	30.85	16.67	72.43	26.7	20.79	1.22	0	4.71	13.73	-22.5	0	1.32
2020	3	26	31.72	18.06	77.47	25.46	16.34	1.66	5.33	3.92	12.52	-24	0	1.36
2020	3	27	27.69	15.44	76.89	36.11	18.4	1.81	0	3.86	10.04	-19	0	1.36
2020	3	28	23.51	15.03	79.15	48.23	7.86	0.85	0	1.68	7.61	-12	0	1.38
2020	3	29	27.26	14.39	87.88	33.25	17.51	0.84	0	3.47	10.17	-17	0	1.41
2020	3	30	25.47	17.94	71.1	43.88	7.98	1.04	0	1.83	10.92	-24	0	1.4
2020	3	31	25.75	17.65	67.28	40.35	13.92	1.2	0	3.05	11.13	-23.5	0	1.35
2020	3	**Average**	27.7	15.92	79.6	33.58	17.31	1.23	2.2	3.68	11.14	-19.61	0	1.34
2020	3	**Total**	858.58	493.41	2,467.60	1,040.86	536.48	38.22	68.07	114.13	345.33	-608	0	41.57
2020	3	**Highest**	31.84	18.06	94.56	77.13	24.71	2.42	31.5	4.96	14.14	-8	0	1.62
2020	3	**Lowest**	18.28	13.14	64.71	19.39	2.56	0.65	0	0.67	6.16	-24	0	1.07

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	4	1	28.63	16.14	70.79	32.89	17.5	2.19	0	3.86	11	-21.5	0	1.34
2020	4	2	20.01	13.56	73.54	46.03	4.9	1.87	0.25	1.37	6.77	-12	0	1.1
2020	4	3	21.46	11.88	94.91	42.22	8.62	1.35	65.79	1.93	5.71	-6.5	0	1.23
2020	4	4	18.91	13.42	96.16	66.45	4.5	0.81	34.8	0.9	4.91	-2.5	0	1.52
2020	4	5	24.92	11.36	97.64	29.06	16.42	1	0	3.18	7.59	-11.5	0	1.31
2020	4	6	27.51	13.29	80.49	25.1	20.64	1.15	0	4.33	10.54	-16.5	0	1.13
2020	4	7	27.43	14.46	69.08	19.56	20.1	1.98	0	4.43	10.92	-18.5	0	0.92
2020	4	8	23.3	14.44	76.42	36.18	9.35	2.04	0	2.14	8.15	-14.5	0	1.21
2020	4	9	22.03	14.7	84.03	53.58	9.13	2.04	0	1.92	7.26	-12	0	1.39

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	4	10	20.2	13.48	92.71	58.72	6.44	0.74	0	1.3	6.67	-10.5	0	1.41
2020	4	11	25.84	13.79	90.99	39.24	16.59	0.92	0	3.32	9.55	-15.5	0	1.4
2020	4	12	28.17	14.48	79.17	28.98	19.57	1.5	0	4.17	11.49	-18.5	0	1.25
2020	4	13	29.23	16.43	64.24	28.63	16.91	1.14	0	3.73	12.15	-22	0	1.21
2020	4	14	24.96	14.12	94.44	43.23	13.51	2.19	20.57	2.95	8.85	-15	0	1.44
2020	4	15	23.36	14.34	94.69	26.9	14.82	1.37	0	2.89	7.99	-13.5	0	1.31
2020	4	16	24.48	11.45	69.91	30.43	18.74	1.6	0	3.64	7.94	-13	0	0.92
2020	4	17	24.89	11.86	76.09	28.88	18.65	1.61	0	3.83	8.95	-15	0	0.97
2020	4	18	24.33	14.89	89.65	41.42	12.88	1.23	0	2.5	8.7	-15	0	1.45
2020	4	19	25.29	14.2	84.46	37.39	14.54	0.87	0	2.77	8.65	-15	0	1.35
2020	4	20	26.07	12.4	83.32	33.23	16.66	0.61	0	3.08	8.98	-14.5	0	1.21
2020	4	21	26.89	12.48	63.59	13.54	18.49	1.45	0	3.84	9.32	-14.5	0	0.83
2020	4	22	26.72	12.07	73.99	26.47	17.95	0.53	0	3.34	9.29	-16	0	1
2020	4	23	25.96	13.52	68.63	32.34	16.92	0.92	0	3.22	9.19	-16	0	1.08
2020	4	24	24.69	13.54	70.35	32.43	17.48	0.92	0	3.34	8.67	-15	0	1.09
2020	4	25	25.45	12.4	83.36	25.82	15.77	1.15	2.03	3.11	8.74	-14.5	0	1.08
2020	4	26	23.35	12.79	92.67	42	12.39	1.58	3.3	2.43	7.16	-10.5	0	1.29
2020	4	27	20.46	11.88	93.1	55.89	8.68	1.5	18.54	1.67	5.7	-8	0	1.36
2020	4	28	16	11.24	97.4	63.59	5.33	2.22	2.03	0.95	2.91	7	7	1.32
2020	4	29	19.54	9.52	97.83	37.35	15.85	1.18	0	2.72	4.24	-1.5	0	1.11
2020	4	30	24.32	9.13	79.83	28.49	16.86	1.39	0	3.09	6.02	-6.5	0	0.94
2020	4	31	--	--	--	--	--	--	--	--	--	--	--	--
2020	4	**Average**	24.15	13.11	82.78	36.87	14.21	1.37	4.91	2.86	8.13	-12.62	0.23	1.21
2020	4	**Total**	724.43	393.27	2,483.48	1,106.02	426.2	41.07	147.32	85.94	243.99	-378.5	7	36.16
2020	4	**Highest**	29.23	16.43	97.83	66.45	20.64	2.22	65.79	4.43	12.15	7	7	1.52
2020	4	**Lowest**	16	9.13	63.59	13.54	4.5	0.53	0	0.9	2.91	-22	0	0.83

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	5	1	26.31	10.91	69.46	20.27	16.98	1.07	0	3.3	8.23	-12	0	0.91
2020	5	2	24.39	10.18	76.5	26.03	16.15	1.15	0	3.13	7.61	-11.5	0	0.93
2020	5	3	26.27	11.01	72.52	16.45	16.88	1.43	0	3.36	8.32	-11	0	0.82
2020	5	4	26.14	11.71	66.08	22.18	16.52	1.08	0	3.3	8.14	-12	0	0.8
2020	5	5	24.78	12.33	84.75	31.66	15.8	0.92	0	2.92	7.62	-13	0	1.13
2020	5	6	25.93	10.18	73.51	12.9	16.3	1.24	0	3.18	7.69	-9.5	0	0.71
2020	5	7	25.22	9.55	80.84	27.54	15.64	0.75	0	2.75	6.59	-9	0	0.92
2020	5	8	23.93	10.47	75.2	33.79	15.27	0.92	0	2.85	7.11	-10.5	0	1.04
2020	5	9	25.17	9.71	80.58	26.83	15.24	0.95	0	2.78	7.37	-10.5	0	0.99
2020	5	10	24.72	10.29	78.1	19.97	15.86	0.98	0	2.89	7.22	-11	0	0.83
2020	5	11	25.07	9.37	67.46	19.18	15.41	1.06	0	2.95	6.83	-9	0	0.79
2020	5	12	24.95	10.46	59.76	15.41	15.4	1.37	0	3.02	7.69	-11.5	0	0.72
2020	5	13	24.49	11.12	56.67	17.94	14.54	1.96	0	3.09	7.39	-10.5	0	0.7
2020	5	14	23.44	10.93	59.95	21.45	15.1	1.37	0	2.88	6.63	-8.5	0	0.73
2020	5	15	21.68	10.44	77.56	31.29	14.27	1.2	0	2.66	5.6	-5.5	0	0.92
2020	5	16	25.96	7.89	59.19	9.18	15.44	1.06	0	2.84	6.3	-6	0	0.52
2020	5	17	22.23	9.56	88.24	30.62	14.85	1.06	0	2.61	5.29	-4.5	0	0.93
2020	5	18	25.42	9.87	68.63	14.71	14.69	1.33	0	2.89	6.87	-8	0	0.72
2020	5	19	25.1	8.76	57.77	17.71	12.62	0.95	0	2.32	6.75	-9.5	0	0.66
2020	5	20	23.74	9.31	72.14	24.39	15.42	0.96	0	2.83	6.41	-8.5	0	0.82
2020	5	21	21.58	10.08	72.43	31.14	15.49	0.79	0	2.61	5.4	-4	0	0.88
2020	5	22	24.14	8.05	72.74	19.15	14.66	0.8	0	2.56	5.71	-4.5	0	0.74
2020	5	23	23.39	8.25	64.4	20.13	14.77	0.9	0	2.63	5.9	-6.5	0	0.69
2020	5	24	21.89	9.66	63.8	27.86	14.47	0.93	0	2.62	5.66	-6	0	0.76
2020	5	25	21.46	11.68	67.39	25.22	10.96	1.25	0	2.37	6.19	-9	0	0.74
2020	5	26	19.79	6.87	50.1	20.29	13.89	2.51	0	2.67	3.86	-0.5	0	0.54
2020	5	27	16.97	3.65	46.62	12.74	15.59	2.18	0	2.58	-0.35	14.5	14.5	0.34

YEAR	MONTH	DAY	TX	TN	RHX	RHN	RS	U2	RAIN	ET0	HU	CU	DPCU	VP
2020	5	28	19.59	3.16	54.98	13.07	15.42	1.41	0	2.65	1.37	7	7	0.38
2020	5	29	22.62	5.78	47.82	14.79	14.95	1.97	0	2.95	3.83	1	1	0.46
2020	5	30	25.11	9.18	50.2	18.86	14.98	0.87	0	2.72	6.44	-7.5	0	0.61
2020	5	31	24.33	7.94	63.16	18.96	14.35	0.97	0	2.63	6.19	-7	0	--
2020	5	**Average**	23.74	9.3	67.05	21.35	15.09	1.21	0	2.82	6.19	-6.9	0.73	0.76
2020	5	**Total**	735.82	288.37	2,078.52	661.71	467.91	37.39	0	87.57	191.88	-214	22.5	22.72
2020	5	**Highest**	26.31	12.33	88.24	33.79	16.98	2.51	0	3.36	8.32	14.5	14.5	1.13
2020	5	**Lowest**	16.97	3.16	46.62	9.18	10.96	0.75	0	2.32	-0.35	-13	0	0.34

DESCRIPTION	UNIT	STATION TYPE
DAILY MAXIMUM TEMPERATURE	°C	AWS
DAILY MINIMUM TEMPERATURE	°C	AWS
TOTAL RAINFALL [CALCULATED FROM HOURLY DATA]	mm	AWS
TOTAL RADIATION [CALCULATED FROM HOURLY DATA]	MJ/m^2	AWS
AVERAGE WIND SPEED [CALCULATED FROM HOURLY DATA]	ms	AWS
DAILY MAXIMUM RELATIVE HUMIDITY	%	AWS
DAILY MINIMUM RELATIVE HUMIDITY	%	AWS
TOTAL RELATIVE EVAPOTRANSPIRATION [CALCULATED FROM HOURLY DATA]	mm	AWS
TOTAL HEAT UNITS [CALCULATED FROM HOURLY DATA]	Unitless	AWS
TOTAL COLD UNITS [CALCULATED FROM HOURLY DATA]	Unitless	AWS

DAILY POSITIVE CHILLING UNITS [CALCULATED FROM HOURLY DATA]	Unitless	AWS
VAPOUR PRESSURE [CALCULATED FROM HOURLY DATA / 06:00-18:00]	~~~	AWS
SATURATED VAPOUR PRESSURE [CALCULATED FROM HOURLY DATA]	~~~	AWS
VAPOUR PRESSURE DEFICIT [CALCULATED FROM HOURLY DATA / 06:00-18:00]	~~~	AWS
AVERAGE TEMPERATURE [[TX + TN] / 2]	°C	AWS
AVERAGE RELATIVE HUMIDITY [[RHX + RHN] / 2]	%	AWS
HIGHEST WIND SPEED MEASUREMENT FOR THE 24 HOUR PERIOD	m/s	AWS
TIME OF HIGHEST WIND SPEED MEASUREMENT FOR THE 24 HOUR PERIOD	time	AWS
DAILY MAXIMUM TEMPERATURE	°C	MWS
DAILY MINIMUM TEMPERATURE	°C	MWS
AVERAGE DAILY MAXIMUM RELATIVE HUMIDITY	%	MWS
AVERAGE DAILY MINIMUM RELATIVE HUMIDITY	%	MWS
TOTAL DAILY RAINFALL	mm	MWS
TOTAL DAILY APAN EVAPORATION	mm	MWS
DAILY WIND RUN	KM/day	MWS
SUNSHINE HOURS	Hours	MWS

Quality analysis for final effluent used for irrigation of the feasbility study at Rooiwal

University of Pretoria

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Date / Datum: 01/07/2020

REPORT NO: WATER 202021 11982
VERSLAG NR:

Sender ID: Betsiel **Lab. No:** W 9

pH	pHs	SAR	Electric Conductivity
7.79	8.13	2.23	62.40 mS/m at 25 °C

ANIONS	mg/l	mmol(c)/l
Fluoride (1.5)	0.00	0.00
Nitrite (4.0)	0.17	0.00
Nitrate (44.0)	42.47	0.69
Chloride (250)	64.21	1.81
Sulphate (500)	59.97	1.25
Phosphate	15.19	0.32
Carbonate (20.0)	0.00	0.00
Bicarbonate	67.71	1.11
Subtotal	249.72	5.18

CATIONS	mg/l	mmol(c)/l
Sodium (400)	65.60	2.85
Potassium (400)	13.20	0.34
Calcium (200)	37.20	1.86
Magnesium (100)	17.10	1.41
Boron (1.5)	0.05	0.01
Subtotal	133.15	6.47

Sodium Carbonate	0.00	0.00
Sodium Bicarbonate	0.00	0.00
Alkalinity	55.50	1.11
Temp. Hardness	55.50	1.11
Perm. Hardness	108.51	2.17

Total	382.00
Less (*)	33.86
Total disolved Solids	348.15

* Correction for any volatile substances, HCO3/2 or .... HCL + HNO3 + HF + ...
() Figures in brackets are the recommended maximum values for human use in mg/l.

Nutrient analysis of the cabbage sample for Rooiwal trial. Control: irrigated with groundwater, Trials 1-3: irrigated with sewage effluent

ANALYSIS REPORT: ARC - INSTITUTE FOR SOIL, CLIMATE AND WATER
ONTLEDINGSVERSLAG: LNR - INSTITUUT VIR GROND KLIMAAT EN WATER

600 Belvedere Street, Arcadia, Pretoria. P.Bag X79, Pretoria, 0001.
Telephone: (012) 310 2500 Telefax (012) 323 1157

Report Number: PLANT 2020/21-0001

Client Name: UP- Betsie Le Roux
Report date: 11-09-2020
Sample name: Cabbage

Lab. No.	P1	P2	P3	P4	
Sender No.	**Control**	**T1**	**T2**	**T3**	**Units**
Moisture	90.0	88.6	89.2	89.3	%
N	3.4	3.0	3.0	2.9	%
K	19087	22599	21452	21908	mg/kg
Ca	21020	16349	18494	20628	mg/kg
Mg	1997	1970	2153	2028	mg/kg
P	3303	3076	2896	2731	mg/kg
Na	6820	3209	4958	5815	mg/kg
Mn	18.6	19.2	16.5	16.0	mg/kg
Al	65.0	47.6	66.8	58.6	mg/kg
Fe	85.5	85.1	77.8	88.4	mg/kg
Zn	17.5	19.4	18.8	19.3	mg/kg
B	17.0	20.3	17.4	15.2	mg/kg
Cu	2.4	2.5	2.4	2.8	mg/kg
S	8214.6	8548.1	8885.3	8311.1	mg/kg
F^-	6712.7	5996.1	7553.2	9711.9	mg/kg
Cl^-	7141.4	9665.7	10492.1	4475.2	mg/kg

Heavy metal analysis of the cabbage sample for Rooiwal trial. Control: irrigated with groundwater, Trials 1-3: irrigated with sewage effluent

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Telephone: (012) 310 2500 Telefax (012) 323 1157

Report Number: PLANT 20120/21-0001

Client Name: UP- Betsie Le Roux
Report date: 11-09-2020
Sample name: Cabbage

Lab. No.	P1	P2	P3	P4	
Sender No.	Control	T1	T2	T3	Units
As	< 0.12	< 0.12	< 0.12	< 0.12	mg/kg
Ba	11.15	22.60	19.79	20.49	mg/kg
Cr	2.43	1.76	1.56	2.00	mg/kg
Cd	< 0.2	< 0.2	< 0.2	< 0.2	mg/kg
Co	0.20	0.15	0.17	0.20	mg/kg
Hg	0.25	0.24	0.22	0.27	mg/kg
Ni	5.03	2.34	2.06	2.07	mg/kg
Mo	3.60	3.20	4.32	4.28	mg/kg
V	<0.2	<0.2	<0.2	<0.2	mg/kg
Pb	0.35	0.25	0.20	0.47	mg/kg
Se	<1	<1	<1	<1	mg/kg
Sb	<0.05	<0.05	<0.05	<0.05	mg/kg

