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

by

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DECLARATION

I, Richard Lee Hay declare that the dissertation, which I hereby submit for the degree MSc(Agric) Agronomy at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at any other tertiary institution.

Signed ______________________

Richard Lee Hay

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List of Abbreviations

B	Boron
Be	Beryllium
Cd	Cadmium
Cl	Chloride
CoT	City of Tshwane
DAFF	Department of Agriculture, Forestry and Fisheries
DALRRD	Department of Agriculture, Land Reform and Rural Development
DRDLR	Department of Rural Development and Land Reform
F	Fluoride
FPSU	Farmer Production Support Unit
GDARD	Gauteng Department of Agriculture and Rural Development
Hg	Mercury
LER	Land Equivalent Ratios
Li	Lithium
Mo	Molybdenum
Na	Sodium
NCOP LREMRE	National Council of Provinces Select Committee on Land Reform, Environment, Mineral Resources and Energy
NDP	National Development Plant

Ni	Nickel
NO_2^-	Nitrite
NO_3^-	Nitrate
Pb	Lead
RCBD	Randomised Complete Block Design
RUMC	Rural Urban Market Centre
SAWQI DSS	South African Water Quality Guidelines Decision Support System
Se	Selenium
SI	Sustainable Intensification
SO_4^-	Sulphate
SRI	System of Rice Intensification
SSA	sub-Saharan Africa
U	Uranium
UN	United Nations
V	Vanadium
WFD	Wetting Front Detector
θ_v	Volumetric water content

Abstract

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. Nonetheless, the 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 had no significant effect on the total weed biomass ($p > 0.05$) and that weeding had a significant effect on weed population density ($p < 0.001$) and weed species richness ($p < 0.001$). 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. A second trial to investigate the impact of weeding frequency on yield and water productivity indicated that bi-weekly weeding can result in yields 4.2 times greater than yields obtained in unweeded fields ($p < 0.001$) and irrigation water productivities 4.1 times greater than irrigation water productivity obtained in unweeded fields. This reinforced the need for the

use of basic agronomic practices, such as weeding, to increase production outputs and improve resource use efficiencies.

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 of the 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 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.

Key words: Water productivity • Social media • e-learning

Introduction

By 2030 the United Nations (UN) anticipates that sub-Saharan Africa (SSA) will experience the largest relative population increase of any subcontinent, and is expected to be home to approximately one in six of the world's then 8.55 billion people (UN 2019). As it stands the region is greatly impoverished, home to 56% of the world's population classified as 'extreme poor' in 2015, and is the least food secure region in the world (FAO 2019, IMF 2019). In 2017 599.9 million people in SSA (58.7%) were at least moderately food insecure and 263.9 million (25.8%) severely food insecure, with 232.1 million people (22.8%) undernourished (FAO 2019). Food insecurity in the region is a complex entanglement of factors such as extreme poverty, conflict, and drought prevalence, and increasing food production to both meet the needs of a growing population and close the inequality gaps is no small task (FAO 2019).

Smallholder farmers form the cornerstone of the agricultural sector of SSA with more than 90% of farms smaller than 10 ha in size occupying approximately 85% of the agricultural land, and more than 70% of farms being smaller than 2 ha in size occupying approximately 35% of the total agricultural land (Lowder *et al.* 2016). Despite their small size and typical use of resource-poor agricultural practices, these farms still produce the majority of the region's grains and legumes, and almost all of the tuberous and root crops (Altieri *et al.* 2012, van der Ploeg and Ventura 2014). However, there is still much debate pertaining to the future of smallholder farmers centred largely on their ability to compete at the economic scale of large-scale industrialised agriculture in the rapidly changing agro-food system (Collier and Dercon 2014). Of particular concern are Africa's yield gaps, with the continent achieving the lowest average cereal yields of any continent at less than half that of the global average (Tian and Yu 2019). Yields are a function of complex interactions between genotype, environment, and management practices, and thus the cause of these gaps has been attributed to an extensive list of factors and problems that plague smallholder agriculture in SSA.

In their review of factors explaining yield gaps, Beza *et al.* (2017) found that soil fertility and fertilisation were the focus for most research on yield gaps in the African context. In particular, fertilisation was considered in 57% of the research where it was found to be an explaining factor 96% of the time (Beza *et al.* 2017). This is consistent with the work of Tittonell and Giller (2013) which reports that the largest cause of yield gaps are poor soil health, although the presence of soils that respond poorly to remediation is largely hidden by the heterogeneous patchwork of productive and unproductive soils. Beza *et al.* (2017) further found that factors such as weeding, planting practices, crop characteristics, and crop protection were also often considered but found to be less explanatory, while factors in the land preparation and irrigation categories were less often considered but explained the yield gap in 89% and 67%, respectively, in the cases where considered. These factors should theoretically be addressed through the approach taken by the Borlaugian style of intensification that typified the Green Revolution, which closed yield gaps elsewhere in the world through the widespread adoption of technologies such as synthetic fertilisers, improved germplasm, and mechanisation.

Tittonell and Giller (2013), however, argue that although current research into the intensification of African agriculture has been characteristic of this Green Revolution blueprint, ecologically sustainable agricultural intensification is rarely addressed in a context appropriate for the smallholder agrarian communities that characterise the SSA food system. Aims to close yield gaps through technologies that rely on substantial investment in inputs have been hampered by poorly developed inputs and outputs markets, as well as the poor performance of technologies or inadequacy to fit within local smallholder systems in SSA. As reasoned in their earlier paper through accounts of impoverished smallholder farmers prioritising investments into labour and ploughs rather than fertilizer and improved germplasm for a greater return on investment, these technologies are not inherently inadequate for the African context but the economics currently surrounding them are (Tittonell et al. 2010). Beza et al. (2017) found that factors such as labour (availability, cost, and mechanisation) and intensity (resource use intensity, irrigated area) are stronger explanatory factors of yield gaps to more-widely considered factors like farm size, and so we would expect that if smallholder farmers were given sufficient economic support they would readily adopt any technology or practice to increase yields.

Smallholder agriculture in SSA is also largely based on traditional practices and indigenous knowledge and, despite the emotional appeal that traditional practices may present, their inability to provide for Africa's burgeoning population is self-evident (Tittonell and Giller 2013, Van Ittersum *et al.* 2016). This being said a growing body of research has demonstrated that the yields obtained under such practices, when used in combination with modern agronomic practices and ecological principles, can be boosted to levels that will close yield gaps and mitigate yield losses due to climatic extremes (Jiri *et al.* 2016, Tittonell and Giller 2013). Building onto this the use of improved cultivars can greatly enhance yields under the right conditions, although cultivar choice by smallholder farmers is also highly influenced by local preferences potentially at the expense of productivity (Ortega *et al.* 2016, Tittonell and Giller 2013). Effects of improved cultivar use can also be masked by poor and degrading environmental conditions (van der Laan *et al.* 2017).

Irrigation is one practice used to overcome adverse environmental conditions, and small-scale irrigation has been shown to hold potential for the sustainable intensification (SI) of smallholder agriculture through direct increases in yields and several other indirect social benefits (Collier and Dercon 2014). Increases in yields of staple and high-value crops increase both household food sovereignty and income (Takeshima and Yamauchi 2012), generally resulting in positive economic impacts including increased productivity of labour and land, 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 agrochemical inputs and improved agricultural management strategies (Takeshima and Yamauchi 2012). Currently there are several barriers limiting investment into irrigation by smallholder farmers in the region including poor market access, low incentives for agricultural intensification, limited finance opportunities for smallholder farmers, and lack of knowledge transfer regarding the positive effects of irrigation investment (Calzadilla et al. 2013).

In the South African context, one initiative that aims to provide institutional support to enable smallholder farmers to overcome these barriers and increase participation in the agricultural value chain is the Agri-parks programme, an on-going initiative by the former Department of Rural Development and Land Reform (DRDLR) and Department of Agriculture, Forestry and Fisheries (DAFF) (DAFF 2016). During the 2019 restructuring of ministries DRDLR and DAFF were merged to form the Department of Agriculture, Land Reform and Rural Development (DALRRD), under which the Agri-parks programme now falls. The programme is a major component of National Development Plan's (NDP) proposed rural development strategy of supporting smallholder agricultural production and stimulating agro-processing in rural areas through sustainable production of labour-intensive, high-value commodities on redistributed and communal land (DAFF 2016, DRDLR 2016b). The programme was first mentioned during the 2015 State of the Nation Address by then President Jacob Zuma as part of the 'Nine Point Plan' to ignite economic growth and create jobs (Zuma 2015). The 2014/2015 DRDLR annual report described the Agri-parks to be 'conceived as providing for the creation of sustainable rural enterprises, agro-processing, trade development, production hubs for food security, local markets and financial services', and in 2016 as 'the cornerstone of the Government's priority to Revitalise Agriculture and Agro-processing Value Chain' [sic] (DRDLR 2015, 2016b). The programme largely aims to provide financial and infrastructural support to smallholder farmers to facilitate the SI of the smallholder agricultural community in South Africa.

The Agri-parks model emphasises the incorporation of modern technologies to assist farmers (DRDLR 2020). In recent years the development of tools designed specifically for smallholder farmers, such as the FullStop wetting front detector (WFD) (Stirzaker 2003) and Chameleon soil water sensor (Stirzaker et al. 2014), have proven to be effective in aiding farmers increase yields and reduce inefficiencies. However, there are still a number of challenges in ensuring successful tech-transfer of these tools, some of which were observed in this project. One area of information and technology transfer that has not widely been researched is the use of social media as a platform for agricultural extension and training.

This study aims to 1) investigate the status of the Agri-parks programme in the City of Tshwane (CoT) with a focus on irrigation water usage, 2) identify and demonstrate appropriate interventions to aid smallholder farmers increase water productivities within the context of the CoT Agri-park, and 3) demonstrate the use of Facebook as a platform to host agricultural science e-learning programmes for smallholder farmers.

Chapter 1: Literature Review

1.1 Defining sustainable intensification in the smallholder farmer context

1.1.1 Defining 'intensification'

In order to define a system as intensive a frame of reference must be considered, 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 outputs 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 broad 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 and Kuijper 2014). However, limiting the definition of intensity to include only physical inputs has been criticised as inaccurate as this definition ignores the multiple intangible inputs such as knowledge, management, and skills that can also be intensified (Uphoff 2014). This more holistic stance on intensification is required to address problems such as poor knowledge transfer and skills development. It is important to note that although a new system may initially present itself as more intensive in comparison to a system that has been practiced for decades prior, as was the case with the System of Rice Intensification (SRI) (discussed below), intensity can also decrease with increased proficiency and knowledge (Uphoff 2014). Conversely when SRI was implemented in Asian countries, where rice production was already more labour intensive than the African rice production systems, it was found that conversion to SRI could potentially be a labour-neutral or labour-saving change (Uphoff 2014). This demonstrates the importance of a reference frame, both temporally and spatially, due to situation-specific variability.