Laboratory analyses for soil and chicken manure samples taken at Rooiwal

Rooiwal soil analysis; Particle size distribution

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INSTITUUT VIR GROND, KLIMAAT EN WATER

RESULTS FOR REPORT No:
RESULTATE VIR VERSLAG Nr: GROND 201920 5749

Client : **Z Dlamini**
Klient : Agromet
ARC SCW

Tel :
Fax / Faks :
Date / Datum : 2020/02/13

PARTICLE SIZE DISTRIBUTION - 3 FRACTION / DEELTJIEGROOTTE VERSPREIDING

LabNo		Sender ID	SAND %	SILT %	CLAY %
M	922	Agro Forestry sample 1 15cm	76,0	6,0	18,0
M	923	Agro Forestry sample 1 30cm	76,0	4,0	20,0
M	924	New Spinach sample 2 15cm	68,0	8,0	24,0
M	925	New Spinach sample 2 30cm	68,0	6,0	26,0
M	926	Sewage Soil sample 3 15cm	76,0	6,0	18,0
M	927	Sewage Soil sample 3 30cm	72,0	6,0	22,0
M	928	Zuchini sample 4 15cm	76,0	6,0	18,0
M	929	Zuchini sample 4 30cm	72,0	6,0	22,0
M	930	Beetle Spinach sample 5 15cm	76,0	8,0	16,0
M	931	Beetle Spinach sample 5 30cm	74,0	6,0	20,0

Rooiwal soil analysis; pH and nutrients

INSTITUTE FOR SOIL, CLIMATE AND WATER

INSTITUUT VIR GROND, KLIMAAT EN WATER

Client : **Z Dlamini**
Klient : Agromet
ARC SCW

Tel :

Fax / Faks :

Date / Datum : 2020/02/13

RESULTS FOR REPORT No:
RESULTATE VIR VERSLAG Nr GROND 201920 5749

			1	2	3	4	5	6	7	8	9	10
T	**LabNo**	**SENDER_NR**	**OM**	**Total N**	**pH H2O**	**Res.**	**P**	**Ca**	**Mg**	**K**	**Na**	**Bulk density**
			%	%	N/A	ohm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	g/cm3
M	922	Agro Forestry sample 1 15cm		0,069	6,59	1260	160,22	884	55,3	82,5	32,2	1,167
M	923	Agro Forestry sample 1 30cm		0,037	6,23	1040	141,16	528	58,8	103	24,7	1,300
M	924	New Spinach sample 2 15cm		0,083	6,17	690	138,89	1050	84,1	102	34,2	1,300
M	925	New Spinach sample 2 30cm		0,051	6,12	530	135,28	944	70,8	73,7	33,5	1,267
M	926	Sewage Soil sample 3 15cm		0,080	6,36	670	132,52	865	58,4	64,6	45,9	1,333
M	927	Sewage Soil sample 3 30cm		0,038	6,27	780	95,63	658	47,8	46	42,7	1,233
M	928	Zuchini sample 4 15cm		0,054	5,69	2140	117,58	485	40,8	77,3	23,5	1,167
M	929	Zuchini sample 4 30cm		0,031	6,49	1600	114,68	626	49,7	105	30,1	1,167
M	930	Beetle Spinach sample 5 15cm		0,064	6,37	2010	116,54	736	54,2	76,8	31,3	1,267
M	931	Beetle Spinach sample 5 30cm		0,041	6,46	1240	113,26	519	39,5	46,7	31,7	1,400

METHODS USED FOR ANALYSIS :

Serial	Method
1	% C (LOI)
2	Total N Digest
3	Farmer Topsoil
4	Farmer Topsoil
5	Farmer Topsoil
6	Farmer Topsoil
7	Farmer Topsoil
8	Farmer Topsoil
9	Farmer Topsoil
10	Bulk density

Rooiwal chicken manure (compost heap) analysis; pH and nutrients

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600 Belvedere Street, Arcadia, Pretoria. P.Bag X79, Pretoria, 0001.
Telephone: (012) 310 2500 Telefax (012) 323 1157

Report Number: F 2019/20-0047

Report on: Analysis of two Compost samples
For:
Ziboyile Dlamini
ARC-ISCW
18-02-2020

Lab number:	F350			F351		
Sender number:	Compost 1			Compost 2		
Element	Conc A.D.	Conc Wet		Conc A.D.	Conc Wet	Units
pH *	8,53			8,98		
Elec.Conductivity*	272			404		mS/m
Moisture	2,04	12,4		3,92	39,6	%
Tot.solids	97,96	87,6		96,08	60,4	%
Moisture Lost	10,6	N.A.		37,2	N.A.	%
Ash	80,8	72,2		69,1	43,4	%
Organic Matter	898,8	803,5		891,7	560,3	g/kg
Ash: Dry	82,5			72,0		g/kg
Total C	9,0	8,0		16,6	10,4	%
Total N	1,11	0,99		1,62	1,02	%
C/N Ratio	8,10			10,25		
P	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg
K	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg
Na	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg
Ca	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg
Mg	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg
Fe	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg
Cu	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	mg/kg
Mn	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	mg/kg
Zn	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	mg/kg
B	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	mg/kg
Al	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg
Total S	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	g/kg

A.D. is Air Dried (room temperature). C, N and other elements were determined on air dried samples.
Values in the Conc Wet column have been calculated back to the samples as received (wet).
Moisture Lost is the moisture lost on air-drying.
* The sample (A.D.) to water ratio used is 1g:5ml for pH and 1g:10ml for electrical conductivity.

Rooiwal chicken manure (saw dust) analysis; pH and nutrients

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600 Belvedere Street, Arcadia, Pretoria. P.Bag X79, Pretoria, 0001.
Telephone: (012) 310 2500 Telefax (012) 323 1157

Report Number: F 2019/20-0048

Report on: Analysis of Compost samples
From
Zibuyile Dlamini
ARC-ISCW
18-02-2020

Lab number:	F352			
Sender number:	Chicken manure			
Element	**Conc A.D.**	**Conc Wet**	**Conc Dry**	**Units**
pH *	8,14			
Elec.Conductivity*	812			mS/m
Moisture	7,02	18,6		%
Tot.solids	92,98	81,4		%
Moisture Lost	12,5	N.A.		%
Ash	15,1	13	16	%
Organic Matter	915	800	984	g/kg
Total C	38	33	40	%
Total N	3,15	2,76	3,39	%
C/N Ratio	11,94			
P	#DIV/0!	#DIV/0!	#DIV/0!	g/kg
K	#DIV/0!	#DIV/0!	#DIV/0!	g/kg
Na	#DIV/0!	#DIV/0!	#DIV/0!	g/kg
Ca	#DIV/0!	#DIV/0!	#DIV/0!	g/kg
Mg	#DIV/0!	#DIV/0!	#DIV/0!	g/kg
Fe	#DIV/0!	#DIV/0!	#DIV/0!	g/kg
Cu	#DIV/0!	#DIV/0!	#DIV/0!	mg/kg
Mn	#DIV/0!	#DIV/0!	#DIV/0!	mg/kg
Zn	#DIV/0!	#DIV/0!	#DIV/0!	mg/kg
B	#DIV/0!	#DIV/0!	#DIV/0!	mg/kg
S	#DIV/0!	#DIV/0!	#DIV/0!	g/kg
Al	#DIV/0!	#DIV/0!	#DIV/0!	g/kg

A.D. is Air Dried (room temperature). C, N and other elements were determined on air dried samples.
Values in the Conc Wet column have been calculated back to the samples as received (wet).
Moisture Lost is the moisture lost on air-drying.
* The sample (A.D.) to water ratio used is 1g:5ml for pH and 1g:10ml for electrical conductivity.

Appendix 7: Learning programme chapter URLs and posts, as prepared in Google Docs

https://www.facebook.com/IngestaFarming/posts/975465866130400?__tn__=K-R

Chapter 1: Introduction to weeds

Weed management is one of the most important parts of any successful farming enterprise. Across the world the negative impacts of weeds are underestimated by many farmers, because the losses caused by weeds are not always seen immediately. Weeds are the most common crop pest, and in one hectare of agricultural soil there can be over 10 million weed seeds, and a million vegetative propagules [1]. In order to win the battle against weeds in our fields we must first understand what makes weeds successfully our land.

→ What is a weed?

There are many different definitions of a weed, but the one we will use when discussing weeds is from the Weed Science Society of America: "a plant that causes economic losses or ecological damage, creates health problems for humans or animals, or is undesirable where it is growing" [2].

→ Characteristics of a weed:

There are many characteristics that a plant must have in order to be a successful weed. These include:

• Seeds that can germinate in many different environments.
• Seeds that can stay alive for a long period of time.
• Not all seeds germinating at the same time.
• Grows quickly before producing flowers.
• Seeds produced for as long as the growing conditions allow.
• Seeds produced quickly if growing conditions are good.
• Some seeds produced even if growing conditions are not good.
• Reproduction is mostly cross-pollination (Sexual reproduction) to increase genetic diversity, but the plant has the ability to pollinate itself if necessary (Asexual reproduction).
• Cross-pollination is done by unspecialised pollinators or by wind.
• Adaptations for short-distance and long-distance seed dispersal.
• Perennial species have quick vegetative growth and may be able to grow from small pieces.
• Perennial weed species break apart easily so that the whole plant is not removed from the ground easily.
• Can compete aggressively with other plants.

→ Impact of weeds in sub-Saharan Africa:

In sub-Saharan Africa cultivation is mostly done by hand. This is highest in Central Africa, where 85% of the total land area is cultivated by hand [3]. 70% of Western Africa, 54% of Southern Africa, and 50% of Eastern Africa are also cultivated by hand [3]. Draught animals such as oxen are used to prepare 11% of agricultural land in Central Africa, 22% of agricultural land in Western Africa, 21% of agricultural land in Southern Africa, and 32% of agricultural land Eastern Africa [3]. Tractors are only used to prepare 4% of agricultural land in Central Africa, 8% of agricultural land in Western Africa, 25% of agricultural land in Southern Africa, and 17% of agricultural land in Eastern Africa [3].

Preparing a field by hand is a difficult task and uses more energy (human muscle power) than any other method of field preparation. This energy investment goes mostly to planting and weeding, which use up to 40% of the total energy needed to prepare a field by hand. Hand weed control requires many hours throughout the growing season. While there are many factors which affect the number of hours spent weeding a field, research [4] has shown that a farmer will hand-weed for approximately 276-309 hours per hectare of maize per season. This is more than 10 full days! In one growing season a farmer will also spend approximately 150-324 hours per hectare of sorghum, 200-418 hours per hectare of rice, and 378 hours per hectare of ground nuts.

The number of times a field is weeded during a growing season will also influence yield. Research [5] has shown the following yields from cotton fields with different weeding strategies:

• 3 weedings in the season yielded 549 kg per hectare.
• 2 weedings in the season yielded 400 kg per hectare (↓ 27%)

• 1 weedings in the season yielded 242 kg per hectare (↓ 55%)
• 0 weedings in the season yielded 71 kg per hectare (↓ 87%)

The timing of weeding is also very important. Research [5] has found that if the farmer weeded the field three times in the season, but delayed the first weeding by one week, the initial weed growth increased by 6000%. This requires twice the initial labour to clear the weeds from the field. It was also found that if the first weeding was delayed by two weeks the initial weed growth increased by 2000%, requiring three times the initial labour to clear the field of weeds. This is why it is so important to weed your fields while weeds are still small!

However, farmers are busy people and it sometimes becomes impossible for the farmer to keep up with controlling weeds in all their fields. In Malawi one-third of the maize fields of small scale farmers are left unweeded during critical stages of the growing season [6]. Small scale farmers often leave up to 50% of their land unplanted, as they know they cannot control weeds over their whole farm for the whole growing season [7]. Because of this weeds can cause yield losses of between 25 and 100% [8]. This learning programme is designed to give farmers an introduction into the basics of weed science and equip them with the knowledge to better manage their fields.

→ Summary:

There are many reasons why weeds are successful at invading our fields. It is best to remove weeds while they are still small, as this uses less energy and reduces the negative effect they will have in your crop.

→ Test:

Click on this link and complete the short test to earn your certificate:

https://docs.google.com/.../1FAIpQLScJVzHMI.../viewform...

If you have not yet registered for the learning programme, please register here:

https://docs.google.com/.../1FAIpQLSeUjhy7y3A.../viewform...

→ References:

1. Menalled, F. and M. Schonbeck, Manage the weed seed bank—minimize ‘‘deposits’’and maximize ‘‘withdrawals.’’. margins, 2011. 1: p. 8.
2. Weed Science Society of America Do you have a weed, noxious weed, invasive weed or “superweed”? 2016.
3. Mrema, G., J. Kienzle, and J. Mpagalile, Current Status and Future Prospects of Agricultural Mechanization in Sub-Saharan Africa (SSA). Agricultural Mechanization in Asia, Africa and Latin America, 2018. 49(2).
4. Akobundu, I.O., Weed science in the tropics. Principles and practices. 1987: John Wiley.
5. Prentice, A., Cotton with special reference to Africa. Cotton with special reference to Africa, 1972.
6. Orr, A., B. Mwale, and D. Saiti, Modelling agricultural 'performance': smallholder weed management in Southern Malawi. International Journal of Pest Management, 2002. 48(4): p. 265-278.
7. Bishop-Sambrook, C., Labour saving technologies and practices for farming and household activities in eastern and southern Africa: Labour constraints and the impact of HIV/AIDS on rural livelihoods in Bondo and Busia Districts, western Kenya. 2003.
8. Vissoh, P.V., et al. Weeds as agricultural constraint to farmers in Benin: results of a diagnostic study. NJAS-Wageningen Journal of Life Sciences, 2004. 52(3-4): p. 305-329.

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https://www.facebook.com/IngestaFarming/posts/976271312716522?__tn__=K-R

Chapter 2: The weed seedbank

In Chapter 1 we learnt about the characteristics that make a successful weed, and how controlling weeds while they are still young will save us time and energy. However we can reduce the number of weeds we need to control if we can reduce the number of weed seeds in our fields. In order to control the number of weed seeds we need to understand how weed seeds are transported to our fields, what we can do to prevent more seeds from arriving, and how we can reduce the number of weed seeds that germinate.

→ What is the weed seedbank?

The weed seedbank is the total number of living weed seeds stored on the soil surface or buried in the soil profile. These seeds are not just the seeds that were dropped from last season's weeds, but also dormant seeds that have collected over many seasons. As mentioned in Chapter 1, agricultural soils can contain millions of weed seeds per hectare. In order to manage the weeds in our fields we need to understand the factors that affect weed populations.

→ What happens to weed seeds?

Weed seeds reach your field through many different ways. The largest input of weed seeds into your fields is from seeds dropped by weeds growing in and around your fields. Weed seeds can also be transported into your fields by animals, wind, water, and agricultural practices. Figure 1 shows the range of distances weed seeds can travel through different dispersal mechanisms. Read the caption for more information about how you can reduce the spread of weed seeds between your fields. Figure 2 shows the dynamics of the weed seed bank. Read the caption for explanations of the various factors that affect the weed seedbank

→ How do management practices affect weed seed distribution in the soil profile?

Management practices have a large effect on the dynamics of the weed seedbank. Tillage generally moves weed seeds deeper into the soil profile. These seeds are then less likely to germinate successfully, increasing seed death. However, large seeded weeds such as Datura (Figure 3) may still be able to germinate from deep in the soil profile. In no-till systems weed seeds remain close to the surface, however are more likely to be predated by mice, birds, and insects.

→ How long can a weed seed survive in the seedbank?

This depends on many factors. Environmental conditions such as soil temperature and soil moisture affect how quickly a seed decomposes. Biological process such as predation affect how many seeds remain in the soil profile long enough to germinate. Lastly some weed species have evolved the ability to survive for longer periods of time than other species.

→ Why is it important to prevent weed seed production?

Preventing new seeds from being added to the weed seedbank is the best approach to reduce the weeding requirement in future seasons. A 2005 study [1] showed that if standard weed management approaches were used without weed seed shed prevention, weed patches could expand as much as 330% over a six year period. As we have already discussed, weed seeds can travel between fields. Preventing weed seed shed means not just controlling the weeds within your field, but also in surrounding areas.

→ Managing the weed seedbank:

There are four main approaches to managing the weed seedbank: Prevention, reduction, rotation, and increasing seed losses [2].

Prevention - The most efficient approach in the long run.

• Cleaning tractors, ploughs, combines and other machinery before using them
• Ensuring manure and composts are properly composted
• Using certified weed-free seed will prevent adding more seeds to your field's weed seedbank.
• Filtering irrigation water

Reduction - Slows down the spread of weeds across fields.

• Increasing planting densities to out-compete weeds
• Killing weeds through mechanical or chemical means before they set seed

Rotation - Rotating crops will alter the management practices of the field

• Growing different crops in sequence that require different cultivation practices prevents the same weeds from establishing year after year
• Planting and harvesting dates. This will disrupt weed communities and change the weed species composition of the field.

Increasing seed losses - Increasing seed predation through no-till practices or tilling seeds deeper into the soil profile will increase seed losses from the weed seedbank.

→ Summary:

Weed seeds can travel far distances to our fields. It is impossible to stop all weed seeds from entering our fields but, where we can, we should make every effort to stop them from spreading. We should also try to increase the number of weed seeds that do not germinate, so that we have less weeds to control later.

→ Test:

Click on this link and complete the short test to earn your certificate:

https://docs.google.com/.../1FAIpQLSdaWyRCy47.../viewform...

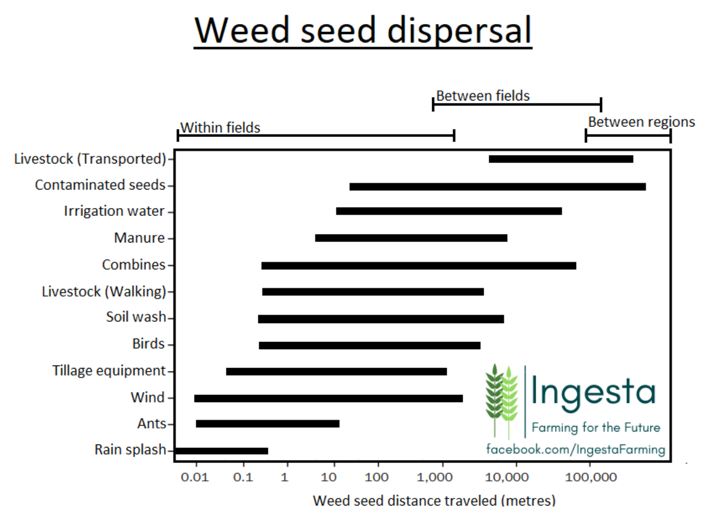
If you missed Chapter 1, you can access it here:

https://www.facebook.com/IngestaFarming/posts/975465866130400

→ References:

1. Beckie, H.J., L.M. Hall, and B. Schuba, Patch management of herbicide-resistant wild oat (Avena fatua). Weed technology, 2005. 19(3): p. 697-705.

2. Menalled, F., Weed seedbank dynamics & integrated management of agricultural weeds. Montana State University, 2008.



Adapted from Mohler, C.L., Liebman, M. and Staver, C.P., 2001. Weed life history: identifying vulnerabilities. *Ecological management of agricultural weeds*, pp.40-98.

Figure 1: There is little a farmer can do to prevent the spread of weed seeds by environmental factors such as rain splash, wind, and wildlife. However, farmers can prevent the spread of weed seeds by ensuring that tillage (e.g. ploughs) and harvesting equipment (e.g. combines) are cleaned before moving them to another field. This is particularly important in co-operatives where machinery is shared between a number of farmers. When buying seed to plant your crop, ensure that it comes from a supplier who can guarantee that it is free of any weed seeds. Farmers should ensure manure and compost that is applied to their fields has been composted properly to kill off any weed seeds.

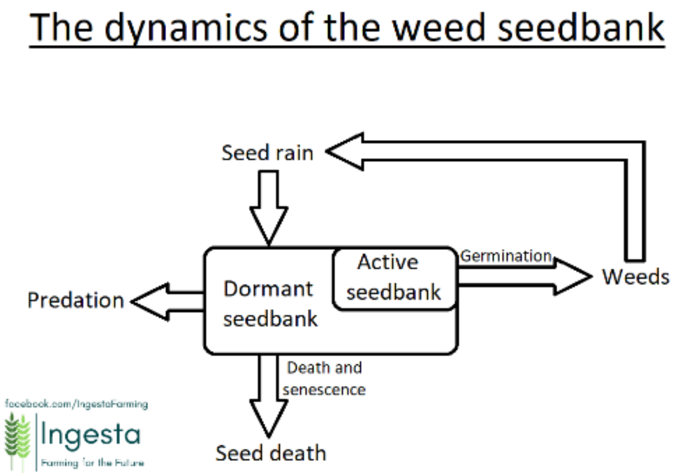


Figure 2: This figure shows the dynamics of the weed seedbank. The dormant seed bank refers to the seeds in the seedbank that are in a state of dormancy (Not yet ready to germinate). The active seedbank refers to the seeds that are ready to germinate as soon as the conditions are good. Seed rain is the addition of seeds from any of the dispersal mechanisms shown in Figure 1. Seed death and predation represent losses of seeds from the seed bank, and farmers should practice management practices that promote seed death or the predation of weed seeds.

Figure 3: A picture of Datura, a common weed in our field. This species has large seeds that may germinate even if they are buried deep into the soil profile during tillage.

https://commons.wikimedia.org/wiki/File:Datura_stramonium_Flor_2010-10-04_DehesaBoyalPuertollano.jpg

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https://www.facebook.com/IngestaFarming/posts/977067455970241?__tn__=K-R

Chapter 3: Competition

In Chapter 1 and Chapter 2 we discussed what makes a weed successful and how we can prevent weed seeds from germinating in our fields. We will never be able to stop every weed from germinating, and so in order to make decisions about controlling established weeds, we must understand how they compete with our crops.

→ What is competition?

In agriculture competition can be defined as the reduction in a crops ability to grow due to shared use of a resource that is limited in supply. Competition occurs when the demand for a resource is larger than the available supply. When two organisms compete for resources, the organism that is best suited to the environment will succeed. In agriculture we alter the environment to favour our crop plants. This gives them an advantage over the weed species. If the competition is between two different species, such as between a crop and a weed, it is called interspecific competition. However, competition is not just between different species. It can also be between two plants of the same species, and is known as intraspecific competition. Intraspecific competition occurs when crops are planted too close together resulting in competition for similar resources and, just like interspecific competition, a lower yield.

→ Competition for nutrients:

The first thing most of us think about when we think of our crops competing is for nutrients. Competition for nutrients is affected by a number of factors. These include the movement of nutrients in the soil, and the nutrient requirements of the crop. As the plant grows its nutrient requirements increase, and so competition for nutrients increases throughout the season. Competition for nutrients affects many other plant functions. For example, if a plant experiences a nutrient deficiency that limits root growth it will most likely not be able to take up enough water through its stunted roots and will experience drought stress as well.

→ Competition for light:

Competition for light can affect many properties of a crop. These include how fast it grows, how the plant grows, the size of the leaves the plant produces, and the direction the leaves face. These can have a negative effect on the yield, particularly if more energy is devoted to out-competing weeds than what is dedicated to producing a harvest.

→ Competition for water:

Competition for water changes throughout the season. As a crop grows, so its water requirements increase. However, as root systems grow so they are able to access water from deeper within the soil profile. The water use efficiency, or amount of water a crop needs to produce a certain dry mass, plays a major role in competition for water. Plants that are more water use efficient are better able to grow, and out-compete other plants during periods of drought.

→ Factors affecting crop-weed competition:

There are a number of factors that affect crop-weed competition, as shown in Figure 1. Monocultures or limited rotations increase weed competition by allowing certain weed species that have similar lifecycles to your crop to grow to maturity and set their seed every season. By increasing the number of different types of the crops in your system, and using crops with different lifecycles, you can disrupt the lifecycles of weeds and reduce weed competition. Low crop canopy cover will also increase weed competition, and this is why it is important to ensure your crop establishes itself as quickly as possible. There are several actions you can take to ensure your crop establishes as quickly as possible:

• Use of good quality seed that has a high germination guarantee
• Planting at the optimal times
• Ensuring the crop receives enough irrigation water
• Fertilising correctly
• Practicing good pest management practices

→ Crop-weed competition:

The longer weeds compete with your crop, the greater the potential negative effect they will have on your crop. However, negative effects will only be seen once the resource being competed for can no longer meet the needs of the plants competing for it. Early on in the season, when plants are small, competition is mainly for resources such as water and nutrients. Later on in the season once plants have grown larger, competition is mainly for light. Figure 2 shows the response of yield to weed-free conditions and weed interference. Read the caption for more details about this figure. Figure 3 shows the critical weed-free periods of maize and soybeans. As we can see, the critical weed-free period is early in the season when the crop is young and still establishing the canopy. Once the canopy has been established, the crop will have a competitive advantage over newly emerging weeds. This is because the crop will be intercepting almost all of the sunlight that shines on the field. Read the caption for more details about this figure.

→ Summary:

Crops will compete with weeds for different resources at different times of the season. However, the most important time to weed your fields is during your crop's critical period of weed control.

→ Test:

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https://docs.google.com/.../1FAIpQLScxVaAyJFK.../viewform...

If you missed Chapter 1 you can access it here:

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https://www.facebook.com/IngestaFarming/posts/976271312716522

A reminder that if you complete all 14 Chapters and the final test, you will earn a certificate for successfully completing this learning programme! 🙂

→ References:

1. Page, E.R., et al. Why early season weed control is important in maize. Weed Science, 2012. 60(3): p. 423-430

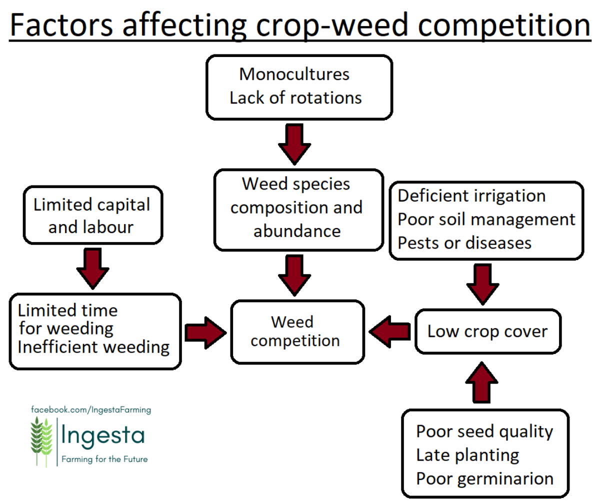


Figure 1: The factors that affect crop-weed competition in your field

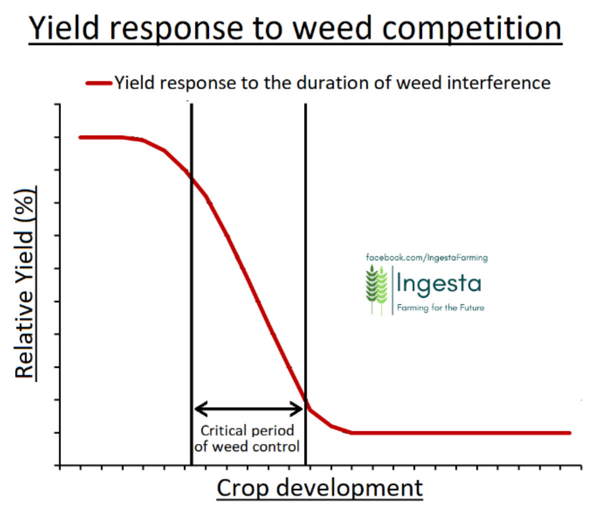
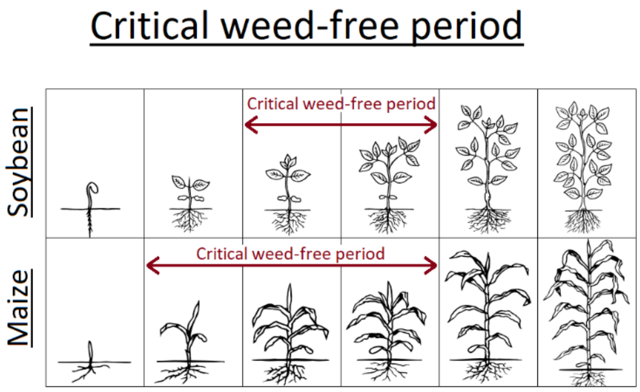


Figure 2: The red line shows us what would happen to our relative yield if we weeded the field at the start of the season, but then stopped weeding during the critical period of weed control. Here we see that relative yield decreases a lot. Even if we begin weeding again after the critical period of weed control, the damage has been done to the crop and relative yield will not increase again. The critical period of weed control is the most important time to weed your fields. However, as Figure 3 shows, the period of critical weed control is different for every crop.



Adapted from Ontario Ministry of Agriculture F, Affairs R 2017. Agronomy Guide for Field Crops. Publication 811. Queen's Printer for Ontario Toronto, ON, Canada.

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Figure 3: This diagram shows the critical weed-free period for maize and soybean. As discussed under Figure 2, controlling weeds during the critical weed-free period is very important for ensuring good yields. For example in maize, if weeding is delayed from the 3rd to the 5th leaf-stage (Total number of leaves on the maize plant) then yield will decrease by approximately 2.76% (Page et al., 2012) . However, if weeding is delayed from the 3rd to the 10th leaf-stage then yield will decrease by approximately 15.81% (Page et al., 2012).

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Chapter 4: Allelopathy

The negative effects of weeds are not always from direct competition for limited resources. One of the other ways your crop can be negatively affected by weeds is through allelopathy. The effects of allelopathy are often very complex. However, by understanding allelopathy we can also use it to our advantage.

→ What is allelopathy?

Allelopathy is the production of chemicals that influence the growth and development of plants and other organisms. This effect can be either positive or negative. Allelopathy is not the same as competition because here the growth of one plant is not affected by a lack of resources. Instead, the growth is directly affected by the allelochemicals. The effect of the allelochemicals depends on the concentration that they are found in. For example, some allelochemicals that prevent growth at high concentrations can increase the growth of a plant if the plant is only exposed to low concentrations.

→ Sources of allelochemicals:

Allelochemicals are released into the environment in four ways:

1) Volatilisation: Allelochemicals are released into the atmosphere

2) Leaching: Rain or irrigation leaches the allelochemicals from the above-ground parts of the plant (Leaves, stems, etc.) and washes them onto other plants or into the soil

3) Root exudation: Allelochemicals are released from the roots

4) Decomposition: Allelochemicals are released from decomposing plants, or produced by microorganisms that are feeding on decomposing plants

→ Mode of action:

There are a wide variety of allelochemicals produced by different species, and so there are many effects that they can have on your crop. These effects can either affect your crop directly or indirectly. Direct effects affect the growth and metabolism processes of the plant, slowing or preventing germination, or increasing or decreasing root and shoot growth. Indirect effects include changing soil properties or nutritional status, or influencing the population or activity of soil micro-organisms and nematodes.

→ Factors affecting allelochemical production:

There are many factors that affect allelochemical production. These include light, mineral deficiencies, drought stress, and temperature. Different factors affect different species in different ways, and so unpacking how different environmental conditions will affect allelochemical production in your field is often difficult.

→ Allelopathy and Agriculture:

As we have already discussed, allelopathy can be either positive or negative. One common example of positive allelopathy is the use of marigolds (Figure 1) to reduce nematode infestations [1]. Marigolds release allelochemicals into the soil which deter nematodes. Planting marigolds in between your crops will help protect them against nematode attacks. A common example of negative allelopathy is Yellow Nutsedge (Cyperus esculentus, Figure 2). Yellow Nutsedge is a common weed in African fields. Allelochemicals released by Yellow Nutsedge reduce the growth and cause large yield losses in maize, soybeans, sorghum, soybean and cowpea cucumbers tomato and cucumber [2, 3]. However, a cultivar of sweet potato known as "Regal" has been shown to have a negative effect on the growth of Yellow Nutsedge, when the two species are grown together [4]. The research showed that the dry mass of Yellow Nutsedge shoots grown in a field of "Regal" sweet potatoes was less than 10% compared to the dry mass of Yellow Nutsedge that grew in neighbouring fields without the "Regal" sweet potato [4]. Sorghum, sunflowers, cowpea, and species of the cabbage family (Brassicaceae) have also shown potential for being allelopathic to shown to be allelopathic against several weed species [5]. Intercropping maize and cowpea on alternate ridges has been shown to common weed species, such as those shown in Figures 3, 4, 5, 6 [6]. Sunflowers are particularly important allelopathic crops. In trials where wheat was grown in rotation after sunflowers, the allelopathic effect of the sunflower residues reduced total weed density by 24-75% and total weed biomass by 12-67% which resulted in an increase in the wheat yields [5].

These examples shows the benefits of a complex cropping system, however we must remember that these allelopathic crops can also have negative impacts on our other crops

→ Summary:

Crops will compete with weeds for different resources at different times of the season. However, the most important time to weed your fields is during your crop's critical period of weed control. Some crop species can have an allelopathic effect on weeds as well, but we must be careful that this allelopathy does not also have a negative effect on our other crops.

→ Test:

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→ References:

1. Hooks, C.R., et al. Using marigold (*Tagetes* spp.) as a cover crop to protect crops from plant-parasitic nematodes. Applied Soil Ecology, 2010. 46(3): p. 307-320.
2. Drost, D.C. and J.D. Doll, The allelopathic effect of yellow nutsedge (Cyperus esculentus) on corn (Zea mays) and soybeans (Glycine max). Weed Science, 1980. 28(2): p. 229-233.
3. Alsaadawi, I. and N. Salih, Allelopathic potential of Cyperus rotundas LI Interference with crops. Allelopathy Journal, 2009. 23(2).
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5. Jabran, K., et al. Allelopathy for weed control in agricultural systems. Crop Protection, 2015. 72: p. 57-65.

6. Saudy, H.S., Maize-cowpea intercropping as an ecological approach for nitrogen-use rationalization and weed suppression. Archives of Agronomy and Soil Science, 2015. 61(1): p. 1-14.