1.1.2 Defining 'sustainability'

Quantifying the sustainability of any practice is a complex, and multi-faceted problem. 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. Uphoff (2014) proposes instead 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. van Noordwijk and Brussaard (2014) stress the importance of the relationship between the environmental effects of obtaining a specific yield relative to the environmental costs associated with increasing this yield. Accepting lower yield gaps may thus be justifiable, should the environmental impact of increasing production increase at proportionally larger rates.

1.1.3 Defining 'sustainable intensification'

Defining 'sustainable intensification' from an agricultural perspective appears to bring together two seemingly contrasting and highly subjective concepts. Pretty (1997) first used the term to describe increasing productivity of smallholder agricultural systems while simultaneously protecting the ecosystems they occupy. Pretty (1997) demonstrated that low-input agriculture had the potential to be highly productive when local knowledge is utilised, and farmers participate in technological development. Since then the term has been used to describe various industrial agriculture practices which, although starkly contrast Pretty's usage in smallholder agriculture, also seek to increase productivity while decreasing environmental footprints. Although one can define sustainable agricultural intensification in a number of ways, there is growing consensus that the emphasis should be placed not on the semantics, but rather on the premisses of the term (Vanlauwe *et al.* 2014). These premisses are defined as 1) increased production being a necessity, 2) increased production being 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) strategies being context-dependent to account for site-specific biophysical and social differences (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:

- The use of crop cultivars and livestock breeds which are the most productive, relative to the external and internal inputs
- The reduction, if not total elimination of unnecessary external inputs
- An increased use of ecosystem services and processes
- The reduction in the use of practices and/or technologies with known or potential adverse effects on human and ecosystem health
- A more productive use of human capital
- 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 tied ridges, terracing, and swales, conservation agriculture, agroforestry, and patch intensification (Claessens *et al.* 2014, Pretty and Bharucha 2014).

1.2 Criticisms and challenges in the wide-spread adoption of sustainable intensification in sub-Saharan Africa

The most glaring criticism that SI faces is that increasing yields and decreasing the environmental impacts of the agricultural sector will do little to address the inequalities of food distribution and widespread malnutrition in SSA (Pretty and Bharucha 2014). In response to this Pretty and Bharucha (2014) theorise that through increasing both yields and crop diversity, food sovereignty of rural communities will be increased while malnutrition will decrease. In saying this it is also only through social and political transformations of the global food system that the inequalities of food distribution can be addressed.

Sustainable intensification has also been criticised for its potential to be a mechanism for 'greenwashing' conventional agricultural practices (Pretty and Bharucha 2014). However, this criticism is rendered obsolete if the measures are taken to ensure that all practices and policies promoted for implementation are indeed ecologically sustainable. As with the criticism regarding food sovereignty, it is only through policy transformations that such measures can be implemented to ensure the validity of sustainability claims. Proponents of ecological intensification, as opposed to SI, argue that the only true form of sustainable agriculture is one based on natural ecosystems (Tittonell 2014). Their criticism of the Borlaugian style of intensification through increased use of external inputs is that it is built on the premise of plants being simple carbon-based machines in a unidirectional nutrient scheme. This view is said to place too much emphasis on the ability of external inputs to fuel the production system, and not enough emphasis on the ability of crop and livestock to contribute to ecosystem services and soil fertility (Uphoff 2014). Ecological intensification is, however, not entirely suitable for all of SSA for a number of reasons. For instance, much of Africa's smallholder cereal production is limited by nutrient deficiencies as opposed to water deficiencies, integrated crop and livestock systems are already commonplace, and the use of green manures and agroforestry are not always suitable for heavily populated areas (Tittonell and Giller 2013). In other areas, ecosystems may be so degraded that their normal services no longer function, and natural resources are scarce. In both cases yield response to ecological intensification may be slow or non-existent and so external inputs such as synthetic fertilizers may be a necessity (Tittonell and Giller 2013). In all production systems there exist inherent trade-offs that could potentially be criticised. While these trade-offs make agriculture a contested topic, through proper planning and research the site-specific combination of trade-offs with the least impact on the surrounding community and ecosystems can be found and the inevitable trade-offs justified (Kuyper and Struik 2014).

However, this lack of research is also a major challenge that faces the development and promotion of SI in smallholder agriculture in SSA. Globally the yield gap between organic and conventional agriculture is approximately 20% (Tittonell 2014). However, research pertaining to conventional agriculture receives the majority of governmental funding and nearly all of the funding provided by the private sector (Tittonell 2014). With increased funding for research into SI practices more suited for the economic realities of the smallholder farmer in SSA, this yield gap can be expected to close as more advancements are made. In order for this to be achieved, a paradigm shift of agronomic thought must occur. Tittonell (2014) reports that most of the progress made in agronomy in recent history has been achieved through studies of the ecology of monocultures that dominate conventional agriculture. This is largely due to the widely-held perception that agricultural science and ecology were separate anthropogenic and natural entities (Caron *et al.* 2014), and thus ecological principles were largely ignored by agriculturalists just as agricultural principles were ignored by environmentalists. Recently the two disciplines have become more integrated, leading to interdisciplinary research. Thus far agronomic research focussing on the difference between classical agronomy and agroecology have shown agroecological systems to be more resilient to environmental shocks, as discussed by Tittonell (2014). Research into the use of so-called "orphan crops" has also become more prevalent in the discussion on bolstering food security across the world (Kuyper and Struik 2014).

Further research would also logically produce more efficient systems as the knowledge base grows amongst smallholder farmers, thereby addressing the common misconception of SI practices always being more labour-intensive (Pretty and Bharucha 2014). As discussed below the adoption of SRI was initially labour intensive in the African context, however, labour-intensity decreased as farmers became more proficient (Uphoff 2014). Such improvements in labour-intensity will be beneficial in regions with elevated HIV infection rates, or where large scale urban migration has occurred from rural areas where labour may be a limiting factor (Vanlauwe *et al.* 2014). This being said, for many regions of SSA labour is by no means a limiting factor. For instance, across the Sahel labour-intensive *tassas* and *zai* pits have been adopted by many smallholder farmers to increase water infiltration (Pretty and Bharucha

2014). Here the abundance of family labour allows these labour-intensive practices to be exceptionally viable (Pretty and Bharucha 2014).

Although it has been theorised that with the trend in farm sizes decreasing many farms may become, or already are, too small for effective intensification (Vanlauwe *et al.* 2014). There are also fears that if SI is not adopted holistically at a community level, it will be isolated and thus ineffective (Tittonell and Giller 2013). While these are certainly valid concerns, the success of the reclamation of three million hectares of the Sahel, through the use of *tassas* and *zai* pits demonstrates that large-scale realisation is possible (Pretty *et al.* 2011).

1.3 Adoption and impacts of smallholder farm sustainable intensification projects in sub-Saharan Africa

1.3.1 Adoption of sustainable intensification practices

Despite these challenges, the adoption of SI practices across parts of SSA has been achieved. An integral part of this adoption process, as with any decision making process in agriculture, is the analysis of risk aversion (Kuyper and Struik 2014). Although by definition sustainably intensified agriculture is inherently less vulnerable to environmental and anthropogenic stresses and shocks, it may not always be viewed as such by farmers (Pretty *et al.* 2011). In order to realise widespread adoption of SI practices across SSA, risk aversion through the adoption of said practices must be demonstrated. As already mentioned, an increase in research would produce more tangible evidence for farmers to use in their decision making process. Kotu *et al.* (2017) showed that SI practices are more likely to be adopted as a package rather than as single technologies or practices, requiring farmers to grasp a number of key concepts simultaneously and emphasising the importance of a holistic agricultural extension and training services in the rollout of new practices and technologies.

Investment into SI practices requires capital at crucial times during the growing and pre-growing season, thus making access to profitable markets essential (Vanlauwe *et al.* 2014).

More favourable policies and incentive structures would assist farmers with these investments and increase the rate at which SI practices are adopted (Vanlauwe *et al.* 2014). Government funded programs, such as the fertiliser subsidy schemes in Malawi and the African Research Centre on Banana and Plantains in Western Africa, have proven that government intervention is welcomed if effective (Pretty *et al.* 2011). Investment from the private sector, especially that of multi-national corporations who make use of smallholder farmers throughout Africa, can greatly assist in the adoption of sustainable agricultural practices as these companies have the extensive networks and resources to facilitate large-scale adoption (Caron *et al.* 2014). However, even with investments by government and the private sector, large-scale adoption is only possible with sufficient research to validate it. Although Tittonell (2014) reports of a sharp increase in inter-disciplinary agricultural research over the last few decades, a greater emphasis must be placed on African research institutions to produce integrated research more suited to the African context (Caron *et al.* 2014). Such research cannot be treated in isolation, and should be designed to benefit all the stakeholders of smallholder agriculture.

1.3.2 Yields

Tittonell and Giller (2013) report that even the simplest improvements in agronomic practices can have a pronounced impact on yield. In a study determining local reference maize (*Zea mays* L.) yields in response to fertilizer applications, the lowest yields of the researcher-managed control (unfertilized) plots were significantly higher than the yields in the best performing local fields (Tittonell and Giller 2013). The authors also reported several studies demonstrating that responses to fertilisers across various non-cereal crops increased significantly when more appropriate agronomic practices were adopted (Tittonell and Giller 2013). If other inputs can be used more efficiently by merely addressing basic agronomic principles, then it logically follows that the potential of SI to bolster yields while reducing agricultural environmental impacts may be larger than originally thought.

In a meta-analysis of 286 projects over 37 Mha in 57 African countries, reported in Pretty and Bharucha (2014), it was found that adopting various sustainable intensification practices increased average yields by 79%. In further studies reported by Pretty and Bharucha (2014) it was found that with sufficient support, smallholder farmers could increase their yields by up to 113%.

1.3.3 Indigenous knowledge

Sustainable intensification practices based on local resources and indigenous knowledge may play an important role in perpetuating cultural practices and traditions well into the 21st century (Tittonell 2014). As mentioned, there is no universal blueprint for SI and by drawing on the indigenous knowledge of an area agronomic practices that are more effective can be established to fit local conditions. New practices are also more likely to be adopted by smallholder farmers if they present similarities to the traditional practices that the farmers are familiar with (Tittonell 2014). Onus must be placed on research institutions to integrate modern practices and traditional knowledge in a way that is both scientifically sound and applicable in the context of African smallholder farmers (Tengö *et al.* 2017). In a long-term study summarised by Pretty and Bharucha (2014) it was found that after 22 years of integrating their indigenous knowledge with modern SI practices, a shift in thinking had occurred within the observed communities. All farmers emphasised the necessity of building up their natural resources base, improving soil health, minimising external inputs, promoting nutrient cycling, engaging in post-harvest value-adding to increase income, and the need to address the challenges created by rising land costs and diminishing water availability (Pretty and Bharucha 2014). This indicates that more responsible farming communities can be created through integration of traditional knowledge and modern practices (Pretty and Bharucha 2014), albeit more likely as integrated packages rather than the adoption of singular practices or technologies as previously discussed.

1.3.4 Judicious resource usage

In creating farming communities that are more responsible, a culture of judicious resource usage can also be created. All resources, both anthropogenic and natural, carry environmental and economic costs that can be minimised through judicious usage. In the case of irrigation water, simple drip irrigation schemes and water harvesting or conservation practices may be of great benefit to smallholder farmers by increasing the percentage of effective irrigation water (MacDonald *et al.* 2016). Such technologies are potentially only economically viable at a larger scale than that of the smallholder farmer, however simple management interventions such as mulching and zero-tillage are viable at smaller scales (MacDonald *et al.* 2016). Judicious usage allows for a greater spread of the irrigation water resources amongst irrigators, and it follows logically that the same principles described for irrigation water here can be applied to other resources.

1.3.5 Biodiversity

One of the major criticisms of the modern agricultural system is the simplification of diversity in order to create an artificial ecosystem (Altieri 1999). Two premisses of SI are to preserve local ecosystem services and increase resilience to all forms of shocks and stresses, and these can only be achieved through biodiversity (Pretty *et al.* 2011). Agrobiodiversity is generally substantially higher in smallholder farms than in industrialised agricultural systems, and so increasing biodiversity further would not require large changes to this style of production (Altieri *et al.* 2012). Increased agrobiodiversity has been found to positively impact dietary outcomes of smallholder farmer households and increase revenue streams (Jones 2017) and is often thought to increase ecosystem services, subsequently reducing pest-pressure and reliance on agrochemicals, improving soil health and conservation, raising yields, and increasing both water-use efficiency and nutrient cycling (Altieri *et al.* 2012, Lin 2011). However, the relationship between increased agrobiodiversity and ecosystem services is not always inherently clear (Wood *et al.* 2015). Jackson et al. (2007) argues that despite the case for deploying agrobiodiversity conservation measures because of the current lack of scientific understanding of the totality of ecosystem services provided by agrobiodiversity, a much stronger case can be made for conservation if there is definitive information on its ecosystem services. This again emphasises the point that, while there may be benefits to practices commonly viewed as examples of SI, these practices must be supported by scientific evidence.

1.4 Examples of successful SI projects in SSA

1.4.1 Intercropping

A number of studies have demonstrated the benefits of intercropping for smallholder farming operations, of which the primary option for many African subsistence farmers is a maize/bean (*Phaseolus vulgaris* L.) polyculture (Tsubo and Walker 2002). Such intercropped plots may yield up to 30% more than monocultured plots due to several underlying mechanisms including reduced insect abundance and disease incidence, and increased total radiation interception and lateral root density (Zhang *et al.* 2014a). The use of crops with different root architecture, such as in maize-bean and maize-bean-squash (*Cucurbita pepo* L.) intercropping, results in larger soil exploration by roots and spatial resource partitioning (Postma and Lynch 2012). It has also been demonstrated that nitrate (NO_3^-) uptake in such intercropped plantings can increase by up to 7% more than in monoculture plantings, direct competition for immobile soil nutrients is negligible, competition for light can increase cereal growth significantly, and that overall these intercropped plantings will generally over yield on poor soils (Postma and Lynch 2012). Furthermore, in terms of Land Equivalent Ratios (LER), intercropped plantings may obtain values greater than one, indicating a negative yield gap in relation to monocultured plots (van Noordwijk and Brussaard 2014), greatly improving food security in vulnerable regions (Rusinamhodzi *et al.* 2012). Intercropping of cash crops, such as bananas (*Musa* spp. L) and coffee (*Coffea arabica* L.), has also proved to significantly raise LER values and farmer income. In this instance the banana plants both provide shade, reduce the incidence of coffee leaf rust, and increase plot revenue in excess of 50% (Campbell *et al.* 2014). Research into integrated crop and livestock systems, such as intercropped soybean (*Glycine max* (L.) Merr.) and palisade grass (*Urochloa brizantha* [Hochst. ex A.Rich.] R.Webster), has been shown to increase cereal production and recover degraded pastures without requiring the expansion of agricultural lands (Crusciol *et al.* 2014). This style of intercropping increased the economic LER of the land by a factor of 1.6, as compared to soybean monocultures (Crusciol *et al.* 2014). Additionally, by allowing the livestock to graze the soybean residues and palisade grass for 200 days after the soybean harvest, farmers were able to increase their annual income by up to 60%. Further investigation into various combinations of intercropping strategies may produce systems with even greater LER values and economic increases for small holder farmers (Crusciol *et al.* 2014).

1.4.2 System of Rice Intensification

The SRI is a system of rice (*Oryza* spp. L.) production developed in Madagascar in the mid 1980's, and is now practiced in more than 50 different countries which boosts yields through a number of mechanisms (Uphoff 2014). Wider spacing reduces seed requirements by up to 90% and allows roots and canopies the freedom for more vigorous growth, irrigation requirements are reduced by 25 to 50% through the use of judicious irrigation practices and water harvesting, use of agrochemicals is reduced through improved plant health, and the use of synthetic fertilisers is reduced through improved nutrient cycling (Uphoff 2014). This has improved yields in Madagascar from 2 t ha^{-1} to 8 t ha^{-1}, and has allowed farmers to produce more productive phenotypes from both improved and unimproved rice genotypes. Although SRI was initially a more labour-intensive production system, when compared to traditional paddy production, labour-intensity declined as the farmers increased their proficiency through growing experience (Uphoff 2014). This further emphasises the importance of skills transfer in implementing SI in SSA.

1.4.3 Transgenic crop improvement

Transgenic crop improvements are rarely associated with smallholder farmers, due to the economic costs associated with their development. However, mounting evidence suggests that this technology may be a necessity for smallholder farmers in the future (Pretty and Bharucha 2014). Traditional breeding is a slow and laborious process and, as renewed interest in orphan varieties of legumes and cereals grows, transgenic technology may be the key to making these species commercially viable (Pretty and Bharucha 2014). Transgenic technology can also be used to speed up the improvement of many annual crop species. Transgenic crops that reduce reliance on pesticides (e.g. Bt Brinjal [*Solanum melongena* L.]) have shown promising results for smallholder agriculturalists elsewhere in the world (Padmanaban 2009). Similarly biofortified transgenic crops such as Golden Rice show potential for reducing malnutrition and vitamin deficiencies in rural and impoverished communities, thus addressing the ideals of food security (Potrykus 2012). It is important to note that while transgenic crops require significant financial investment for their development, the long-term gains from their development are far greater (Potrykus 2012). Both Bt Brinjal and Golden Rice are however case studies for the antiscientific agenda that stifles transgenic technology (Lee and Krimsky 2016, Ritika 2017). As stated by numerous authors, sustainable intensification cannot judge a practice or technology on its acceptability but rather by its scientific merit (Pretty *et al.* 2011).

1.4.4 Mulching

Not all SI practices require advanced technological innovation. Mulching, the age-old agronomic practice of applying a layer of material onto the soil surface to function as a permanent or semi-permanent protective cover, confers several beneficial effects that align with the premises of SI. These beneficial effects include reductions in water and soil loss rates, overland flow generation rates and velocity, sediment and nutrient concentrations in runoff, and topsoil temperature fluctuations, increases in infiltration capacity, water intake and storage, and activity of soil fauna such as earthworms, and positive effects on soil nutrients, soil structure and organic matter content (Prosdocimi *et al.* 2016). A wide variety of materials, such as vegetation residues, biological geotextiles, gravel and crushed stone, are used as mulches, although the extent of these impacts is dependent on a number of factors (Chalker-Scott 2007).

In a comprehensive review of the impacts of mulching, 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 create unnaturally dry soils in the long term by limiting recharge and subsequently increasing runoff and erosion. 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 versions, all mulches are better than bare soil (Chalker-Scott 2007).

Mulches provide soils with protection from various types of erosion, with even comparatively thin layers of organic mulch such has a 0.015 m 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, it was noted that mulching is a preventative approach and was found to have little impact on reversing compaction when applied retrospectively.

Mulches have largely 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 evapotranspirative cooling (Chalker-Scott 2007). In both instances the trade-offs for increased water demand must be calculated against the other positive effects of the mulches.

Living and organic mulches are 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 nutrient leaching and runoff losses 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).

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.

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, although pest incidence should still be monitored as it remains a possibility. 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 (Chalker-Scott 2007). 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.

1.5 Smallholder irrigation schemes as a form of sustainable intensification

Overall, SSA is largely dependent on rain-fed agriculture, accounting for 97% of all cropland, leaving the region vulnerable to the negative impacts associated with high rainfall variability as a result of anthropogenic climate change (Amjath-Babu *et al.* 2016, Calzadilla *et al.* 2013, Lim Kam Sian *et al.* 2021). Despite smallholder irrigation being promoted extensively across the region, both the rate of investment and impact have been lower than initially expected (Calzadilla *et al.* 2013). This has been attributed to a number of factors including poor market access, low incentives for agricultural intensification, limited finance opportunities for smallholder farmers, and lack of knowledge transfer regarding the positive effects of irrigation investment (Calzadilla *et al.* 2013). Costs of small-scale irrigation technology also remain higher in SSA than in other comparable regions of the developing world (Calzadilla *et al.* 2013). However, in areas where smallholder farmers are receiving adequate assistance, the investment in small-scale irrigation technologies has proved to be profitable (Giordano and de Fraiture 2014).

There are several indirect social benefits associated with increased investment in small-scale irrigation (Collier and Dercon 2014). Firstly, farmers are able to increase yields of both staple and high-value crops, improving both household food sovereignty and income (Takeshima and Yamauchi 2012). This increased productivity could result in positive economic impacts, including 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 agrochemical inputs and improved agricultural management strategies (Takeshima and Yamauchi 2012). The cumulative effect of these benefits can lead to communities of smallholder farmers 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). Direct economic benefits may still arguably be less than those achieved by industrial agriculture. Despite this, Christiaensen *et al.* (2011) reports that in low-income and resource-rich countries, smallholder 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 less than $1 per day which, in the South African context, stands at 23% of the population (SALDRU 2020).

The success of small-scale irrigation schemes has been mixed and a significant number are reported to have been underutilised 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).

1.5.1 Policy Changes

Smallholder irrigation has remained largely unnoticed by researchers, policy makers, and donors, is rarely included in official statistics and public policies, and remains largely unregulated and uncoordinated as a result (Giordano and de Fraiture 2014, Namara *et al.* 2010). This fragmented approach has led to 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 smallholder farmers and pastoral communities (Giordano and de Fraiture 2014, Namara *et al.* 2010). This would reduce the negative impacts associated with the currently uncoordinated system approach prevalent in SSA. Namara *et al.* (2010) add 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 and sustainable distribution of water must be ensured not only within the irrigation scheme itself, but also within the catchment that the irrigation scheme draws its water resources from.