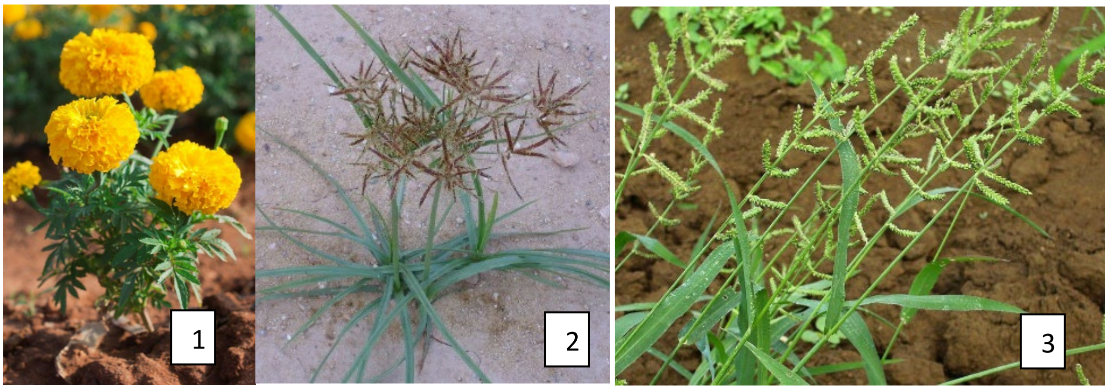

Figure 1: A marigold in flower. Picture from https://commons.wikimedia.org/wiki/File:Tagetes_erecta_chendumalli_chedi.jpg

Figure 2: Yellow Nutsedge https://commons.wikimedia.org/wiki/File:Cyperus_rotundus_Habitus_2010-7-11_LagunadelaMata.jpg

Figure 3: Jungle rice, a common weed in African fields. Intercropping maize and cowpea on alternate ridges has been shown to reduce the presence of this species in fields.

https://commons.wikimedia.org/wiki/File:Echinochloa_colona.jpg

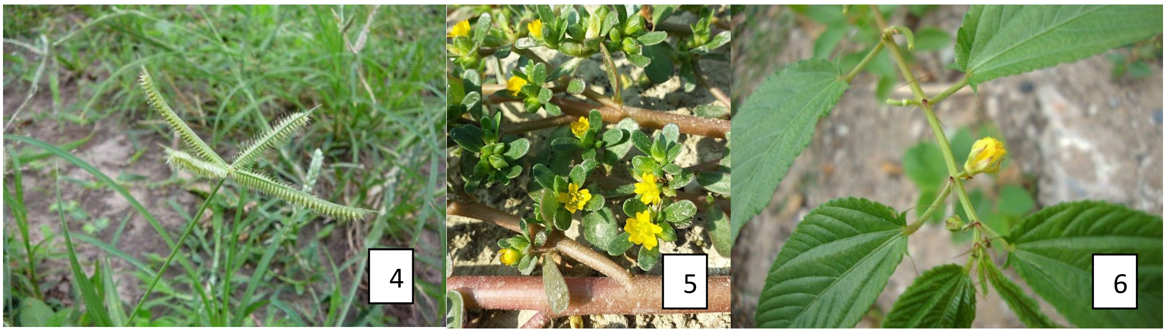

Figure 4: Egyptian crowfoot grass, a common weed in African fields. Intercropping maize and cowpea on alternate ridges has been shown to reduce the presence of this species in fields.

https://commons.wikimedia.org/wiki/File:Dactyloctenium_aegyptium_0001.jpg

Figure 5: Common Purslane, a common weed in African fields. Intercropping maize and cowpea on alternate ridges has been shown to reduce the presence of this species in fields.

https://commons.wikimedia.org/wiki/File:Portulaca_oleracea_sl7.jpg

Figure 6: Jute Mallow, a common weed in African fields. Intercropping maize and cowpea on alternate ridges has been shown to reduce the presence of this species in fields.

https://commons.wikimedia.org/wiki/File:Corchorus_olitorius_(2).JPG https://www.facebook.com/IngestaFarming/posts/978763215800665?__tn__=K-R

Chapter 5: Invasive weeds

As we discussed in Chapter 1, weeds are defined as plants that interfere with human activities. Invaders are a type of weed species that has been brought to our country from another part of the world, and have begun to spread into our environment where they interfere with the ecosystem. These plants present a great threat

→ Impacts of invasive species

Invasive species have many negative impacts on our livelihoods and our natural ecosystems. These include [1-3]:

• Loss of biodiversity – When invasive weeds enter an ecosystem they replace the indigenous plants that have historically grown there. This can lead to local extinctions of indigenous plant species. Many bird, insect, and other animal species will not be able to feed or live in invasive weeds, and will be forced to leave the area to find a better ecosystem to live in.

• Ecological imbalance – When invasive weeds replace indigenous plants they cause an ecological imbalance by changing natural cycles. Many indigenous species, such as the Australian wattles (Figure 1) are very flammable. This increases the risk of fires in the area, which may threaten fire-sensitive species.

• Prevention of access – Some invasive weeds such as the prickly-pear (Figure 2) have spines or thorns. When these species take over an area and form thickets that are impenetrable. This can prevent access to water supplies, grazing areas and shade trees.

• Soil erosion – Invasive species such as the Australian wattles (Figure 1) are easily ripped out by strong winds or floods. This will leave the soil exposed and susceptible to soil erosion.

• Reduced water resources – Many invasive weeds threaten our water resources. When these species invade ecosystems, they replace indigenous species that have a lower water requirement. Gum trees (Figure 3) and wattles (Figure 1) have a very high water requirement, and have been shown to be one of the leading causes of streams and rivers drying up. A 2007 student estimated that up to 16% of the water that could be harvested in South Africa's catchments is lost to invasive species. This is particularly concerning as we are already a water stressed region, and will experience less rainfall in the future due to climate change.

• Changing natural soil composition – Some invasive weed species have the ability to change the composition of the soils they grow in. The needles of pine trees (Figure 4) are acidic, causing soil acidification underneath the tree. Amaranth (Figure 5) has a very high nitrogen requirement and so can deplete the available nitrogen in the soil faster than other plants, causing nitrogen deficiencies.

• Create dense floating mats – Invasive weeds that grow in water, such as water hyacinth (Figure 6), can form thick mats when they invade a water source. This can block irrigation pumps, reduce the flow of water along canals, and even cause livestock to drown. This is because the livestock see a solid mass that they can walk on, become tangled in the plants, and drown in the water.

• Increase agricultural input costs – Nearly all of the worst agricultural weeds are invasive weed species. Controlling these weeds is expensive and time consuming. Hopefully through this learning programme you will be equipped with the knowledge to control weeds more efficiently and reduce your costs!

→ Invasive weeds in South Africa:

In South Africa we have the National Strategy on Biological Invasions. The aim of this strategy is to and reduce the negative impacts of invasive species in the country through four objectives:

1. Prevent the introduction of new species that pose a risk of becoming invasive
2. Remove invasive weed where possible
3. Reduce the spread of invasive weeds
4. Reduce the negative impacts of existing invasive weed populations

With all management decisions, planning an effective control strategy for invasive weeds requires an understanding of the impacts of the plant we want to control. Not all invasive weeds have the same impact on the environment, and they can also have different impacts in different areas. Blackjack (Figure 7) and pompom weed (Figure 8) are two common invasive weeds. However blackjack is not as aggressive as pompom weed, and usually only grows in disturbed soil. Pompom weed is a very aggressive invasive weed, and has invaded many of our grasslands and replaced indigenous species. Blackjack is therefore less of a threat to the environment that pompom weed, and this will affect our management strategy. In South Africa we rank weeds into three categories, based on the threat they pose.

Category 1: Declared invasive weeds

These invasive weed species pose a great threat to our environment. They must either be completely removed (Category 1a) or controlled to a safe level (Category 1b) by the person on whose land they are growing.

Category 2: Declared invasive plants with commercial value

These invasive weed species pose a threat, but also have economic value. These include trees that are used for timber, or grasses that are used for feeding livestock. A permit from the government is required to have these species growing on your land, and you must ensure that they do not spread beyond the border of your property.

Category 3: Invasive ornamentals

These invasive weed species have historically been used in gardens. Although existing plants are allowed to continue growing, the person on whose land they grow must take action to ensure they do not spread. No new plants may be planted.

→ Common invasive weeds:

The figures are all of common invasive weed species you will probably see in your area. The captions contain information about each species. You can use the figures to identify these species and take the appropriate actions to remove or control them. For more information about specific invasive weeds you can go to www.invasives.org.za

→ Summary:

Invasive weeds present a great threat to both us and the environment we live in. Although some species have an economic benefit, every effort must be made to remove invasive weeds where there have no economic benefit.

→ Test:

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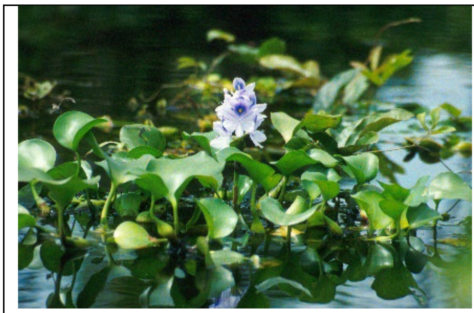
1. Blignaut, J.N., C. Marais, and J. Turpie, Determining a charge for the clearing of invasive alien plant species (IAPs) to augment water supply in South Africa. Water SA, 2007. 33(1).

2. Bromilow, C., Problem plants and alien weeds of South Africa. 2010: Briza.

3. Armstrong, A. and H. Van Hensbergen, Impacts of afforestation with pines on assemblages of native biota in South Africa. South African Forestry Journal, 1996. 175(1): p. 35-42.

 Figure 1: Wattle	Origin: Australia Type: Tree Category: 1a Impact: Reduces biodiversity by out-competing indigenous plants. Reduces available water due to their large water requirement. Increases the risk of fire in some ecosystems. Control: Cut down and the stump treated with a herbicide to prevent regrowth Picture from https://commons.wikimedia.org/wiki/File:Acacia_dealbata-1.jpg
 Figure 2: Prickly-pear	Origin: The Americas Type: Succulent Category: 1b Impact: Forms thorny thickets that prevent access to areas and reduces grazing potential Control: Herbicide application and biocontrol (More information in Chapter 8) Picture from https://commons.wikimedia.org/wiki/File:Prickly_Pear_Cactus_(33246173733).jpg
 Figure 3: Gum trees	Origin: Australia Type: Tree Category: 1b Impact: Reduces biodiversity by out-competing indigenous plants. Reduces available water due to their large water requirement. Control: Cut down and the stump treated with a herbicide to prevent regrowth. Picture from https://commons.wikimedia.org/wiki/File:Eucalyptus_trees_in_Njoro_kenya.jpg
 Figure 4: Pine trees	Origin: Europe Type: Tree Category: 2 Impact: Reduces biodiversity by out-competing indigenous plants. Reduces available water due to their large water requirement. Increases the risk of fire in some ecosystems. Control: Ring-barked or cut down. Picture from https://commons.wikimedia.org/wiki/File:Pine_tree_from_Dharamshala.JPG
 Figure 5: Amaranthus	Origin: The Americas Type: Herb Impact: A common and aggressive weed in fields. Can deplete soils of nitrogen quickly. Can poison livestock if eaten. Control: Broad-leaf herbicide. Picture from https://commons.wikimedia.org/wiki/File:Amaranthus_cruentus1.jpg

 Figure 6: Water hyacinth	Origin: South America Type: Water weed Category: 1b Impact: Forms thick, floating mats on the surface of water sources. Can block pumps, reduce the flow of water in irrigation canals, and cause livestock to drown. Reduces biodiversity by out-competing indigenous plants. Control: Easily pulled from the water and killed through drying and burning, or herbicide. Picture from: https://commons.wikimedia.org/wiki/File:Water_hyacinth.jpg

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Chapter 6: Weed management

Chapters 1-5 provided us with information about what makes weeds so successful and how they affect our lives. The next section of this learning programme focuses on the different methods we can use to control these weeds. This chapter provides the basics theory needed to design an effective weed management strategy.

→ Components of a good weed-management programme:

There are three main components to a good weed management strategy: Prevention, Eradication, and Control.

Prevention:

• Using certified seed: This stops us from bringing weed seeds into our fields during planting. Although cheap seed may be attractive economically, managing extra weeds brought in during planting can be more expensive in the long-run.

• Clean implements, machinery, vehicles: Washing farm implements (Hoes, spades, etc.), machinery (Ploughs, combines, etc.), and vehicles will prevent the spread of weed seeds that have become trapped in tyre ridges or on mud clumps. This will prevent the spread of weeds between farms or between fields.

• Cut weed-infested fields before the weeds produce seeds. This will prevent the addition of more seeds to the field's weed seedbank.

• Don't allow livestock to move from weed-infested fields to clean fields. Many weeds have evolved ways to be transported on the hair of animals. If animals do need to be moved from areas that are infested with weeds, ensure they are washed before they are allowed into clean fields.

• Control weeds in livestock feed and bedding grounds/kraals. Many weed seeds have evolved ways to survive passing through animals. These weeds will then grow from within the animal manure.

• Only use well-composted manure in your fields. The composting process is efficient at killing weed seeds that may be in animal manure. Using only composted manure will ensure that you do not add additional seeds to your fields during manure application.

• Practice whole-farm weed control. Although weeds along your fence lines and farm roads, or in your irrigation ditches and kraals will not directly affect your crop, their seeds will spread to your fields. This will make weed control in the next season more difficult. Practise weed control over your entire farm.

Eradication:

• Removing all weeds from a specific area. Although this is the ideal form of weed control, it is difficult to achieve. This is because it requires killing all living seeds, plants and parts of plants that could grow again.

Control:

• Reducing the population of weeds in a specific area. This can either be done through two methods: The Control at Any Price strategy or the Economic Threshold strategy

¬ The Economic Threshold strategy: The economic threshold is the number of weeds that will cause a yield loss equal to the economic cost of controlling the weeds. This strategy is generally used for weeds that do not cause significant damage to a crop when they are present in low numbers.

¬ The Control at Any Price strategy: With this strategy, we remove all weeds without factoring in the cost of weed control. This strategy can be more expensive than the Economic Threshold strategy in the first few years, however it may prove to be more economical in the long-term. This is because it is easier to prevent a few plants from producing seeds than it is to prevent many plants from producing seeds. Because the Control at Any Price strategy removes all weed plants, there will be no seeds entering the weed seedbank, and so there will be few weeds germinating in the future.

→ Basic principles of weed management systems:

Because our farms are dynamic systems, we cannot view the three components of weed management on their own. For this reason we combine these three components into four basic principles that will form the foundation of our weed management programme:

1. Slowing the growth of weeds
2. Preventing or slowing the production of weed seeds
3. Reducing weed seed reserves in the soil
4. Preventing or reducing the spread of weeds

→ Steps to effective weed management:

The four basic principles of weed management lead us to seven steps that make a weed management programme effective. These steps are:

1. Monitor weed populations
2. Identify problem weed species
3. Predict changes in weed populations
4. Decide whether control is needed
5. Consider management practices and needs
6. Choose control method
7. Evaluate long-term impact

→ Summary:

In order to make a weed management programme we must focus on all aspects of weed populations. This means making decisions that will help reduce current weed populations, as well as potential future populations.

→ Test:

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Chapter 7: Physical weed control

In this section we will discuss the different methods of physical weed control. The best method will depend on many different factors, such as your budget, the crop you're growing, the farm's climate, what other weed control strategies you are using. By knowing what different physical weed control options are available, you can make the most appropriate decision for your farm

→ Tillage:

Although tillage is practiced mainly to prepare the soil in our fields for planting, it is also an effective form of weed control. However, the type of tillage we practice will directly and indirectly affect our weed-management. Tillage practices can be broadly placed into two categories

• Conventional Tillage: Conventional tillage (Figure 1) involves deep ploughing, deep disking, ripping, shallow tyne workings, and fine seed-bred preparation. Tillage leaves very few residues left on the soil surface, as most of them are incorporated into the soil. Conventional tillage is effective for breaking apart soil compactions and increasing infiltration rates of water into the soil profile. However, this approach also results in a bare soil surface that is exposed to wind and water erosion.

• Conservation tillage: Conservation tillage, also known as reduced or minimum tillage, are a collection of tillage approaches that leave more than 30% residue cover on the soil. The aim of conservation tillage is to reduce the disturbance of the soil, and to leave plant residues.

The effects of tillage practices on weed management are varied. Studies in America have shown that compared to a field where no tillage was used, deep tillage can reduce weed emergence rates by 44 to 92% [1]. When conventional tillage without deep tillage was used, weed emergence rates by 38-80%, but in some cases also caused an increase in weed emergence of up to 75% [1]. When minimum tillage was used, weed emergence increased by 26 to 213% [1]. The differences in the effects of tillage practices are due to the differences in field conditions. As mentioned in Chapter 2 some large seeds, such as those of the Datura plant, can survive being buried deep within the soil profile. Deeper tillage is more effective on smaller seeds, such as those from Amaranthus, which cannot germinate when buried deep in the soil profile. In conventional tillage without deep tillage, weed emergence can increase because these tillage practices create favourable germination conditions for our crop. By doing this we also create favourable germination conditions for weed seeds. Because the main goal of tillage is soil preparation, the type of tillage practices you choose will probably be determined by a number of other factors that are specific to your production system and not by your approach to weed control.

→ Hand weeding:

Hand weeding is the oldest form of selective weed control. Hand weeding is a common practice with small-scale farmers across the world. In developing countries where the cost of labour is low hand weeding may be more economical than chemical control. In developed countries where the cost of labour is high hand weeding is generally only used in sensitive high-value crops. However, in recent years it has also become an important approach in removing herbicide resistant weeds as part of many integrated weed management programmes. In the Georgia, United States of America cotton is an important crop. Between 2000 and 2005 only 17% of Georgia cotton growers hand weeded, with the other 93% using only chemical control measures [2]. This meant that only 5% of the area where cotton was grown was hand weeded, and this cost these farmers $0.97 per hectare. Through the misuse of herbicides, herbicide resistant weeds such as Palmer Amaranth became a big problem for farmers. Between 2006 and 2010, 92% of Georgia cotton growers had to use and-weeding to control herbicide resistant weeds [2]. This meant that 52 of the area where cotton was grown was hand weeded, and this now cost these farmers $9.59 per hectare. This example shows the importance of not being reliant on one single weed control method, but to use an integrated approach.

→ Mowing and grazing:

The aim of mowing/grazing is to cut/graze weeds down before they are able to produce seeds. Mowing/grazing can reduce the competitive ability of perennial weeds (Weeds that grow for more than one season) by forcing them to regrow every time they are mowed/grazed. Regrowing uses stored food reserves in the weed's roots, and with enough mowing/grazing events the weed may use all of its stored reserves and die. However, mowing/grazing many also cause weeds to grow back with more than one stem, which could increase the number of seeds the weed is able to produce. The height at which weeds are mowed/gazed has a large effect on the control effectiveness. Weeds should be cut as close to the soil surface as possible, as this will reduce the regrowth. However, one disadvantage of mowing/grazing is that it can favour low-growing weeds.

→ Thermal control:

Thermal control refers to any control method that uses heat to control weeds. Soil solarisation is a method of killing weed seeds in the soil, by using a plastic cover to heat the soil. On a sunny day a large sheet of plastic will be placed over the soil, as shown in Figure 2. The plastic traps heat like a greenhouse and will increase the temperature of the soil to more than 80°C [3]. Solarisation can be used to significantly reduce weeds. However, the process of solarisation also kills many beneficial soil microbes which can reduce soil health [3].

Flaming is another method of thermal weed control. In this method controlled fire is used to cause damage to living weeds and weed seeds in the soil. This method is generally used before the crop emerges, as shown in Figure 3. Some crops a higher temperature tolerance than weeds, and so flaming can be used to control weeds while the crop is growing, as shown in Figure 4. If you want to watch a video of a farmer using row flaming to control weeds in his maize field, click here: http://bit.ly/RowFlamingVideo. The obvious danger of row flaming is that you can also damage your crop, and so we have to be very careful when using this method

→ Mulching:

Mulching is the use of a soil cover to form a physical barrier that will prevent weeds from emerging. This reduces the amount of light reaching the soil, which will either prevent weed seeds from germinating or will reduce the growth of weed seedlings. Common mulches include:

• Crop residues: Crop residues (Figure 5) such as maize stubble and straw are commonly used as mulch. These residues also have the benefit of increasing soil fertility by increasing soil organic matter and recycling nutrients back into the soil. Residue mulch has a significant effect on water use, with a 2013 study reporting that wheat-straw used as mulch can reduce evaporation losses of soil moisture by 35% [4]. However, these residues may also be a home for pests and diseases and can increase disease pressure. If residues are collected from fields that have many weeds, they can also increase the number of weed seeds in a field. These residues can also release allelochemicals into the soil, as discussed in Chapter 4.

	Figure 1: Conventional tillage. Photo from https://upload.wikimedia.org/wikipedia/commons/6/6a/Tillage_in_Guarda_Veneta.jpg
	Figure 2: Soil solarisation. Picture from https://www.indiamart.com/proddetail/soil-solarization-film-7619071133.html
	Figure 3: Thermal control by flaming before planting Picture from https://www.cenex.com/about/cenex-information/cenexperts-blog-page/agriculture-and-farming/Flame-Weeding
 Flame Engineering's Red Dragon row crop flaming units and kits are available in two-, four-, six-, and eight-row configurations. Kits are also offered in 12- and 16-row configurations.	Figure 4: Thermal control through row flaming Picture from: https://bpnews.com/index.php/publications/magazine/current-issue/2024-studies-find-propane-weed-flaming-best-organic-certified-method-for-farmers
	Figure 5: Crop residues used as mulch Picture from: https://commons.wikimedia.org/wiki/File:Heinrich_Farms,_south_of_Lubbock,_Texas._Conservation_tillage_methods_growing_cotton_in_terminated_wheat_cover._(24998995402).jpg

	Figure 6: Plastic mulch Picture from https://www.indiamart.com/proddetail/plastic-mulch-film-11514568512.html

• Plastic covers: The use of plastic sheet mulches (Figure 6) is common in the production of high-value vegetable and fruit crops. This is due to the high economic cost of the plastic. Plastic mulch has a significant effect on water use, with a 2013 study reporting that plastic mulch can reduce evaporation losses of soil moisture by 46% [4]. However plastic covers can increase soil temperatures, which can affect soil health.

• Cover crops: Cover crops are crops grown to protect the soil and increase soil fertility. Cover crops increase soil fertility by increasing soil organic matter and recycling nutrients back into the soil. However, as we discussed in Chapter 3, if nutrients or water are in limited cover crops will compete with the main crop. As discussed in Chapter 4, cover crops can also release allelochemicals into the soil.

→ Summary:

As we have seen there are many different methods of physical weed control. Each of these options has its own pros and cons. The best physical weed control option will depend different factors that are specific to your production system, but the most effective weed management strategy is always one that uses many different control measures!

→ Test:

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2. Sosnoskie, L.M. and A.S. Culpepper, Glyphosate-resistant Palmer amaranth (Amaranthus palmeri) increases herbicide use, tillage, and hand-weeding in Georgia cotton. Weed Science, 2014. 62(2): p. 393-402.
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Chapter 8: Biological control

In this chapter we will learn the basics of biological control. Biological control programmes that control weeds are usually run by governments, due to the high cost of the research that is needed before a biological control agent is released. However, as farmers who benefit from these programmes it is important that we understand the work that goes into controlling weeds around us.

→ What is biological control?

Biological control is a form of weed control that uses insects or diseases to reduce the number of weeds in an area. These are collectively known as “biological control agents”. The objectives of biological control are not to remove all the weeds, but instead to reduce and keep the number of weeds below a level that can cause economic or environmental damage. Biological control requires a lot of research by scientists to identify suitable biological control agents and study the potential effects they will have on the environments they are released into. However, once this research has been done and it is proven that a biological control agent is safe to release, the biological control agent will provide free control of the weed forever.

→ Characteristics of biological control agents:

There are a number of characteristics that make a biological control agent successful, such as

- Can successfully reduce a weed population to low numbers
- Does not harm other species
- Breeds or spreads fast enough to stop the weed population from growing again
- Is able to survive once the weed population has been reduced
- Can adapt to the local environment it is introduced to
- Does not have its own predators or diseases

However, because the biological control agents are free in the environment there is also the potential that they will cause damage to crops or other non-weed plants. This is why it is important for scientists to research the specific biological control agent before it is released.

Biological control is best suited for:

- Low-input cropping systems
- Situations where rapid killing of weeds is not necessary
- Where one weed species is dominant

Biological control is not suited for production systems that practice intensive cultivation, crop rotation, or pesticide use. This is because these practices disrupt the life-cycles of the biological control agents, reducing their numbers making them less effective at controlling the weed.

→ Biological control in South Africa:

The first use of biological weed control in South Africa was against the drooping prickly pear (Figure 1). The drooping prickly pear was already recognised as an invasive weed and a major threat to our environment in the 1800s. In 1913 an insect known as the cochineal (Figure 2) was brought to South Africa from South America [1]. The cochineal is a sap-sucking insect that feeds on the prickly pear, sucking out water and nutrients from the leaves. This can be seen in Figure 3. The cochineal has been extremely successful in controlling invasive prickly pear in South Africa.

The next invasive weed to be controlled by biological control was the jointed cactus (Figure 4). This cactus was brought to South Africa from South America in 1800. It was first used as a garden hedge, but quickly became invasive. By 1892 this cactus had covered 850 000 ha of land in the Karoo, preventing livestock from grazing on this land. Despite programmes to use mechanical clearing and arsenic herbicides to control this weed, it continued to spread. In 1933 a moth known as the Cactus Moth was identified as a potential biological control agent, because this moth’s caterpillars feed on cactus leaves. However, this moth did not prove to be very effective at controlling the jointed cactus. In 1935, another type of cochineal that could feed on the jointed cactus was discovered. As part of a government programme to control the joined cactus, millions of these insects were bred at a government facility and released into the environment. The programme was a success and since then the jointed cactus has been controlled to population levels that don’t have a negative effect on our environment.

A total of 106 biological control agents have been released in South Africa [2]. Of the 106, 75 have established themselves and have controlled 28 invasive weed species to a level where the weeds no longer pose a serious threat to the environment [2].

→ Conflict of interest:

Some of you may be wondering how the prickly pear is both an invasive weed and a crop in South Africa. The invasive type, the drooping prickly pear that does not produce good quality fruit is a different species to the sweet prickly pear that is used in agriculture. However, they are closely related and are susceptible to the same pests. The cochineal may be a great biological control agent, but it is now also a problem for prickly pear producers in South Africa who have to control the insect in their fields.

In South Africa 20 of the 50 most invasive plant species were deliberately introduced into the country. These include the pine and eucalyptus (Gum) trees used by the forestry industries. Because we have no control over biological control agents once they have been released in the environment, releasing biological control agents to control invasive pine and eucalyptus trees will cause massive damage to our timber industry.

Today the decision to release the cochineal into our environment was seen as a mistake by many of our prickly pear farmers. However, in 1932 when the decision was made it was farmers who lobbied government to release the insect to help them control this weed in their grazing land. Biological control agents can be an effective method of controlling weeds, but it requires a lot of research to identify suitable species to use as biological control agents and to ensure they do not attack to crops or other non-weed plants.

→ Summary:

Biological control is an effective form of weed control, but requires a lot of research. As farmers we need to ensure our governments support biological control research so that we can benefit from the results.

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2. Klein, H. and A. McConnachie, Management of information on biocontrol agents for invasive alien plants in South Africa. 2012: ARC Plant Protection Research Institute. p. http://biodiversityadvisor.sanbi.org/.../BIMF-2012-Klein.pdf.

Figure 1: Drooping prickly pear

Picture from https://commons.wikimedia.org/wiki/File:Opuntia_monacantha.jpg

Figure 2: A group of cochineal insects

Picture from https://en.wikipedia.org/wiki/File:Dactylopius_coccus_(Barlovento)_04_ies.jpg

Figure 3: Cochineal insects feeding on a prickly pear leaf

Picture from https://upload.wikimedia.org/wikipedia/commons/5/5e/Cochineal_Bugs_on_Prickly_Pear_-_Flickr_-_treegrow.jpg

Figure 4: The joined cactus

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Chapter 9: Cultural control

Cultural control is one of the most under-estimated weed management approaches. By changing simple management practices we can reduce the amount of weeding that we would normally need to do. Under optimal growing conditions, the plant that emerges first will have a competitive advantage over other plants in the field. As agriculturalists, we want to ensure that our crop emerges before the weeds, to ensure the crop is at an advantage. Many of our crops can out-compete weeds in the field if they are properly managed. This is because their growth will be vigorous and they will close the canopy quickly, shading out weeds. Some cultural control options include:

→ Stale or false seed beds:

This is the practice of encouraging weed seeds to germinate and emerge from the soil, before killing them by flaming them, applying herbicides, or using shallow cultivation to physically control them. This is done before the crop is planted. This practice is based on three principles:

1. Tillage and field preparation creates favourable growing conditions that will encourage weed seed germination.
2. While only a small portion of the seeds in the weed seedbank are active (Chapter 2), those that are active will all germinate at the same time if growing conditions are favourable.
3. Almost all weeds emerge from seeds that are close to the soil surface, and so deep cultivation is not needed to kill the weed seedlings.

→ Crop rotation:

This is arguably the most important practice for long-term weed control. Figures 1 and 2 show two different fields. In Figure 1, a maize monocrop is grown for two seasons. In Figure 2, a rotation of ground nuts followed by maize is grown. The symbols represent different management practices that will kill weeds. By using crops with different planting, we disrupt the lifecycles of the weeds in our fields, preventing a build-up of seeds in the weed seedbank. The captions of Figures 1 and 2 contain more information about how crop rotation helps us control weed populations.

→ Crop cultivar:

Many crop cultivars have characteristics that can help control weeds. These include:

• Rooting patterns – Cultivars with larger root systems will be able to access more water and nutrients than weeds with smaller root systems, making the crop more competitive.
• Early vigour – Cultivars that grow vigorously at the start of the season will have an advantage over weeds. This is because they will establish quicker, having a greater access to light and nutrients.
• Leaf size – Larger leaves are efficient at competing for light, and will out-compete weeds. This will prevent the weeds from intercepting light, reducing their growth and potentially killing them.
• Allelopathy – As mentioned in Chapter 4, some crops have an allelopathic effect on weeds. Using cultivars with a high allelopathic effect can be a very efficient way to control certain weed species.

→ Crop establishment

Ensuring that your crop establishes as early and as quickly as possible is an important part of ensuring that the crop has a competitive advantage over weeds. This can be done by:

• Increasing soil temperatures – By using mulches to increase soil temperatures we can increase soil temperatures and plant earlier in the season when temperatures may be too cold for weed germination.
• Using cold-tolerant cultivars – Some cultivars have a high tolerance for cold temperatures, and can germinate at low temperatures. These cultivars can be planted early in the season when temperatures may be too cold for weed germination.
• Using fast-maturing cultivars – Some cultivars grow much faster at the start of the season than other plants. These cultivars will out-compete weeds by establishing their canopies and shading out light as fast as possible

→ Planting density:

Planting at higher densities can help give your crop a competitive advantage. In order to maximise weed control, it is recommended that you plant at your crop’s highest recommended density to maximise weed control. This will ensure that the crop canopy establishes quickly, reducing weed growth. However, care must be taken to ensure that the crop plants do not compete with each other, as discussed in Chapter 3.

→ Intercropping and cover crops:

Planting multiple crops in the same field at once can also help control weeds. Much like crop rotation, planting multiple crops at one results in many different management events which will prevent the build-up of weed populations. Using crops that have allelopathic effects (Chapter 4) on weeds can also help protect crops that don't. However, again we must ensure that our crops are not competing with each other (Chapter 3)

→ Soil Fertility:

Soil fertility has a large effect on the competition between crops and weeds. It is important to ensure that our crop has access to all the nutrients it needs to grow, but we must remember that weeds will also have access to these nutrients. Studies on maize have shown that increasing fertiliser applications without weed-control can increase yield losses cause by weeds by 62% [1]. Certain weeds can cause nutrient deficiencies for your crops. For example, Amaranthus is a heavy feeder of nitrogen, and can cause nitrogen deficiencies in your crop if it is not controlled.

→ Water management:

Like fertiliser, irrigation will boost crop growth but will also boost weed growth.

→ Fencerows and boundary areas:

As mentioned in Chapter 6, weeds growing along fence-lines, field edges, and roads are a significant contributor to the weed seedbank. Practicing whole-farm weed control will reduce the number of seeds added to the weed seedbank from these areas.

→ Summary:

Making simple changes to our management practices can have large effects on the competition between weeds and our crops. By choosing the correct cultivars for our regions and ensuring optimal crop growth, we can increase our crop's competitive advantage over weeds.

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Chapter 10: Chemical control Part 1 - Herbicides

In the next five chapters we will be talking about herbicides and herbicide use. Herbicides are important tools for effective weed management. However if they are not used properly they can result in economic losses and environmental harm. The next chapters will provide you with an understanding of how to use herbicides safely and effectively.

→ Introduction:

Herbicides are chemical formulations that have the potential to kill plants. Herbicides are either broad-spectrum (Will kill all plants) or selective (Will only kill certain plants). They are effective tools for controlling weeds, but must be used with care. Any misuse can result in severe economic losses and environmental damage.

The first selective herbicide on the market was 2,4-dichlorophenoxyacetic acid, commonly known as 2,4-D. 2,4-D is a synthetic auxin. Auxins are the hormones in plants that control growth. 2-4-D only affects broad-leaf plants and has no impact on grasses. When broad-leaf plants are sprayed with 2,4-D it is absorbed through the leaves. This causes the plant to grow uncontrollably and unsustainably, resulting in the stem to curling over, the leaves withering, and the plant eventually dying. Because 2,4-D only affects broad-leaf plants, it has no effect on grass species (Cereals) such as maize and wheat. The use of selective herbicides has revolutionised how we are able to control weeds in certain crops.