1.5.2 Importance of catchment-scale water use efficiency

Currently much of the investment by smallholder farmers in SSA into irrigation equipment has been made by individual farmers, on the advice of local irrigation equipment suppliers (Giordano and de Fraiture 2014). Without the influence of an irrigation scheme or water user association, these individual farmers make water-withdrawal decisions automatically with the aim of maximising their own production (Wichelns 2014). They are therefore 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 smallholder farmers in China, similar trends are expected in SSA due to the similarities between these agrarian societies. Thus, it is logically possible that the expansion of small-scale irrigation systems in SSA 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 Jevon's Paradox or the 'Rebound Effect', which describes the 'behavioural response of increasing [energy] consumption as gains in the efficiency of consumption reduce the per unit price' (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). Jevon's Paradox can result in usage increases of 5-65%, which may place increased pressure on limited water resources (Hertwich 2005). Pfeiffer and Lin (2014) reported a rebound effect of over 100% over the 10 year period, in which an increase in irrigation efficiency resulted in a shift towards more efficient nozzles in the centre-pivot systems investigated. 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 maize, lucerne (*Medicago sativa* L.), 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 unproductive 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).

1.5.3 Access to technology

One of the largest criticisms for the failure of the Green Revolution to increase agricultural production in SSA was the unsuitability of many of the imported technologies to fit within the context of the smallholder farmer. In the 1980's 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 smallholder 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 smallholder farmers, and generated a net income of $150 million per annum for these smallholder 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) reported 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 SSA than in other comparable regions of the developing world, in areas where smallholder 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). Relative operational costs of small-scale irrigation systems, as well as economic losses such as leached fertilisers caused by mismanaged irrigation, can also be reduced through increased irrigation efficiency.

Several tools have already been developed to assist smallholder irrigators better schedule their irrigation to improve efficiency, such as the WFD (Stirzaker 2003) and Chameleon soil water sensor (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 Chameleon soil moisture sensor 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 Chameleon sensor arrays give a picture 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. Stirzaker et al. (2017) reported that small-scale irrigators have used a combination of the Chameleon soil water sensors and WFDs successfully, increasing irrigation efficiency and reducing uneconomic losses such as leaching.

One other avenue to provide irrigators with the information to make informed irrigation-management decisions in open-access, decision-support software. One such example is the South African Irrigation Water Quality Guidelines Decision Support System (SAWQI DSS), a multi-tiered open-access software that allows the user to assess either the fitness-for-use of, or water quality requirement for, irrigation water. The software performs analyses based on the following suitability indicators (du Plessis *et al.* 2017):

- 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 NPK 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 South African Water Quality Guidelines, 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. The software is user-friendly, requiring only a basic understanding of water-quality analyses in order to input data to generate reports. For both tiers the SAWQI DSS provides reports with a four-colour fitness-for-use ranking, simplifying interpretation for all users.

1.5.4 Access to finance and markets

Finance remains a major constraint inhibiting technology investment by smallholder farmers in SSA, particularly in resource-poor communities. Giordano and de Fraiture (2014) reported that in patriarchal societies, such as those in SSA, 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-scale 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 the rate of irrigation investment in SSA (Giordano and de Fraiture 2014).

Improving market-access is one other method for increasing investment into small-scale irrigation, by presenting more economically viable opportunities for smallholder farmers. Aggregation of smallholder 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 SSA countries to increase the number of smallholder farmers involved in the production of high-value commodities (Namara *et al.* 2010).

A third economic aspect that must be considered with regards to irrigation investment is the trading of water rights. In a study performed by Zhang *et al.* (2014b), looking at the economics and practicalities of trading water rights by smallholder farmers in China, it was found that the lack of communication between local government and farmers severely hampered the effective trading of water rights. Only 27.9% of farmers were aware that it was possible to swap water rights within the community and only 10.8% knew that they were allowed to buy or sell water against payment (Zhang *et al.* 2014b). Furthermore, only 1.9% of the farmers knew of the maximum price that could be charged for trading water with the rest of the farmers who actively traded water, setting prices far below this maximum value. Farmers were also reluctant to trade water rights with other communities within the catchment scheme due to a level of distrust (Zhang *et al.* 2014b). The study concluded that in order to improve the economic efficiency of the trading of water rights, several policy changes needed to be made. These policy changes were focussed on empowering the farmers with sufficient knowledge regarding the legalities of trading their water rights, creating formal markets through which water rights can be traded, transaction costs related to water rights reduced, and existing restrictions on water prices removed (Zhang *et al.* 2014b). By equipping the farmers with this knowledge about their assets and facilitating water exchange markets at a community and catchment-scheme level a more efficient irrigation scheme would be created.

1.6 The Agri-parks initiative as a sustainable intensification programme

1.6.1 Overview

The Agri-parks concept is said to be drawn from a combination of "existing models both, locally and abroad, including educational/experimental farms, collective farming, farmer-incubator projects, agri-clusters, eco-villages, and urban-edge allotments and market gardens" (DRDLR 2020). The Agri-parks will exist on both public and private lands and serve as transition zones between urban and agricultural uses (DRDLR 2020). According to a 2016 DRDLR presentation the programme is guided by 10 principles (DRDLR 2016a):

1. Establishment of one Agri-park in each of the 44 district municipalities
2. Agri-parks should be farmer controlled
3. Agri-parks should be the catalyst around which rural industrialisation will takes place
4. Agri-parks should be supported by government for 10 years to ensure economic sustainability
5. Agri-parks should aim to strengthen partnership between government and private sector stakeholders to ensure increased access to basic services and production on the one hand, while developing existing and create new markets to strengthen and expand value-chains in-line with the Agricultural Policy Action Plan
6. Agri-parks should, where possible, maximise benefit to existing state land with agricultural potential in the provinces
7. Agri-parks should maximise access to markets to all farmers, with a bias to emerging farmers and rural communities
8. Agri-parks should maximise the use of high value agricultural land
9. Agri-parks should maximise use of existing agro-processing, bulk and logistics infrastructure, including water, energy and roads
10. Agri-parks should support growing-towns and revitalisation of rural towns in terms of high economic growth, high population growth over past 10 years, and promotion of rural urban linkages

These principles form the basis for the programme's strategic objectives to (DRDLR 2020):

- Kick start the 'Rural Economic Transformation' in all 44 of South Africa's district municipalities (Figure 1-1)
- Promote growth of the smallholder sector by contributing to the 300 000 new small-scale producers, as well as to the 145 000 new jobs in agro-processing by the year 2020 as laid out in the NDP
- Promote the skills of, and support to, smallholder farmers through the provision of capacity building, mentorship, farm infrastructure, extension services, production inputs and mechanization inputs
- Enable producer ownership of the majority of Agri-parks equity (70%), with the state and commercial interests holding minority shares (30%)
- Bring under-utilised land (with particular focus on communal areas and land reform projects) into full production over the next three years, and expand irrigated agriculture
- Contribute to achievement of the NDP's 'inclusive rural economy' and target of 1 million jobs created in agriculture sector through creating higher demand for raw agricultural produce, primary and ancillary inputs, as well as generating increased downstream economic activities in the sector

The DRDLR is to achieve these objectives by providing both 'networks of contacts between producers, markets, and processors' and 'the physical infrastructure required for the transforming industries' (DRDLR 2020). The primary focus of the Agri-parks is then the processing of agricultural products through 'linkages between the parks and surrounding agricultural land' (DRDLR 2020). The key to this is the use of 'commodity and value chain analyses and mapping exercises' to focus each Agri-park on the production of 'specific prioritised commodities that have the highest prospect of succeeding in their region' (DRDLR 2016b). According to the 2015/2016 Department of Agriculture, Forestry and Fisheries (DAFF) annual report, at the time the Agri-parks programme aimed to generate 100 000 jobs over a three year period (DAFF 2016). The approach was to 'include the selection and training of smallholder farmers, as well as selecting farms per province for the placement, incubation and training of unemployed agricultural graduates and other agro-entrepreneurs', through a model with a ‘strong social mobilisation component so that black farmers and agri-business entrepreneurs are actively mobilised and organised to support this initiative’ (DRDLR 2020).

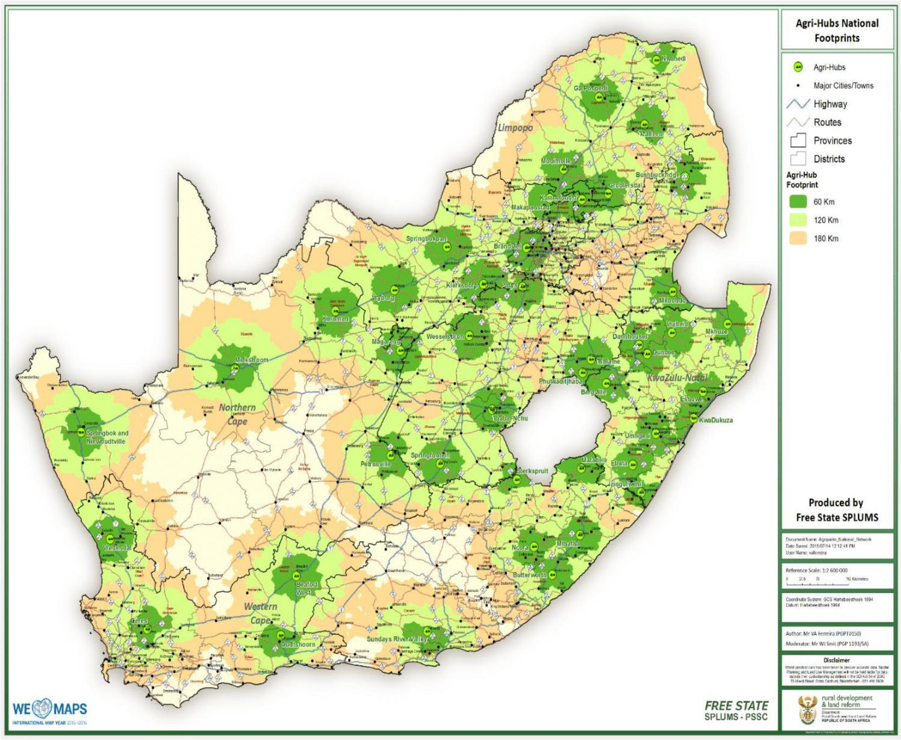

Figure 1-1: National Agri-park Network (DRDLR 2017b)

An Agri-park in defined as ‘a networked innovation system of agro-production, processing, logistics, marketing, training and extension services, located in a district municipality’ which ‘enables a market-driven combination and integration of various agricultural activities and rural transformation services’ (DRDLR 2016a). The model consists of three interrelated components as shown in Figure 1-2, although both the definitions and objectives of these components lack clarity and there seems to be much overlap in the services they provide. It is possible that such overlaps are due to the differences in scale that the services are provided at, however this not mentioned in any of the available literature. The three components are described in DRDLR (2017b) as follows (Edited only where absolutely necessary for clarity and grammatical correctness):

1) The Farmer Production Support Unit (FPSU) - a rural smallholder farmer outreach and capacity-building unit for the facilitation and provision of:
   - Agricultural inputs such as seed, fertilisers, herbicides, pesticides, and fuel
   - Extension support and training through the use of universities, agricultural graduates, and the National Rural Youth Service Corps
   - Mechanisation support services such as ploughing, spraying, and harvesting, and machinery and servicing workshop facilities
   - Local logistics support such as delivery of agricultural inputs and collection and transportation of primary produce and secondary products to local markets
   - Weighing, sorting, processing, milling, packaging, and auctioning facilities for local markets
   - Small business development and training
   - Financial services such as market information on commodity prices and banking facilities
2) The Agri-hub - a production, equipment hire, processing, packaging, logistics, innovation, and training unit which supports a number of FPSUs by providing:
   - Storage and warehousing facilities such as cold storage, dehydrators and silos
   - Weighing facilities
   - Agri-processing facilities such as mills and abattoirs
   - Enterprise development areas that lease space to high intensity start-up industries that can benefit from the inputs of outputs of the Agri-hub, such as piggeries, tunnel grow crops, and bio-gas production
   - Large scale nurseries to supply FPSUs
   - Packaging facilities for national and international markets
   - Logistics hubs for collection of goods from the FPSUs
   - Transport service workshops and spare parts for larger maintenance tasks of Agri-hub and FPSU equipment
   - Agricultural technology demonstration parks to train farmers in the Agri-park catchment area
   - Soil testing laboratories
   - Accommodation for extension training and capacity building programmes

- Housing and recreational facilities for workers and Agri-hub staff
- Business, marketing and banking facilities

3) The Rural Urban Market Centre (RUMC) located on the periphery of large urban areas which will provide support to multiple Agri-parks by:
    - Linking and contracting rural, urban and international markets by providing logistical and transportation support for collection of produce from FPSUs or Agri-hubs
    - Acting as a holding-facility with large warehousing and cold storage facilities, releasing produce to urban markets based on seasonal trends to enable market management
    - Providing market intelligence and information feedback, to the Agri-hubs and FPSUs, using latest Information and communication technologies and assisting farmers in managing contracts

On paper, the Agri-parks initiative presents itself as the model SI project by making use of existing agricultural land, aggregating smallholder farmers, providing support across all aspects of the production chain, and prioritising assistance historically disadvantaged farmers in marginalised communities. In recent years, there has been little mention of the developments of the Agri-parks in the DRDLR's annual reports and no feasibility studies of the planned or current water uses by Agri-parks have been available (DRDLR 2015, 2016b, 2017a, 2018, 2019).

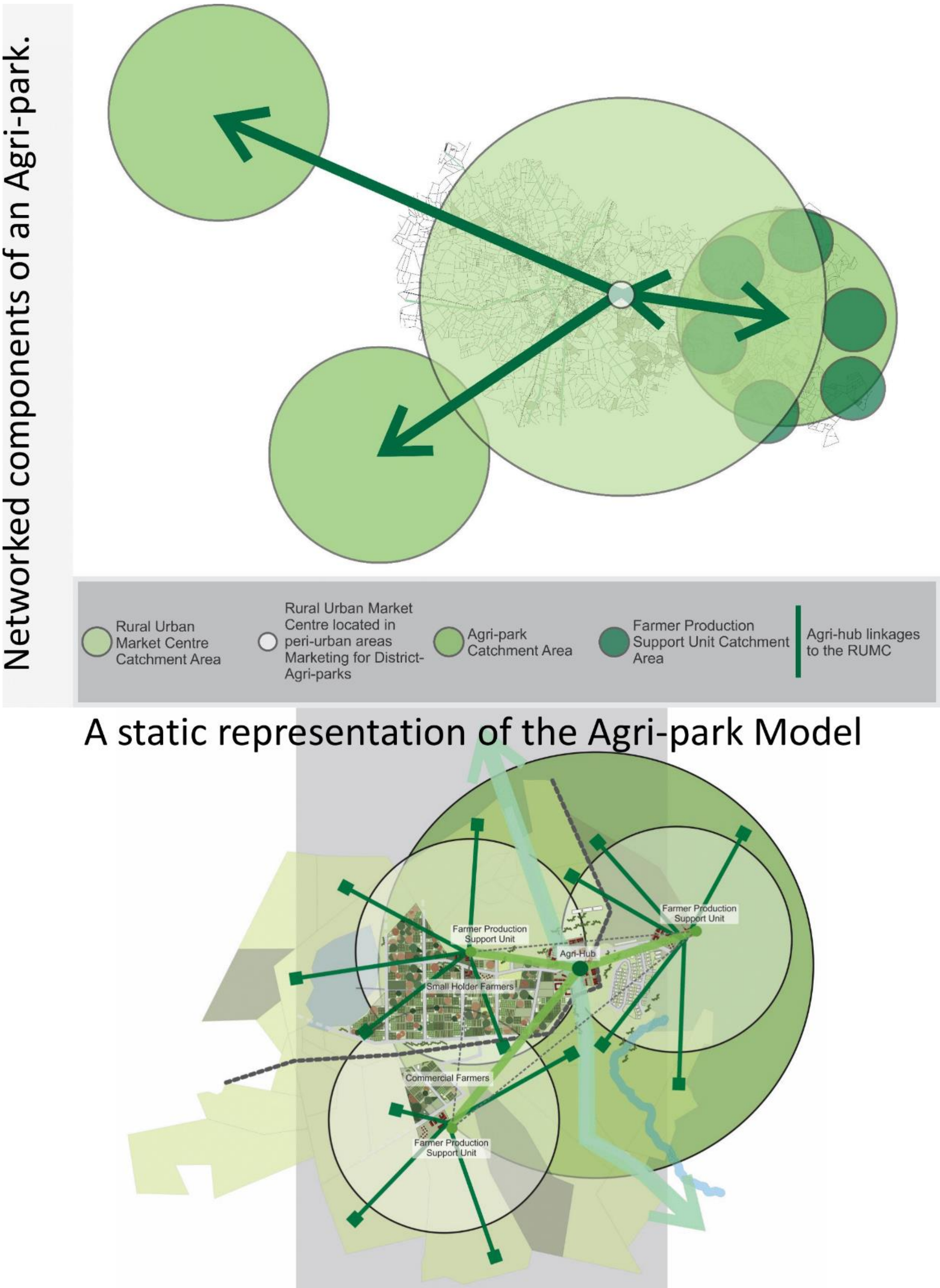

Figure 1-2: The Agri-parks Model (DRDLR 2017b)

Chapter 2: The Agri-parks initiative in the City of Tshwane

2.1 Introduction and overview

Due to the discrepancies between the literature on the Agri-parks and the current reality of the Agri-park sites within the City of Tshwane Metropolitan Municipality (CoT) discussed in this chapter, the chapter does not follow the traditional layout. Instead, it was decided that for the sake of clarity a better approach would be to split the chapter into first providing an overview of the discrepancies between literature and reality that were noted early on. This is followed by an overview of the sites including site history, descriptions of the farmers as case studies, analyses of irrigation water quality as the first step towards quantifying irrigation water resources, and closes with general discussions and conclusions of the project. This chapter also refers to literature that was either not known or available at the time of the literature review, or not considered relevant for the scope of the literature review, but is now considered necessary to provide context.

According to CoT officials, the CoT hosts four Agri-parks at Rooiwal, Soshanguve, Mamelodi, and The Innovation Hub. This is a substantial deviation from the original concept of one Agri-park per district municipality, with all four sites found to be considerably smaller than the Department of Rural Development and Land Reform's (DRDLR) model (Figure 1-1). To date none of the available literature published by national governmental departments refer to any Agri-parks projects in the CoT and, as CoT is considered a metropolitan municipality and not a district municipality, this is in line with the first of the Agri-parks guiding principles of 45 Agri-parks being establishment in the 44 district municipalities (DRDLR 2016a). Literature from national government indicates that the sites identified in Gauteng were at Rietkuil in the Emfuleni Local Municipality of the Sedibeng District Municipality, and at Randfontein in the Rand West City Local Municipality of the West Rand District Municipality, in line with the original scope of one Agri-park per district municipality (DRDLR 2016a). No available literature makes reference to any changes to later include metropolitan municipalities, yet later presentations by the Gauteng Department of Agriculture and Rural Development (GDARD) show nine Agri-parks sites for the province, located at (GDARD 2017):

1) Tarlton in the Mogale City Local Municipality (West Rand District Municipality)
2) Bekkersdal in the Rand West City Local Municipality (West Rand District Municipality)
3) Merafong in the Merafong City Local Municipality (West Rand District Municipality)
4) Sebokeng in the Emfuleni Local Municipality of the (Sedibeng District Municipality)
5) Eikenhof in the Midvaal Local Municipality of the (Sedibeng District Municipality)
6) Wattville in the City of Ekurhuleni Metropolitan Municipality
7) The Innovation Hub in the CoT Metropolitan Municipality
8) Rooiwal in the CoT Metropolitan Municipality
9) Soshanguve in the CoT Metropolitan Municipality

In presentations by GDARD the terms Agri-hub and Agri-park are used seemingly interchangeably (GDARD 2017), however this is in contradiction to the original model where an Agri-hub is a component of an Agri-park (DRDLR 2017b). To further add to the confusion, a municipal spatial development framework commissioned by DRDLR for the Sedibeng District Municipality lists the Rietkuil Agri-hub and Sebokeng Agri-park as two separate entities and makes specific reference to the Sebokeng Agri-park having 15 Farmer Production Support Units (FPSU) (Sedibeng District Municipality 2019). This is again in contradiction to the original model where FPSUs supply one or more Agri-hubs within an Agri-park (DRDLR 2017b).

A later report by the National Council of Provinces Select Committee on Land Reform, Environment, Mineral Resources and Energy (NCOP LREMRE) states that 'even though the announcement of the Agri-park development in 2015 came with a Presidential commitment of R2 billion a year over 10 year', a presentation by Department of Agriculture, Land Reform and Rural Development (DALRRD) focused on budget constraints and that of the 44 Agri-parks only five have been prioritised for completion (NCOP LREMRE 2019). The report continues stating that only 27 FPSUs would be made fully operational by 31 March 2020 at the latest (NCOP LREMRE 2019). None of the five Agri-parks prioritised for completion are located in Gauteng, and neither of the two FPSUs in Gauteng that were set to be operational at the end of March 2020 (Tarlton and Bekkerdals) are located in CoT, although the committee did visit the Innovation Hub and RandWest Agri-parks (NCOP LREMRE 2019). To further add to the discrepancies in terminology, the NCOP LREMRE refers to the Innovation Hub and RandWest sites interchangeably as Agri-parks and FPSUs, but specifically notes that DALRRD is 'now focusing on FPSUs without making mention of the Agri-hubs and RUMC originally required to complete the support infrastructure' (NCOP LREMRE 2019). The NCOP LREMRE report gives a list of what DALRRD considers the minimum requirements for a functioning FPSU (Table 2-1), which was not included in the original model. The report states that, following a presentation by GDARD, it was clear that there were 'differences in emphasis on key aspects of the development' with GDARD highlighting that the FSPUs are designed for primary collection, some storage and processing for the local market, and extension services including mechanization (NCOP LREMRE 2019). However, it is not clear at 'what stage of project implementation was [the] change made in National FPSU design and operational criteria' (NCOP LREMRE 2019). Despite this, both CoT and GDARD officials insist that the sites at Rooiwal, Soshanguve, Mamelodi, and The Innovation Hub are all independent Agri-parks, and GDARD presentations show that all Agri-parks should be fully operational by the end of the 2017 financial year (Figure 2-1).