→ Advantages:

The popularity of herbicides is thanks to their many benefits for farmers. Perhaps the most important advantage of herbicides is that they significantly reduce the amount of time and effort needed to manually control weeds. As mentioned in Chapter 1, much of the agricultural land in sub-Saharan Africa is weeded by hand, which requires hundreds of hours of manual labour per hectare every season. In Chapter 1 we also talked about how farmers will sometimes choose not to plant on all their land, or will abandon up to 50% of their crop as they cannot keep up with the weeding requirements. Selective herbicides such as 2,4-D make it easier to control weeds within densely-planted crop rows, where other methods of control may be difficult or impossible to use without damaging the crop. The use of herbicides can also greatly reduce tillage requirements, which can increase soil health and reduce a farm's carbon footprint through decreased tractor usage.

→ Limitations:

However, as with all technologies there are also limitations. If not used correctly herbicides can damage crops and cause environmental contamination, which is why as scientists we advocate for the safe and judicious (Done with good sense and judgement) use of herbicides. Some herbicides are able to remain active in a field for more than one season, which will limit our choice of crops for the following season. Over-reliance and misuse of herbicides can lead to herbicide resistance developing, which reduces the effectiveness of the herbicide in the future. Herbicides also require high managerial input. Decisions about the correct herbicide to use, the timing and method of application, and the handling of the product require a lot of knowledge. These decisions should not be made by someone who does not have a good understanding of herbicides.

→ Toxicology:

The most important component of herbicide research is understanding the potential effect of herbicides on human health. There is a lot of misinformation about herbicide toxicity on the internet and in the media. This is often reported as "herbicides are chemicals so they must be bad". As a result of this, many people have a fear of herbicides. There is also a misconception that organic farming does not use herbicides, or that organic herbicides are always safer than synthetic herbicides. This is not the case.

Chemistry is foundation of all life because everything we know is made of chemical compounds. Water, vitamins, minerals, proteins, and carbohydrates are all chemical compounds that we need on a daily basis. Even the cells that make up your body are built from chemical compounds. Organic and synthetic herbicides are chemical compounds as well, and their relative safety depends on the properties of the individual chemical compound and not which group it falls into. Chemical compounds by themselves are not good or bad. What is important is the dosage, or the amount, of the specific chemical compound we are exposed to. Drinking a glass of water will quench your thirst, but drinking a lake will drown you.

When we talk about herbicides we often confuse the words "toxicity" and "hazard". "Toxicity" is a measure of the amount how harmful or lethal a chemical compound is. "Hazard" is the probability of coming into contact with a harmful dose of a specific chemical compound. Farmers, who handle highly concentrated formulations of herbicides, are more likely to come into contact with a harmful dose of the herbicide if they aren't careful than someone who doesn't work with herbicides. Similarly, a football player is more likely to be hit by a ball, than a football supporter who is sitting far away on the stands.

There are two types of toxicity: Acute and Chronic

• Acute toxicity is a life-threatening one-time dosage, or the amount of a chemical compound you would have to be exposed to at once to have a good chance of dying. Acute toxicity is expressed as the Lethal Dose or LD50. This is the dose (In milligrams of chemical compound per kilogram of bodyweight) that killed 50% of the test species. Figure 1 shows the LD50s of some common chemical compounds. At the top of the list we see water, with an LD50 of 90000 mg/kg. This means that if your drink 90000 mg, or 90 g, per kilogram of body weight, you have a high chance of dying. This is the equivalent of a 50 kg person drinking 4.5 litres of water at once. Eugenol (Clove oil), an organic herbicide. Eugenol has an LD50 of 2700 mg/kg, which is 135 g for a 50 kg person. In comparison Glyphosate, a common synthetic herbicide, has an LD50 of 5600 mg/kg, which is 280 g for a 50 kg person. However, we also see chemical compounds like Vitamin D3, which has an LD50 of 37 mg/kg, which is only 1.85 g for a 50 kg person.

• Chronic toxicity is the maximum amount of a chemical compound a person can be exposed to every day, before long-term harm is caused. Chronic toxicity is expressed as the "Lowest Observable Adverse Effects Level" (LOAEL) and the "No Observable Adverse Effects Level" (NOAEL). NOAEL is the highest dose at which no negative effects will be seen, and LOAEL is the lowest dose at which negative effects will be seen. Figure 2 shows the LOAELs of many common chemical compounds.

Figures 1 and 2 are great visual representations of the relative toxicities of common chemical compounds. If you want more in-depth discussion on toxicity go to https://thoughtscapism.com/2018/05/07/measures-of-toxicity/

→ Residues:

Residues are the amount of herbicide that remain on the crop. Residues are how consumers who don't work with herbicides are exposed to them. Herbicide residues are strictly controlled to protect the public's health, with limits enforced by national governments. As farmers it is our duty to protect the people that buy our produce, and this is why it is critical that we follow the recommended guidelines for the herbicides we use in our fields. In Chapter 11 we will discuss herbicide use.

→ Summary:

Herbicides are a useful tool that can be used to manage weeds in our fields. However, as with all technologies, herbicides must be used correctly to avoid negative effects on our crops and our environment. The most important lesson from today's chapter is that everything is made from chemicals, and that it is the dosage of chemicals that we are exposed to that determines how harmful they are to us.

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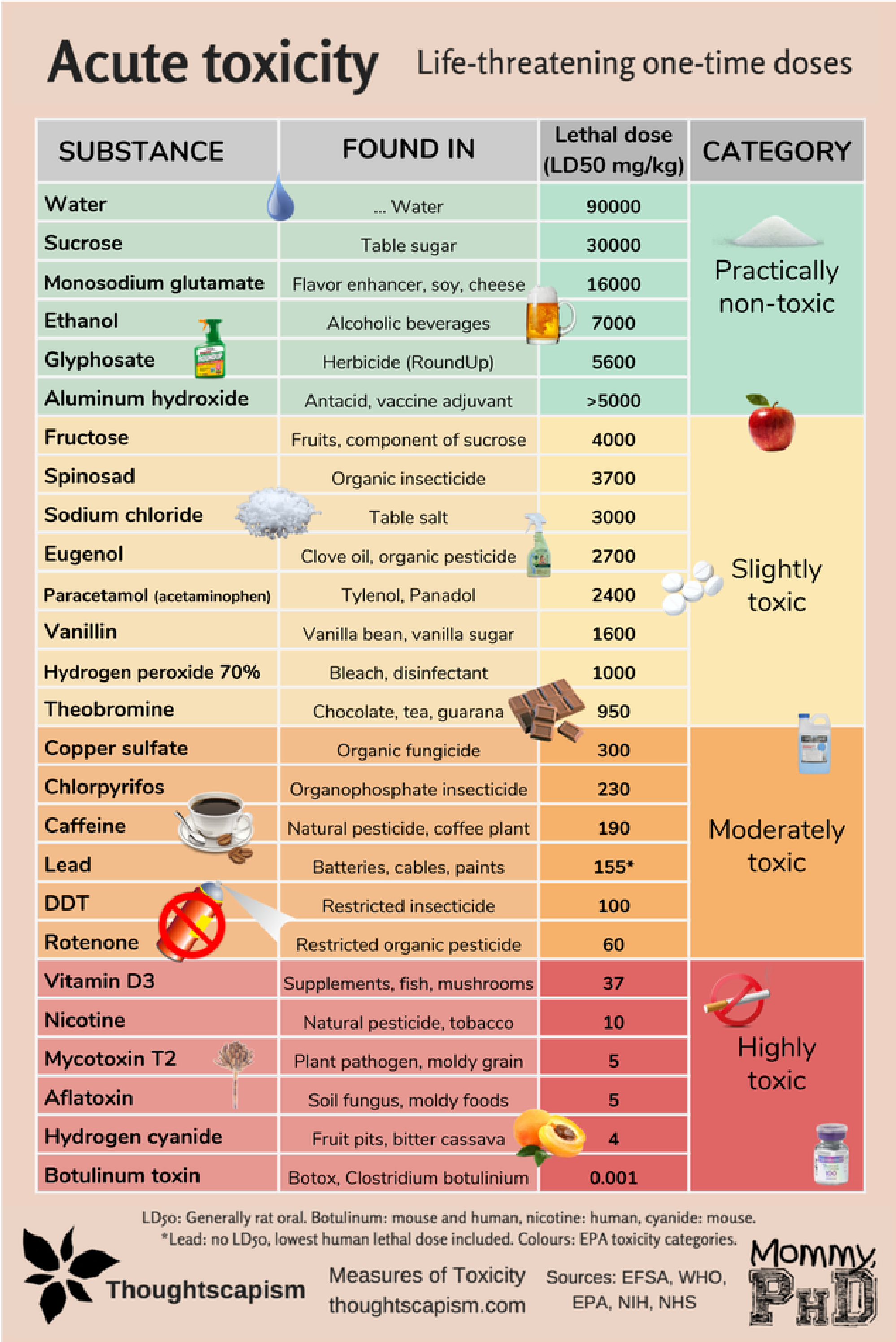
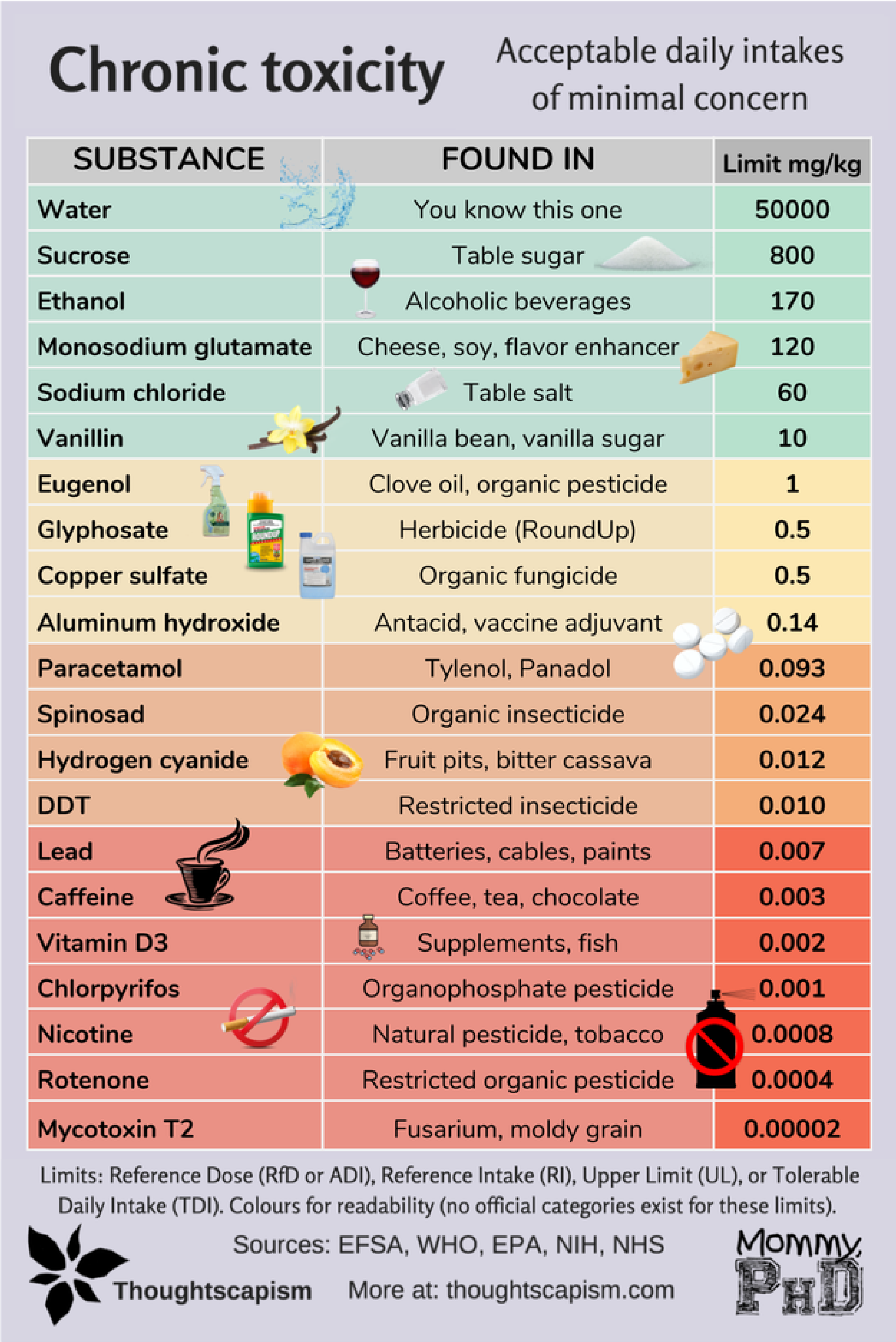


Acute toxicity Life-threatening one-time doses

SUBSTANCE	FOUND IN	Lethal dose (LD50 mg/kg)	CATEGORY
Water	... Water	90000	Practically non-toxic
Sucrose	Table sugar	30000	
Monosodium glutamate	Flavor enhancer, soy, cheese	16000	
Ethanol	Alcoholic beverages	7000	
Glyphosate	Herbicide (RoundUp)	5600	
Aluminum hydroxide	Antacid, vaccine adjuvant	>5000	
Fructose	Fruits, component of sucrose	4000	Slightly toxic
Spinosad	Organic insecticide	3700	
Sodium chloride	Table salt	3000	
Eugenol	Clove oil, organic pesticide	2700	
Paracetamol (acetaminophen)	Tylenol, Panadol	2400	
Vanillin	Vanilla bean, vanilla sugar	1600	
Hydrogen peroxide 70%	Bleach, disinfectant	1000	
Theobromine	Chocolate, tea, guarana	950	
Copper sulfate	Organic fungicide	300	Moderately toxic
Chlorpyrifos	Organophosphate insecticide	230	
Caffeine	Natural pesticide, coffee plant	190	
Lead	Batteries, cables, paints	155*	
DDT	Restricted insecticide	100	
Rotenone	Restricted organic pesticide	60	
Vitamin D3	Supplements, fish, mushrooms	37	Highly toxic
Nicotine	Natural pesticide, tobacco	10	
Mycotoxin T2	Plant pathogen, moldy grain	5	
Aflatoxin	Soil fungus, moldy foods	5	
Hydrogen cyanide	Fruit pits, bitter cassava	4	
Botulinum toxin	Botox, Clostridium botulinium	0.001	

LD50: Generally rat oral. Botulinum: mouse and human, nicotine: human, cyanide: mouse.
*Lead: no LD50, lowest human lethal dose included. Colours: EPA toxicity categories.

Figure 1: Acute toxicity. To read more about acute toxicity or to view the high quality version of this image, go to https://thoughtscapism.com/2018/05/07/measures-of-toxicity/



Chronic toxicity

Acceptable daily intakes of minimal concern

SUBSTANCE	FOUND IN	Limit mg/kg
Water	You know this one	50000
Sucrose	Table sugar	800
Ethanol	Alcoholic beverages	170
Monosodium glutamate	Cheese, soy, flavor enhancer	120
Sodium chloride	Table salt	60
Vanillin	Vanilla bean, vanilla sugar	10
Eugenol	Clove oil, organic pesticide	1
Glyphosate	Herbicide (RoundUp)	0.5
Copper sulfate	Organic fungicide	0.5
Aluminum hydroxide	Antacid, vaccine adjuvant	0.14
Paracetamol	Tylenol, Panadol	0.093
Spinosad	Organic insecticide	0.024
Hydrogen cyanide	Fruit pits, bitter cassava	0.012
DDT	Restricted insecticide	0.010
Lead	Batteries, cables, paints	0.007
Caffeine	Coffee, tea, chocolate	0.003
Vitamin D3	Supplements, fish	0.002
Chlorpyrifos	Organophosphate pesticide	0.001
Nicotine	Natural pesticide, tobacco	0.0008
Rotenone	Restricted organic pesticide	0.0004
Mycotoxin T2	Fusarium, moldy grain	0.00002

Limits: Reference Dose (RfD or ADI), Reference Intake (RI), Upper Limit (UL), or Tolerable Daily Intake (TDI). Colours for readability (no official categories exist for these limits).

Sources: EFSA, WHO, EPA, NIH, NHS

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Figure 2: Chronic toxicity. To read more about chronic toxicity or to view the high quality version of this image, go to https://thoughtscapism.com/2018/05/07/measures-of-toxicity/

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Chapter 11: Chemical control Part 2 - Herbicide Legislation and Labels

In Chapter 10 we learnt that it is the dosage of a chemical compound that makes it toxic. Herbicides are generally sold as concentrates, because it is cheaper to transport the raw herbicide formula than it would be to transport the mixture. Because herbicide concentrates have a much higher concentration than the final mixture, they have the potential to be more dangerous. This is why it is important for us to ensure we understand all of the safety information provided to us by herbicide labels.

→ Legislation:

In South Africa herbicides are regulated by the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act No. 36 of 1947) [1]. This act is commonly referred to as the Agricultural Inputs act, and is in place to:

"provide for the appointment of a Registrar of Fertilizers, Farm Feeds and Agricultural Remedies; for the registration of fertilizers, farm feeds, agricultural remedies, stock remedies, sterilizing plants and pest control operators; to regulate or prohibit the importation, sale, acquisition, disposal or use of fertilizers, farm feeds, agricultural remedies and stock remedies; to provide for the designation of technical advisers and analysts; and to provide for matters incidental thereto."