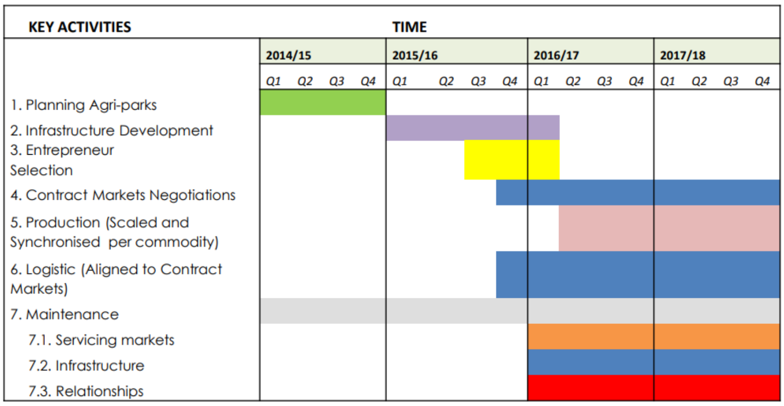

Figure 2-1: Generic project plan for all Agri-parks (GDARD 2017)

Table 2-1: The DALRRD minimum requirements for a functioning FPSU (NCOP LREMRE 2019)

Category	Minimum requirements
Administrative Infrastructure	• Administrative offices aligned to the Human Resource contingent • Ablution facilities • Accommodation for FPSU Manager
Security infrastructure	• Fencing • Security Office • Security Lighting
Human Resources	• FPSU Manager • Extension Officer(s) • Veterinary support • Soil Specialist(s) • General Workers (facilities and stores) • Qualified Mechanic (2x apprentices) • Caretaker/Groundsmen/Artisan • Security Officers • Secondary Coop Manager and support staff
Mechanisation (in support of FPSU catchment commodities)	• Tractors • Planters and or required equipment to support farmers • Repair and Maintenance (Workshop Tools)
Production Infrastructure (dependent on commodities supported from the FPSU)	• Pack-house • Cold storage • Storerooms • Dipping and Handling Facilities
Services infrastructure	• Water • Sanitation • Energy/Electricity • Access Roads • Paving
Office furniture, equipment and supplies, communication infrastructure	• Tables • Chairs • Tables
Production inputs (linked to production plans)	• Seed • Fertilizer • Tools

2.2 Site descriptions and histories

In order to determine the progress of the Agri-parks project in CoT, the research team made contact with CoT officials from the municipality's Department of Agriculture and Environmental Management during the second quarter of 2018. From information received from CoT officials the Rooiwal, Soshanguve, and Mamelodi Agri-parks had been remodelled from existing agricultural projects, while the Innovation Hub Agri-park is a new project constructed in 2016. At the time the Rooiwal and Soshanguve Agri-parks had a combination of plastic multi-span and shade-net tunnels as well as open fields under irrigation, while the Mamelodi Agri-park had only open field irrigation and the Innovation Hub Agri-park only drip irrigation within multi-span tunnels. For this reason, the Rooiwal and Soshanguve Agri-parks were selected as sites for further investigation for WRC project K5/2823//4 under which this dissertation falls (le Roux *et al.* 2022).

A site visit to the Rooiwal and Soshanguve Agri-parks was conducted on 25 July 2018 with CoT officials. The CoT officials were unable to provide literature on the history of the Rooiwal and Soshanguve sites, and in order to construct a timeline of historical agricultural and developmental history of the two sites historical images available through Google Earth were analysed. Observations made during the initial site visit on 25 July 2018 and from the analysis of the historical Google Earth imagery are detailed and discussed below.

2.2.1 The Rooiwal Agripark

At 34 ha in size, the Rooiwal Agri-park is the largest in the CoT. The Agri-park is situated at 25°33'11.56"S 28°13'56.44"E and 1197 meters above sea level, lies 700 m west of the Apies River, and is bordered by the Rooiwal Waste Water Works to the south and the old Rooiwal Power Station to the east (Figure 2-2). Approximately 400 m north of the Agri-park is an old ash tailings dam belonging to the power station, and to the west lie fallow agricultural fields. Historical images from Google Earth show that agricultural activity on the site began between the second quarter of 2008 and third quarter of 2011 (Appendix 2.1). On-going construction on 13-07-2011, as seen in Figure 2-3, suggests that agricultural activity most likely began in the second quarter of 2011, with the establishment of nine 6 x 30 m chicken-houses (total area: 0.16 ha), ten 10 x 30 m tunnel units (total area: 0.30 ha), three shade-houses (total area: 0.34 ha), and 0.66 ha of ploughed open field. Between 2011 and the launch of the Agri-Parks initiative in 2015, historical imagery from Google Earth shows an additional chicken-house was constructed between 24-10-2011 and 03-03-2012, while the area under open field cultivation fluctuated between 2.73 and 17.5 ha (Appendix 2.1). Between 2013 and 2015, a small 70 m^2 she was built and in 2016 a multi-span tunnel covering 0.55 ha was erected (Appendix 2.1).

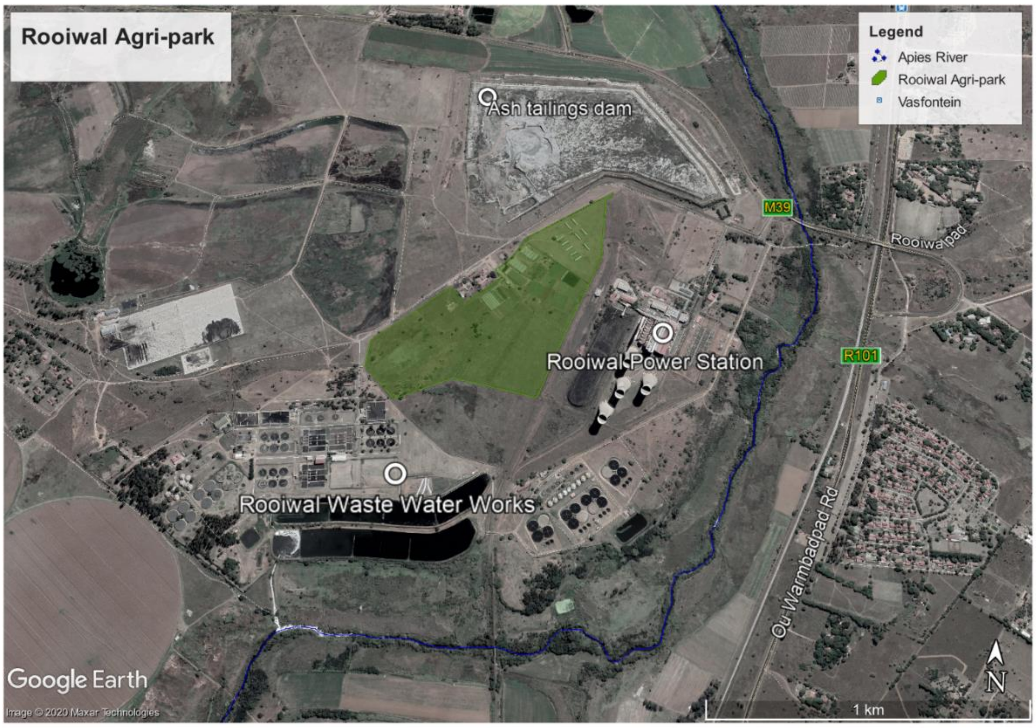

Figure 2-2: Locality map of the Rooiwal Agri-park, City of Tshwane Municipality

At the time of the research group's first site visit on 25 July 2018 all above-mentioned infrastructure was still in place, albeit in various states of disrepair. The two boilers to heat the original tunnel units were dysfunctional (Figure 2-4), sections of the tunnel coverings were missing or replaced with shade net, and cultivation within all tunnels and shade-houses was directly into the ground. This goes against the aim behind the usage of tunnels and shade-houses to create a modified microclimate to reduce the impacts of environmental stresses, and where crops are typically grown in containers of growth mediums and nutrients strictly controlled and supplied directly to the plants, in order to ensure increased production year-round. Thus, despite functioning infrastructure for a fertigation system, production was more akin to open-field cultivation than typical tunnel production (Figure 2-5). Only approximately 6 ha (20%) of the Rooiwal Agri-park's open land was under cultivation on 2018-03-04 (Figure 2-6). At the time, the 70 m^2 shed contained a small cold storage unit and was used as a pack house.

Figure 2-3: Historical Google Earth image of the Rooiwal Agri-park site dated 2011-07-13

Figure 2-4 : Dysfunctional tunnel boiler unit

Figure 2-5: Tunnel and shade-house cultivation at the Rooiwal Agri-park

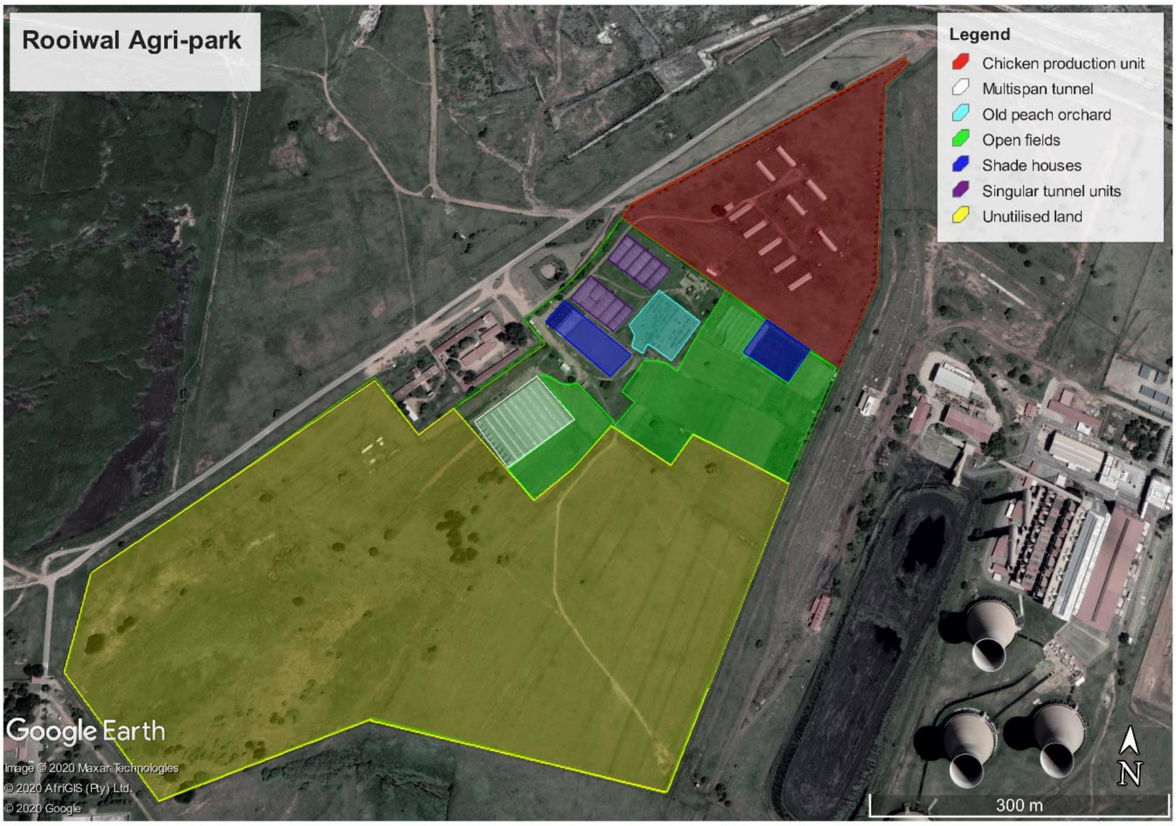

Figure 2-6: Land usage of the Rooiwal Agri-park as of 2018-03-04

In its current form the Rooiwal Agri-park hosts few of the features of the Agri-parks model described in DRDLR (2017b) and the site is solely dedicated to primary agricultural production. From the descriptions provided in DRDLR (2017b), the smallest unit of the Agri-parks model is the FPSU. The FPSU is described as a "rural smallholder farmer outreach and capacity-building unit for the facilitation and provision of agricultural inputs, extension support and training, mechanisation support services, local logistics support, post-harvest processing services, small business development and training, and financial services. In its current form, the Rooiwal Agri-park has 14 of the 33 minimum requirements for a functioning FPSU (NCOP LREMRE 2019) as presented in Table 2-2.

Table 2-2: Observations of the infrastructure and support services of the Rooiwal Agri-park in comparison to DALRRD minimum requirements for a functioning FPSU (NCOP LREMRE 2019)

Category	Minimum requirements	Notes
Administrative Infrastructure	Administrative offices aligned to the Human Resource contingent	None
	Ablution facilities	Yes, there are ablution facilities on site
	Accommodation for FPSU Manager	On-site accommodation occupied by some of the farmers
Security infrastructure	Fencing	Yes, the site is fenced
	Security Office	Yes, there is a security office at the entrance
	Security Lighting	Security lights at the entrance to the site only
Human Resources	FPSU Manager	None
	Extension Officer(s)	None
	Veterinary support	None
	Soil Specialist(s)	None
	General Workers (facilities and stores)	None
	Qualified Mechanic (2x apprentices)	None
	Caretaker/Groundsmen/Artisan	None
	Security Officers	Yes, there are security officers
	Secondary Coop Manager and support staff	None
Mechanisation	Tractors	No, tractors are brought in by the CoT
	Planters and or required equipment to support farmers	None
	Repair and Maintenance (Workshop Tools)	None
Production Infrastructure	Pack-house	Yes, there is a 70 m^2 shed which is used as a pack-house
	Cold storage	Yes, there is a 70 m^2 shed with cold storage
	Storerooms	None
	Dipping and Handling Facilities	None
Services infrastructure	Water	Yes, the site has access to ground water
	Sanitation	Yes, the site is connected to the municipal sewage line
	Energy/Electricity	Yes, the site is electrified
	Access Roads	Yes, the site has dirt access roads
	Paving	None
Office equipment	Tables	None
	Chairs	None
Production inputs	Seed	Yes, the site receives annual donations of seed
	Fertilizer	Yes, the site receives annual donations of seed
	Tools	No, the tools on site belong to the individual farmers

2.2.2 The Soshanguve Agri-park

The Soshanguve Agri-park is located at 25°27'58.00"S 28°6'27.57"E 1163 meters above sea level in Soshanguve Block KK West (Figure 2-7) and, at 3.58 ha in size, is considerably smaller than the Rooiwal Agri-park. The Agri-park lies 150 m west of the Soutpanspruit and is bordered by a sand-mine and fallow agricultural fields. Approximately 650 m north of the Soshanguve Agri-park is a CoT municipal dumping site. Historical images from Google Earth show that agricultural activity has occurred on the site since at least 2004-03-26 (Figure 2-8) with the presence of seven 10 x 30 m tunnel units (total area of 0.21 ha), a 0.24 ha shade house, 0.34 ha of ploughed open field, and a carport. No historical images of the site exist for the years 2005-2010 but the historical image dated 2011-05-22 (Figure 2-9) shows that no agricultural activity was taking place on the site at this time, with all but the carport and frames of the tunnel units remaining. By 2013-03-29 agricultural activity had resumed with the recovering of the seven existing tunnels, the addition of seven more 10 x 30 m tunnel units (total area of 0.42 ha) and 1.9 ha of ploughed open field (Appendix 2.3). The historical images dated 2015-04-05 shows the addition of the office building and 2015-06-02 the addition of 0.43 ha of shade house (Appendix 2.3).

At the time of the research group's first site visit on 25 July 2018 the Soshanguve Agri-park had 14 10 x 30 m tunnel units (total area of 0.42 ha), 0.24 ha under shade netting, and 1.57 ha of open field under cultivation. Additionally the site had a carport, shipping container used as a storeroom for fertilisers and equipment, a prefabricated cold room, an office building with one office and a kitchen with large stainless steel washing basins and counters. As in the case with Rooiwal, the tunnel units at the Soshanguve Agri-park were in a state of relative disrepair. Sections of the plastic sheeting had been replaced with shade netting, none of the tunnels possessed heating or cooling units, the fertigation infrastructure was non-operational, and all cultivation was directly into the ground. Irrigation water was supplied by one borehole on the site. In its current form the Soshanguve Agri-park hosts few of the features of the Agri-parks model described in DRDLR (2017b) and the site is solely dedicated to primary agricultural production. At the time, the Soshanguve Agri-park has 16 of the 33 minimum requirements for a functioning FPSU (NCOP LREMRE 2019) as presented in Table 2-3.

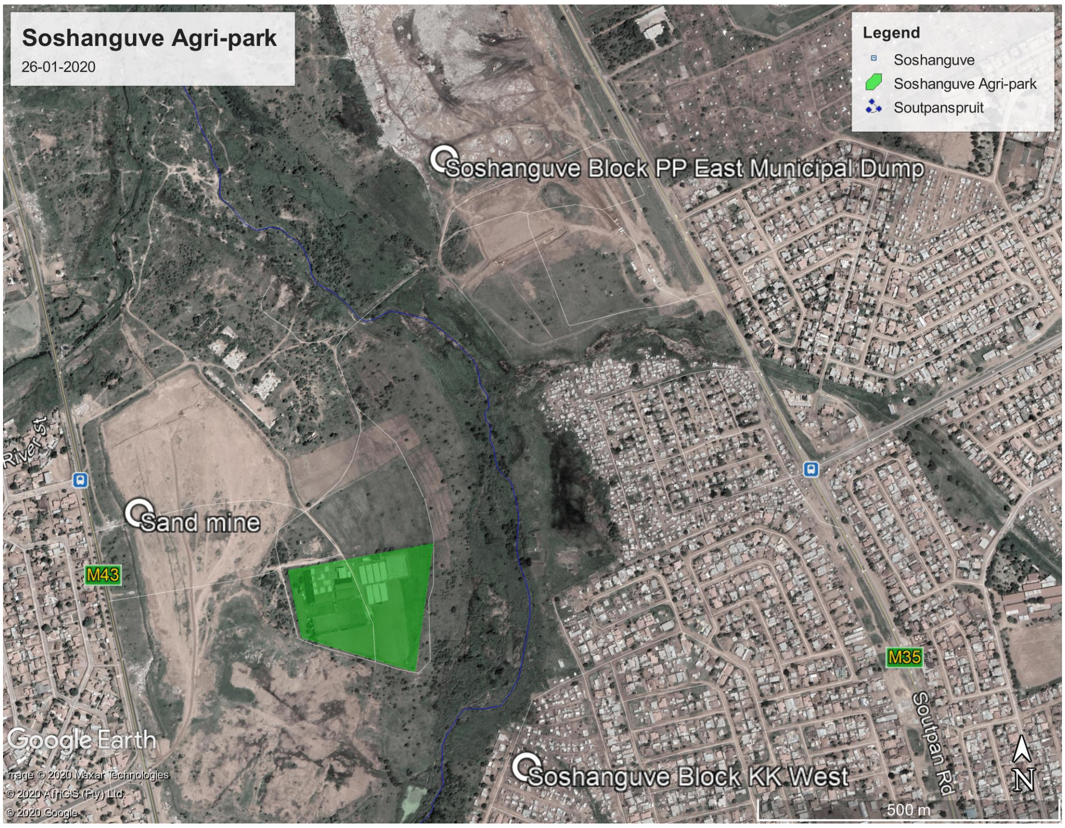

Figure 2-7: Locality map of the Soshanguve Agri-park, City of Tshwane Municipality

Figure 2-8: Google Earth image of the Soshanguve Agri-park site dated 2004-03-26

Figure 2-9: Google Earth image of the Soshanguve Agri-park site dated 2011-05-22

Table 2-3: Observations of the infrastructure and support services of the Soshanguve Agri-park in comparison to DALRRD minimum requirements for a functioning FPSU (NCOP LREMRE 2019)

Category	Minimum requirements	Notes
Administrative Infrastructure	Administrative offices aligned to the Human Resource contingent	None
	Ablution facilities	Yes, there are ablution facilities on site
	Accommodation for FPSU Manager	None
Security infrastructure	Fencing	Yes, the site is fenced
	Security Office	Yes, there is a security office at the entrance
	Security Lighting	Security lights at the entrance to the site only
Human Resources	FPSU Manager	None
	Extension Officer(s)	None
	Veterinary support	None
	Soil Specialist(s)	None
	General Workers (facilities and stores)	None
	Qualified Mechanic (2x apprentices)	None
	Caretaker/Groundsmen/Artisan	None
	Security Officers	Yes, there are security officers
	Secondary Coop Manager and support staff	None
Mechanisation	Tractors	No, tractors are brought in by the CoT or from external contractors by the farmer
	Planters and or required equipment to support farmers	None
	Repair and Maintenance (Workshop Tools)	None
Production Infrastructure	Pack-house	Yes, there is a kitchen area serving as a pack house
	Cold storage	Yes, there is a cold storage unit
	Storerooms	None
	Dipping and Handling Facilities	None
Services infrastructure	Water	Yes, the site has access to ground water
	Sanitation	Yes, the site is connected to the municipal sewage line
	Energy/Electricity	Yes, the site is electrified
	Access Roads	Yes, the site has dirt access roads
	Paving	None
Office equipment	Tables	Yes, there is an office with a desk
	Chairs	Yes, there is an office with chairs
Production inputs	Seed	Yes, the site receives annual donations of seed
	Fertilizer	Yes, the site receives annual donations of seed
	Tools	No, the tools on site belong to the individual farmers

2.3 Farmer case studies

Between 25 July 2018 and 29 January 2019 12 site visits were made to both the Rooiwal and Soshanguve Agri-parks. Site visits were conducted for a number of reasons including to view the sites, meet with the farmers and CoT officials, conduct work for WRC project K5/2823//4 which fell outside the scope of this dissertation, and establish the field trial described in Chapter 3. During these site visits, informal discussions were held with the farmers in order to understand their lived experiences working within the Rooiwal Agri-park. Although it was never the intention of the project to interview the farmers formally, notes were taken during the discussions to inform the decisions made for WRC project K5/2823//4 under which this dissertation fell. At the time, negotiations were in progress between the research team and the WRC reference group regarding the scope of the project, due to the discrepancies between what the Agri-parks were described as in the literature and what was observed on the ground. The small number of farmers was too small of a sample for in-depth interviews, and the data collected would have remained anecdotal.