Different countries will have different acts to control the development, registration, use, and management of herbicides. Despite minor differences between countries, the acts are all in place to protect the health of farmers, consumers, and the environment by ensuring that the registered herbicides have been scientifically proven to work and to be safe when used correctly. These acts should be aligned with the World Health Organisation (WHO) and the Food and Agriculture Organisation of the United Nation's (FAO) International Code of Conduct on Pesticide Management.

→ Labelling:

The labelling of herbicides across the world is based off the International Code of Conduct on Pesticide Management: Guidelines on Good Labelling Practice for Pesticides [2]. This Code of Conduct provides the manufacturers of herbicides with a framework for designing labels. Labels should contain all the information a farmer needs to make safe decisions about their herbicide practices.

The minimum information on the label should tell us is:

- What is in the container
- The potential acute and chronic hazard, and relevant safety information
- Directions for use and disposal
- Supplier identification

All the information contained on a herbicide label is important. This information has been put here to help you use the herbicide safely, to prevent negative effects on your health, your crops, and the environment. In order to ensure that everyone can understand the directions on a herbicide bottle, pictograms are used to show the most important safety information. Pictograms are simple diagrams that represent an action or instruction. Figure 1 shows a number of common pictograms that will be used on herbicide labels, as well as their meanings.

If the herbicide formulation is classified as a hazardous substance, the label will also include the relevant international hazard symbol. The international hazard symbols are explained in Figure 2. Herbicides with these symbols should be handled with extreme care to ensure no dangerous accidents occur.

As discussed in Chapter 10, some herbicide formulations are toxic at lower dosages than others. For this reason simple colour-categories are used to show relative toxicity. The colour category of a herbicide is shown at the bottom of the label, as shown in Figure 3. The categories are:

- Red: Very toxic – Extremely/Highly hazardous. Protective equipment and clothing must be used.
- Yellow: Harmful – Moderately hazardous. All safety measures stated on label must be used.
- Blue: Caution – Slightly hazardous. Use carefully and use protective equipment.
- Green: Keep Locked Away – Store away from children, food, and animals

Following the directions of use will ensure that you are protected while applying herbicides to your fields. If the herbicide requires you to use specific safety equipment, such as a mask or gloves, that you follow these instructions to prevent negative health impacts. It is also important that when applying herbicides you follow the application rates and mixing instructions correctly. Not following these instructions will result in herbicide-resistance developing in the weed populations. Herbicide resistance will be covered in Chapter 13.

→ Home-made herbicides:

In recent years we have seen an increasing number of social media posts promoting making your own herbicides at home. These posts claim that these home-made herbicides are safe and more environmentally friendly. This is not always the case, and these home-made herbicides can have negative impacts on your crop. The two most common home-made herbicides we see are apple-cider vinegar sprays and Epson salts.

All vinegars contain at least 4% acetic acid. Acetic acid is what gives vinegar its sour taste. When we spray weeds with vinegar the acetic acid burns the leaves, potentially killing the weed. However, in spraying weeds with vinegar we are also acidifying the soil. This damages soil health and can lead to nutrient deficiencies of elements that are less mobile under acidic conditions, or cause nutrient toxicities of elements that are more mobile under acidic soil conditions. Of particular concern is aluminium, which becomes more mobile in acidic soils and is highly toxic to plants.

Epsom salts is the common name for magnesium sulphate. Using Epsom salts as a herbicide will increase the salinity (Saltiness) of your soil. Many crops are very sensitive to soil salinity, and will not grow on saline soils. Once a soil has been salted up it is nearly impossible to get rid of the salts.

As agricultural scientists, we do not recommend using these methods, as they can cause permanent damage to your soils.

→ Summary:

When using herbicides it is important that we understand all of the information provided to us by the label. Knowing what the health and safety symbols mean, and following the instructions will ensure that we do not cause negative harm to ourselves, our crops, and the environment.

→ Test

Click on this link and complete the short test to earn your certificate:

https://docs.google.com/.../1FAIpQLSem5YdUXeo.../viewform...

Please note that you will have to complete the tests for all 14 chapters to earn your certificate 🙂

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→ References:

1. Government, S.A., Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act No. 36 of 1947). 2009, Government Printer Pretoria.

2. FAO, Guidelines on good labelling practice for pesticides, in International Code of Conduct on Pesticide Management. 2015, Food and Agriculture Organization of the United Nations: Rome.

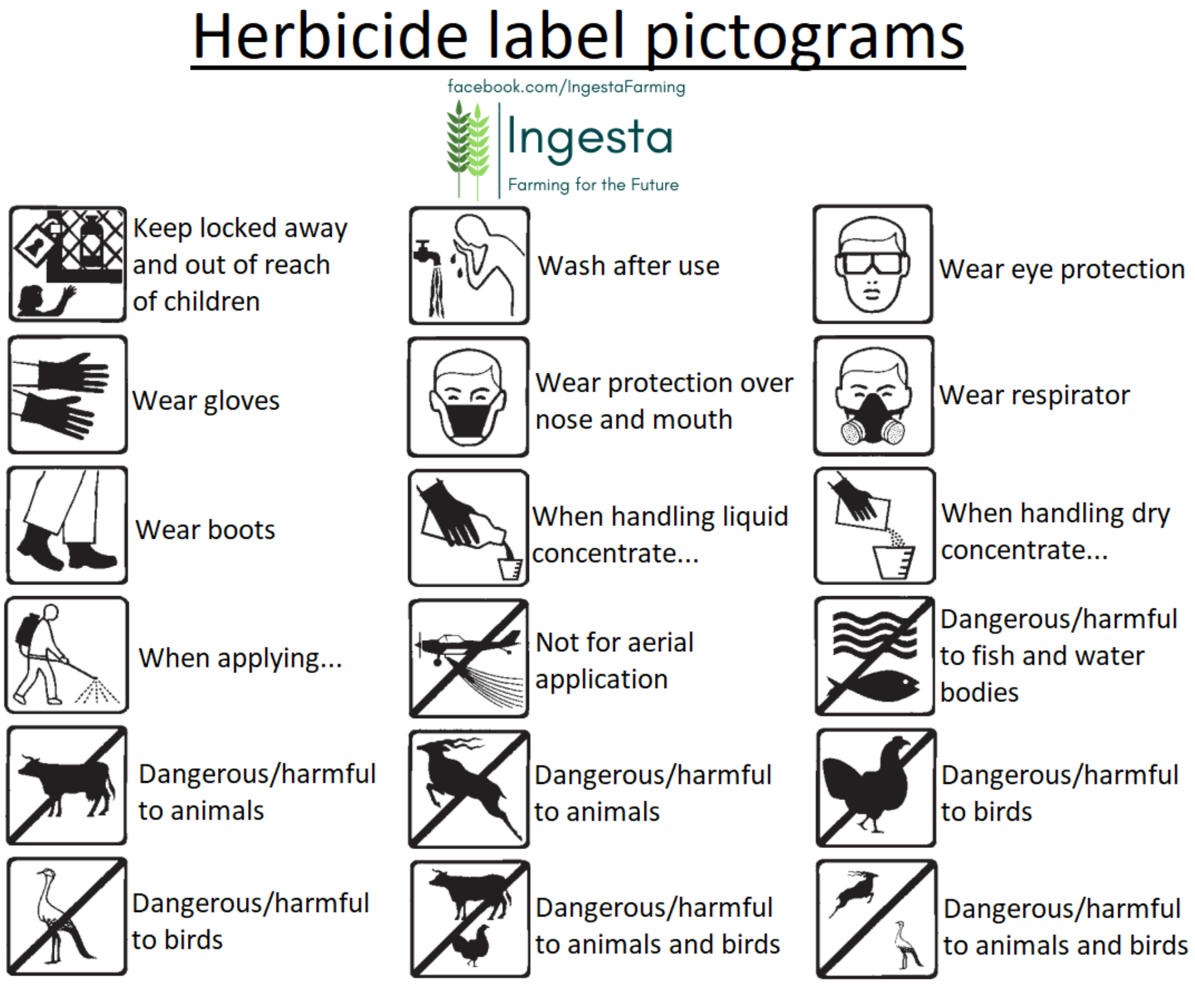

Figure 1: Common pictograms used on herbicide labels.

Figure 2: International hazard symbols

Example of a herbicide label

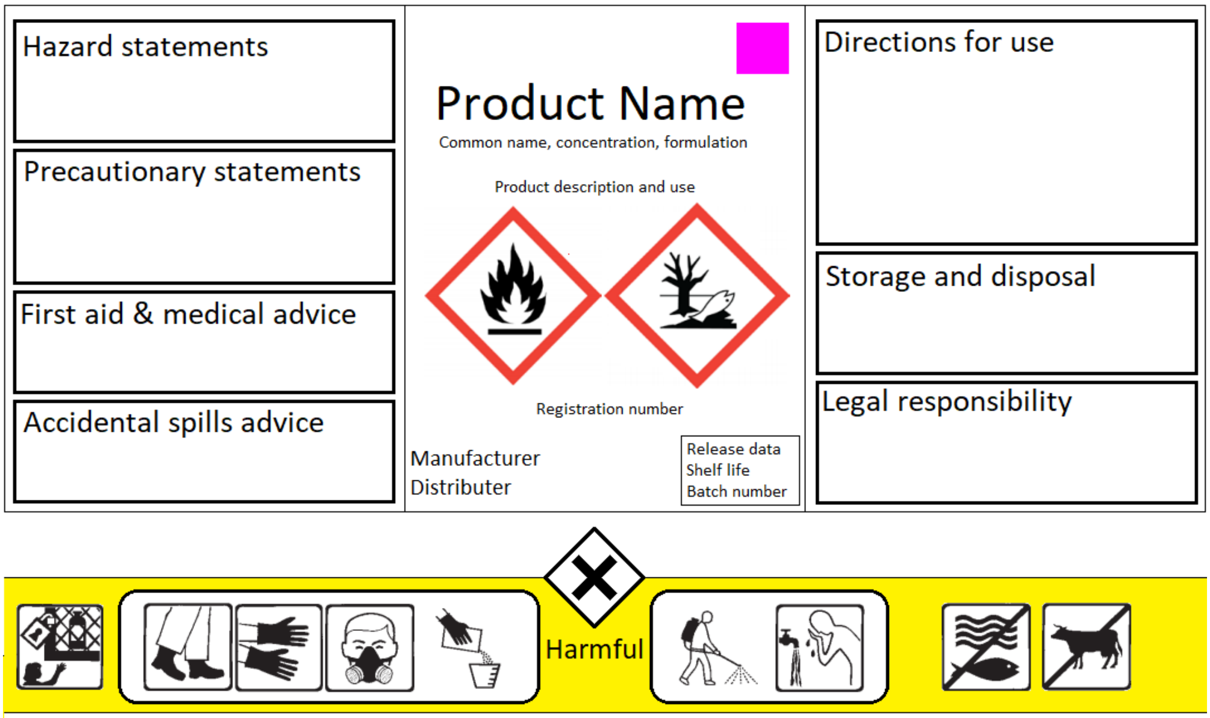

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Figure 3: An example of a herbicide label. The purple square tells us that this is a herbicide. The two international hazard symbols tell us that this formula is flammable and that it is an environmental hazard, and so we must handle this product with care to ensure that no accidents occur. The yellow band at the bottom of the label tells us that this herbicide is potentially harmful if not used correctly, and that all safety measures stated on label must be used. In the yellow band we see the symbols to tell us that:

This product should be kept locked away and out of reach of children.

While handling the dry concentrate we should wear boots, gloves, and a respirator

After applying the herbicide we should wash ourselves

That this herbicide is potentially dangerous/harmful to fish and water bodies, and animals

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Chapter 12: Chemical control Part 3 - Herbicide fate

A recurring theme for this learning programme is safety. As we have already discussed, herbicides are an effective tool for weed control but can cause damage when they are not used correctly. When we apply herbicides to our fields we need to understand what happens to the chemical compounds to ensure our weed control is safe and effective. This chapter covers the fate of herbicides, with practical considerations to improve weed control.

→ Fate of herbicides

When herbicides are applied to a field they will follow one of six different paths: Absorption, volatilisation, runoff, degradation, adsorption, or leaching

Absorption

Absorption is the process in which a herbicide is taken up by plants or soil microbes. If the herbicide is taken up by a weed then this will lead to effective weed control. However if the herbicide is take up by soil microbes instead of weeds, weed control will be less effective.

If a herbicide is taken up by a weed it must follow the path of translocation to the plant's active growing site. There are many factors that affect the translocation of herbicides, and this is why it is important for us to understand the growth patterns of the weeds we are trying to control, as well as the properties of the herbicide we choose to use. In broad-leafed weeds herbicides are generally absorbed through the roots. In grass species, herbicides are generally absorbed through the shoots. These differences in plant physiology are one of the mechanisms for selective herbicides.

Volatilisation

Volatility in the process in which a chemical compound becomes a gas. Understanding volatilisation is important, because if a herbicide volatilises it can cause economic losses through poor weed control, crop injury, and non-target damage. Herbicide volatilisation occurs quicker from wet soils than from dry soils, and slower on cold days than on hot days. Because herbicides are lost during volatilisation, weed control will be reduced.

Runoff

Runoff occurs when herbicides are washed off of plants or out of the soil by rain or irrigation. Because herbicides are lost during volatilisation, weed control will be reduced. Runoff of herbicides can also lead to the contamination of water sources such as streams, rivers, and dams. This can have negative effects on our environment and our water security.

Degradation

There are three types of processes that can degrade herbicides

• Photodegradation – When the chemical compound is broken down by the ultraviolet light in sunlight.

• Chemical Degradation – When the chemical compound is broken down through reactions with other chemical compounds in the soil.

• Microbial degradation – When the chemical compound is broken down by soil microorganisms (Microbes) such as bacteria and fungi. These processes are strongly influenced by environmental conditions such as moisture, aeration, temperature, and soil pH. Soils with large amounts of organic matter, such as compost, will have higher rates of microbial degradation

All three types of degradation are losses of herbicides, and so if there is excessive degradation weed control will be reduced. However, these processes are also important for reducing the carry-over of herbicides into the next season.

Adsorption

Adsorption (Not absorption) is the process through which a chemical compound will bond to the surface of soil particles. When this happens, the herbicide is effectively "locked away" and cannot be taken up by plants or soil microbes. This can reduce weed control but also reduce herbicide leaching. The main soil particles that are involved in adsorption are clay minerals and organic matter. As a result soils with a high clay or organic matter content will experience high rates of adsorption.

Leaching

Leaching is the movement of chemical compounds by water through the soil profile. Leaching can help incorporate soil-applied herbicides into the root-zone of the soil profile, increasing weed control. However, excessive leaching can move herbicides beyond the root-zone and reduce weed control. Leaching can also contaminate groundwater, leading to environmental harm. There are many factors that affect leaching rates such as soil texture, soil permeability, the volume of water that is moving through the soil profile, and adsorption rates. Generally, loose soils with a low clay and organic matter content will experience higher rates of leaching.

→ Herbicide Persistence and Residues:

Herbicides can only be effective if they remain active and available until they are taken up by a weed. However, we only want our herbicides to remain active during the weed control period. Soil persistence is the length of time a herbicide remains active in the soil. Herbicide residue is the amount of herbicide remaining after the weed control period. Herbicide residue can cause crop damage in the following season, and can lead to contamination of groundwater if there is leaching.

→ Practical considerations:

• To reduce runoff, do not apply herbicides on days where it is forecast to rain. The Agricultural Research Council's AgriCloud mobile app is a useful tool to help farmers plan when to apply herbicides.
• Apply herbicides in the morning when the temperatures are not as hot, to reduce volatilisation
• Where possible, incorporate soil-applied herbicides directly into the soil instead of the soil surface. This will reduce volatilisation.
• Incorporating soil-applied herbicides into the soil reduces photodegradation
• Avoid over-irrigation to reduce leaching
• Apply the lowest dosage possible to reduce herbicide persistence, if herbicide persistence is a problem
• When using mixtures of herbicides, try to use smaller amounts of herbicides that have a long soil persistence.

→ Summary:

When we apply herbicides to our fields, it does not necessarily mean that they will reach the intended weeds. By following the application instructions and using good practices we can reduce losses of herbicides into the environment and improve our weed control.

→ Test

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Chapter 13: Chemical control Part 4 – Herbicide resistance

In this chapter, the last part of the chemical control section of the learning programme, we will be covering an important problem facing the agricultural industry: Herbicide resistance. This section covers the basic theory of herbicide resistance in preparation for the final chapter.

→ Mode of action

When a plant is exposed to a herbicide there are a number of physiological responses that will occur. The 'mode of action' is the plant's response to being exposed to the herbicide chemical compound. In other words this is how the plant will die. The 'mechanism of action' is the biochemical and biochemical process that is affected by the herbicide chemical compound. The part of the plant that the herbicide affects is called the 'site of action'.

For example, photosynthesis is the process in which plants use sunlight to convert carbon dioxide and water to make a sugar called glucose. This is how plants feed themselves. Some types of herbicides stop photosynthesis from happening, and so this is the mechanism of action of these herbicides. The mode of action for these plants will be the plant starving because it can no longer produce sugars to feed itself. The site of action for these plants will be the leaves, as this is where photosynthesis happens.

In Chapter 10 we talked about the herbicide 2,4D, and mentioned that it is a synthetic auxin. In plants, auxins are produced in the tips of shoots in an area called the meristem. In a healthy plant the meristem produces auxins which cause the plant to grow. When a plant is exposed the 2,4-D, the chemical compound is transported inside the plant to the meristem which causes the plant to grow unsustainably fast. This makes the site of action of 2,4-D the meristem. The mechanism of action is forced growth. The mode of action is the plant weakening itself by growing faster than what it can support.

Some herbicides affect more than one process. This is something that is very important for preventing herbicide resistance.

→ What is herbicide resistance?

When we talk about herbicides we often hear the terms "herbicide resistance" and "herbicide tolerance". Although these terms sound the same, they are very different and are often confused.

Both herbicide tolerance and herbicide resistance are a weed's ability to survive and complete a full lifecycle (Produce seeds) after being exposed to a dose of a herbicide. However, the difference between the two terms is why the weed is able to survive.

Some weed species are not affected by certain herbicides. This is because the species has a mechanism that prevents the uptake of the herbicide chemical compound, or has the ability to process the herbicide chemical compound without suffering any negative effects. When an entire species is not affected by a herbicide we call this ability to survive exposure herbicide tolerance.

Herbicide resistance is when a weed species is not naturally able to survive exposure to a herbicide, but some individuals have a mutation that has given them the ability to survive a dose that would normally kill the species. These individual weeds are mutants, and do not represent the whole species. However, if care is not taken these individuals can reproduce and become more common in the population. The process of these mutants becoming more common is called selection and is shown in Figure 1.

There are many factors that affect selection. Some of the herbicide factors that can increase selection of herbicide resistant weeds are:

• Herbicides that act on only one site of action: The more sites of action a herbicide has the less likely it is that a weed will develop resistance. This is because more sites of action mean more mutations are needed at once to give the plant resistance. For example, if a herbicide has two sites of actions, and a weed has a mutation at one site that gives it resistance, the weed will still die when exposed to the herbicide because the second site of action is still vulnerable. In order to be resistant the plant would need to develop resistance mutations at both sites of action, and this is very unlikely. Many herbicides only have one site of action. To overcome this problem it is sometimes recommended that a farmer use a mixture of two herbicides with different sites of action. This mixture will work the same as using a herbicide with two sites of action. However, we must be careful as some herbicides cannot be mixed with others. Please consult the herbicide label when mixing herbicides.

• Herbicides that are applied multiple times during the growing season: The more times a herbicide has to be applied, the greater the chance of a resistance mutation developing. Where possible use herbicides that control weeds for entire season with only one application.

• Herbicides repeatedly used for several seasons, or repeated use of herbicides with the same site of action in the same field: If weeds are only exposed to herbicides with the same site of action it increases the chance of a resistance mutation happening. By using different herbicides we decrease the chance of a resistant mutation surviving long enough to produce seeds.

• When herbicides are the only weed control methods used in a field: Only relying on herbicides increases the chance of a resistance mutation happening, because there will be many weeds that will be sprayed. By using other methods of control, such as cultural control, we will decrease the number of weeds that need to be sprayed. This is called Integrated Weed Management, and will be covered in Chapter 14.

→ Characteristics that favour resistance

If a herbicide resistant mutant survives to seeding, there are two important factors that will determine how fast the resistant mutant will become common: Reproductive capability and seed dispersal mechanism.

Reproductive capability is the number of seeds the individual plant is able to produce in its lifetime. Weeds with a resistance mutation will pass this mutation on to the next generation of weeds that they produce. If this weed has the ability to produce many seeds, then there is the potential that there will be many weeds in the next season that will be resistant.

Seed dispersal mechanism is the way in which a weed spreads its seeds. In Chapter 2 we saw that some weeds can spread their seeds hundreds of kilometres from the field they grew in. These weeds usually spread their seeds by wind. Weeds that cannot spread their seeds far are easier to control if they develop resistance, because they will stay in the same field. However, the weeds that spread their seeds will be difficult to control. Our weed management practices will not only affect the weeds in our own fields, but also the fields of other farmers. This is why effective weed control at a national, and even international level is important.

→ Summary

Herbicide resistance is a threat to the effectiveness of our chemical control options. When incorporating herbicides into your weed management strategy do not rely on one herbicide, or herbicides with the same mode of action.

→ Test:

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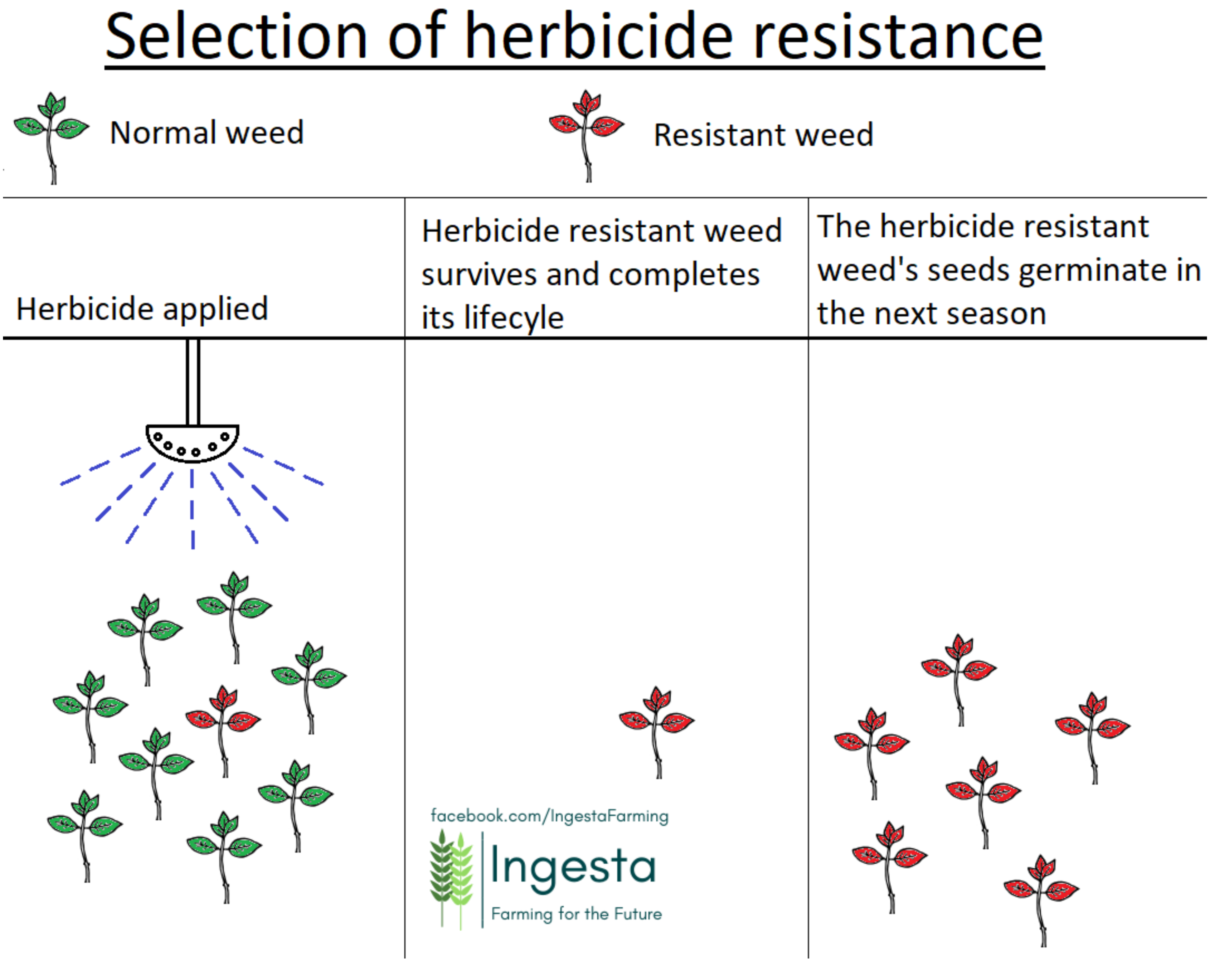

Figure 1: Herbicide resistance selection. As we can see in the resistant weed (Red weed) is not removed it will be able to produce seeds, which will increase the number of resistant weeds in the next season.

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Chapter 14: Integrated Weed Management

In this course we have addressed different weed control methods in separate chapters. However, the most effective weed management strategy is a strategy that uses a number of different control methods. This is called integrated weed management. This chapter will help you use all the knowledge we have learnt from this learning programme to create your own integrated weed management programme to ensure efficient weed control.

→ Introduction to integrated weed management:

Integrated weed management is an approach to weed management that uses many different control methods at once. The goal is to lessen the amount of time and energy needed for weed control, by aiming to reduce the number of weeds that need to be controlled. There is no method of integrated weed management that will work for everyone, because of the many factors that affect weed populations. Instead, we will use a series of question to decide what the best approach for designing our own integrated weed management programme is.

→ What weeds are we controlling?

The first question we need to ask ourselves is what weeds we are controlling. If we are controlling annual weed species (Weeds that complete their lifecycle is one growing season) we will have to control them quickly to prevent them from producing seeds. Perennial weeds (Weeds that complete their lifecycle over many seasons) may not produce seeds as quickly annual weeds, but can be more difficult to control in the long-term. Perennial weeds have evolved various strategies, such as bulbs and the ability to regrow from their roots, which help them survive when the above-ground parts of the plant are destroyed. Some weeds are also able to regrow from small pieces such as leaves or roots. When ploughs cut these weeds into many pieces, we could potentially be creating many more weeds for our fields. As we learnt in Chapter 2, weed seeds can be spread from neighbouring fields and so it is important to identify the weeds not only in our own fields but also in neighbouring fields and along near-by roads and fence lines. Knowing what weeds we are controlling will help us choose management practices that prevent their spread.

→ Where are the weeds coming from?

As we discussed in Chapter 2, preventing weed seeds from entering our fields means there will be lees weeds to remove later on in the season. This will reduce the amount of time and resources that we need to invest into weed control that could instead be spent on nurturing our crop. Identifying the weeds in our area will help us choose ways in which we can reduce the number of weed seeds arriving in our field. If we see that there are many fast-growing annual weeds in our fields, we should implement weed control measures early on in the season to ensure that we successfully kill these weeds before they are able to produce seeds. If we look in our neighbour's fields and see many weeds that produce small seeds which could easily be carried by the wind into our fields, it will be beneficial for us to assist them control these weeds so that their seeds do not end up in our fields. This is also true for weeds growing along our roads and fence-lines, as discussed in Chapter 9.

In Chapter 2 we also talked about how weeds seeds can be transported on the hair of livestock, or on equipment such as ploughs, tractors, and harvesters. Identifying the weeds in the areas our livestock graze will let us know if we need to wash our livestock before allowing them to graze in our fields. Similarly, washing tractors, ploughs, and harvesters before using them in our fields will prevent the spread of weeds that are trapped in the dirt stuck to our equipment. In Chapter 2 we also talked about the importance of using certified weed-free seed where possible.

However, while we can do our best to prevent weed seeds from entering our fields we know that it is impossible to stop them all. This leads us to the next question:

→ How can we control weeds as early on in the season as possible?

The first step in controlling weed seeds as early as possible is by preventing the seeds from germinating successfully. As with preventing weed seeds from entering our fields, preventing weed seeds from germinating successfully will mean we will have less weeds to control later.

In Chapter 2 we talked about how tillage can help bury small seeds deep in the soil profile where there will not germinate successfully, but also how big seeds are not always affected by this practice. In Chapter 7 we talked about how mulches can be used to form physical barriers, which will prevent weed seeds from germinating successfully.

However, stopping weed seeds from germinating can be difficult, as these conditions can also prevent our crop from germinating successfully. For this reason it is often easier to allow the weed seeds to germinate, and control the weeds while they are still young. At this stage in their life the weeds are at their most vulnerable, and so are easily controlled.

In Chapter 9 we talked about using stale or false seedbeds, where we create favourable conditions for weed seeds to germinate and then apply a control measure such as a herbicide application or a second tillage. This can be effective, but as farmers we don't always have time to wait for the weed seeds to germinate before we plant our crop. In Chapter 3 and Chapter 4 we talked about how we can use our crops to control weeds by making our crops more competitive. The various strategies discussed in Chapter 9 will all help make your crop more competitive, and help us attain higher yields. Here we know the weed seeds will still germinate, but will be weak and will not live long enough to be a threat to our crop. How this is achieved will depend on the crops you are using, the resources you have available, the climate of your farm, and the types of weeds you are controlling. It may also require you to experiment with different crops and production methods, but this is a can be a very efficient way of controlling weeds. Of particular importance is the use of crop rotation. As discussed throughout this learning programme using crops with different lifecycles and different management requirements will disrupt the lifecycles of weeds.

However, because weeds are survival specialists we know that some weeds will always be able to establish themselves in our fields. This leads us to our next question:

→ How do we control weeds that have already established themselves in our fields?

The goal of any integrated weed management strategy is to reduce the amount of effort required to control weeds during the season. Weed control in the field while the crop is actively growing can be difficult, because we need to be careful not to disturb the crop. Biological control agents can be of great help here, if they are available. Similarly, selective herbicides can be used to quickly kill weeds without affecting our crop. However, as we have discussed we must make every effort to reduce herbicide resistance from developing. In Chapter 13 we talked about selection for resistance. An integrated weed management strategy prevents the resistant weeds from surviving. This is because an integrated approach will use different types of herbicides to ensure maximum control, and will not rely only on herbicides. After herbicide application we can use a second form of weed control such as hand weeding to remove the few surviving weeds. This will ensure that herbicide resistant weeds do no become more common.

→ Conclusion:

The most important lesson of this learning programme is that weed control is an on-going process. Investing in weed control this season will not only help our current crop, but will reduce the amount of weed control needed in the future. We cannot rely on one single form of weed control, and the most effective weed control strategy will be the one that prevents weeds from completing their lifecycle and producing more seeds. Not all the methods we have talked about will be suitable for your farm, but don't be afraid to try new methods to see if they will help you. Contact your local extension officer, speak to other people in your area, and use the internet to connect with farmers to share information about how best to control your weeds!

→ Test:

Click on this link and complete the short test to earn your certificate:

https://docs.google.com/.../1FAIpQLScYsxUWc04.../viewform...

The final test for this learning programme will be released on Wednesday 23 October, to give everyone a chance to finish all the chapter tests first. The final test will be out of 30 marks, and you will have until Sunday 27 October to complete it. Please note that we will only mark your first attempt at the test, so please do not start the test until you are ready. Once we have marked the tests we will email you your certificates, and select our prize winners.

Appendix 8: Permission Letter for Conducting Research at Pretoria Agri-Parks from the City of Tshwane

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City Strategy and Organizational Performance

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My ref:	**Research Permission/ Le Roux**	Tel:	012 358 4559
Contact person:	**Pearl Maponya**	Email:	PearlMap3@tshwane.gov.za
Section/Unit:	**Knowledge Management**	Date	30 May 2018

Ms Betsie le Roux
Department of Plant and Soil Sciences
University of Pretoria
Cnr Lynnwood Road and Roper Street
Hatfield
South Africa

Dear Ms Le Roux,

RE: IMPROVING AGRICULTURAL WATER USE MANAGEMENT ON FARM AND CATCHMENT SCALE TO SUPPORT RURAL FARMERS IN SELECTED AGRI-PARKS.

Permission is hereby granted to Ms Le Roux and her research team from University of Pretoria to conduct research in the City of Tshwane Metropolitan Municipality.

It is noted that University of Pretoria (UP) in collaboration with Agricultural Research Council will be conducting research which aims to investigate the current or planned agricultural production and to establish how small-scale farmers can improve their water use efficiency. The City of Tshwane further notes that all ethical aspects of the research will be covered within the provisions of UP Research Ethics Policy. You will be required to sign a confidentiality agreement form with the City of Tshwane prior to conducting research.

Relevant information required for the purpose of the research project will be made available upon request. The City of Tshwane is not liable to cover the costs of the research. Upon completion of the research study, it would be appreciated that the findings in the form of a report and or presentation be shared with the City of Tshwane.

Yours faithfully,

PEARL MAPONYA (Ms.)
ACTING DIVISIONAL HEAD: INNOVATION AND KNOWLEDGE MANAGEMENT DIVISION

City Strategy and Organisational Performance • Stadstrategie en Organisatoriese Prestasie • Lefapha la Thulaganyo ya Tiro le Togamaano ya Toropokgolo • UmNyango wezokuSebenza namaQhinga aHleliweko kaMasipala • Kgoro ya Leanopeakanyo la Toropokgolo le Bodiragatši bja Mmasepala • Muhasho wa Vhupulani ha Ḓorobo khulwane na Mashumele • Ndzawulo ya Maqhinga ya Dorobakulu na Matirhele ya Masipala • Umnyango Wezeqhinga Ledolobha Nokusebenza Kwesikhungo