Although these informal discussions did not follow a preconceived methodology, the research team felt it was important to document the narratives captured during this period as they provide real-world context for how the delays in the progress of the Agri-parks project continue to affect the few small-scale farmers who are already involved in the project. Such biographical case studies are not typically a common practice in the agricultural sciences, but are a tool used in the social sciences[1]. Additionally the farmers were classified according to the typology of smallholder farmers presented by Cousins and Chikazunga (2013) in order to provide insight into the scale of agricultural production currently occurring at the CoT Agri-park. As Cousins (2014) describes, farm size (the size of the land area of a production unit) is dependent on context such as climate, crop choice, available technologies, and labour regime and is not inherently related to the scale of production (the capital intensity of the enterprise). The typology proposed by Cousins and Chikazunga (2013) consists of four categories, subsistence orientated smallholders, market orientated smallholders in loose value chains,

[1] See du Toit and Neves (2009 a, b) for examples.

market-orientated smallholders in tight value chains, and small-scale capitalist farmers described in Table 2-4. Such typologies should not be viewed as unchanging categories and farmers may fluctuate between categories on a regular basis, but are a useful tool to identify general patterns and tendencies and the underlying forces and processes that explain them (Cousins 2014).

Table 2-4: Typology of smallholders in South Africa by Cousins and Chikazunga (2013)

	Subsistence-oriented smallholders	**Market orientated smallholders in loose value chains**	**Market-orientated smallholders in tight value chains**	**Small-scale capitalist farmers**
Objective of production	Household consumption of additional food	Household consumption + cash income	Cash income + some home consumption	Profit
Proportion of marketed output	None or insignificant	50% or >	75% or >	100%
Contribution to household income	Reduces expenditure on food	Variable – from small to significant	Significant	Very significant
Labour	Family	Family + some hired	Family + significant numbers hired	Hired
Mechanisation	Very low	Low	Medium to high	High
Capital intensity	Very low	Low	Medium to high	High
Access to finance	Absent	Some	Significant	Very significant

2.3.1 The Rooiwal Agri-park

Farmer A

Farmer A is an independent subsistence farmer who lives near the site of the Rooiwal Agri-park and has cultivated the land on which the Rooiwal Agri-park is situated on before the project that pre-dated the Agri-parks initiative, as confirmed by CoT officials. Farmer A cultivates a section of the Rooiwal Agri-park approximately 0.25 ha in size, producing vegetables for her own personal consumption such as Swiss chard (*Beta vulgaris* L. subsp. *vulgaris* Flavescens Group), beetroot (*Beta vulgaris* L. subsp. *vulgaris* Conditiva Group), lettuce (*Lactuca sativa* L.), and onions (*Allium cepa* L.). During several of the discussions, Farmer A expressed that they only grew enough vegetables for their family's consumption and that they had no desire to produce more than that. Farmer A relies on the CoT for donations of seed and fertilisers, as they could not afford these.

Farmer A irrigates their plot by hand using a watering can that they fill from the storage tanks connected to one of the site's boreholes. Although the CoT had installed drip irrigation lines on the plot, Farmer A had removed the dripper lines and opted to continue to irrigate by hand so that "[they] could see the water going into the soil". According to Farmer A this was necessary as in their opinion the soil did not hold moisture well and that their crops needed more water than what the drip irrigation could supply. Farmer A schedules irrigation according to how the crops looked. Weed control was done by hand with a hoe, with weed residues dried and burnt on the edge of the plot. Farmer A expressed that managing weeds was a challenge due to the physical demand of the work, but that although they could not afford herbicides they were cautious of their use due to concerns about potential negative impacts on her health.

Under the typology presented by Cousins and Chikazunga (2013) Farmer A would be considered a subsistence-oriented smallholder as their objective of production is solely household consumption with no proportion of marketed output, no use of external labour or mechanisation, very low capital intensity and no access to finance.

Cooperative 1

Cooperative 1 is a family-run cooperative made up of Farmer B, Farmer C, and Farmer D, live on site at the Rooiwal Agri-park. Farmer B holds the lead role within the cooperative, taking charge of management decisions and assigning roles to other members of the cooperative and employees. All three members of Cooperative 1 have attended training workshops at the Agricultural Research Council and throughout the discussions held with the research group expressed that they all felt that it was important to increase their knowledge of agricultural science.

Cooperative 1 cultivates approximately 2.81 ha of open field and 0.26 ha under shade netting, producing a number of vegetable crops including Swiss chard, lettuce, onions, mustard (*Brassica juncea* (L.) Czern), okra (*Abelmoschus esculentus* (L.) Moench), kale (*Brassica oleracea* L. Acephala Group), green beans (*Phaseolus coccineus* L.), and peppers (*Capsicum annuum* L. Grossum Group). Cooperative 1 receive annual donations of various vegetable seeds from the CoT, but buy in additional seed and vegetatively propagate choumoellier (a cultivar of kale which produces suckers) to meet their needs.

Along with the seed donations, Cooperative 1 also receives annual donations of fertiliser, typically in the form of bags of 2:3:2 (30). According to Farmer C, the quantities of fertilisers the farmers have received from CoT has been highly variable. Farmer C expressed that the cost of buying synthetic fertilisers was prohibitively high for the family, however in an effort to increase soil fertility the family produced compost on site largely from the adjacent poultry unit. Farmer C expressed considerable pride when talking about the compost operation, constantly mentioning his desire to “provide nutrients through nature’s way”. However, during the site visits the compost pile was consistently observed to be dried out which likely reduced biological activity necessary for effective composting. Cooperative 1 did not conduct soil fertility tests, due to financial constraints.

Cooperative 1 made use of a mix of dragline sprinklers and drip irrigation, connected to storage tanks supplied by the three boreholes on site. Although the CoT was responsible for maintaining and upgrading the site’s infrastructure, Cooperative 1 collectively expressed frustrations regarding the maintenance of the boreholes and cited several examples of delays in the repair of essential components of the site’s irrigation system including borehole pumps. According to Cooperative 1, a major challenge at the site was insufficient irrigation water from the three boreholes. In addition to pump breakdowns, the family stated that the output of the original borehole (which predated the Agri-parks project) had decreased significantly following the installation of the third borehole by CoT for the Agri-parks project. In order to ensure equitable distribution of irrigation water resources, Cooperative 1 had set up an agreement between themselves, Cooperative 2, and Farmer E to irrigate at different times of the day, with Cooperative 1 irrigating only during the mornings from 07:00 to 12:00. Like Farmer A, Cooperative 1 held the belief that the soil did not hold moisture well stating that crops like Swiss chard wilted on hot days even after irrigation. Cooperative 1 routinely expressed that they felt it was important to irrigate efficiently in order to reduce water loss and "to save water for others" in the catchment. Cooperative 1 had invested some of their own profits into buying the drip irrigation in order to reduce their reliance on the dragline sprinklers because they believed that drip irrigation is a more efficient system. Cooperative 1 invested in additional lines of dripper tape when they were able to afford the lines. Cooperative 1 did not measure their irrigation water usage and irrigation between fields was scheduled according to how the family felt the plants looked, but with at least one field being irrigated at any time during their allocated five hours every day.

In addition to the drip irrigation, Cooperative 1 had made additional infrastructural investments to erect the shade house. Weed control in all fields was done by hand with hoes, with weed residues dried and burnt on the edge of the plot. Cooperative 1 employed temporary workers to assist with the weeding when weed pressure was high, and Cooperative 1 had cash reserves available to pay for the labour. Weed pressure in Cooperative 1's fields was exceptionally high and during several of the site visits it was noted that weeds were close to overwhelming the crop, with a number of fields later abandoned when weed pressure became too high and the crop was outcompeted. Farmer C showed hesitation towards the use of herbicides stating that they were worried about the negative impact herbicides can have on the environment and "the health of our people".

Cooperative 1 sell their produce to local markets and informal hawkers, but stated that the contracts with local supermarkets and greengrocers were erratic. Cooperative 1 does much of their business in good faith, not only because of their deep religious beliefs but also because they lack the necessary legal support to negotiate and uphold contracts. Cooperative

1 said they experienced buyers who had contracted certain specified quantities of produce who were then unwilling to take produce at the end of the season. During a site visit Cooperative 1 showed the research team 0.25 ha of lettuce that they had been contracted to grow, which was left to rot in the field after the contractor reneged on the deal and no alternative market could be found. Cooperative 1 did not keep records of the quantities of produce that were harvested or sold.

Under the typology presented by Cousins and Chikazunga (2013) Cooperative 1 would be considered market-oriented smallholders in loose value chains. Cooperative 1's production objective is a cash income, with some household consumption but greater than 50% of the output intended for market. The entire family is involved in the business and thus the contribution of their agricultural production to household income is substantial. The family largely makes use of their own labour, but hires additional labour where necessary. Mechanisation is relatively low with Cooperative 1 only making use of CoT-owned tractors for field preparation. There is low capital intensity with Cooperative 1 largely reliant on donations from CoT, and Cooperative 1 has little access to finance due to the informal nature of the business.

Farmer E

Farmer E, a former employee of the Agricultural Research Council (ARC) who left the institution in 2013 after a successful bid to farm the Soshanguve Agri-park site in 2013, runs their own registered fresh produce company. Farmer E moved operations to the Rooiwal Agri-park in 2017 in order to expand production. Farmer E produces coriander (*Coriandrum sativum* L.) and rocket (*Eruca vesicaria* (L.) Cav.) under multi-span tunnels and cucumbers (*Cucumis sativus* L.) in the tunnel units. Farmer E receives annual donations of seed and fertiliser, typically in the form of bags of 2:3:2 (30), from CoT. Farmer E expressed similar frustrations to the farmers of Cooperative 1 over irrigation water resources, stating that a major challenge at the site was insufficient irrigation water and a lack of maintenance of the critical irrigation infrastructure.

Farmer E had invested in microject sprinklers to irrigate the leafy herbs, and dripper lines to irrigate the cucumbers. Irrigation was done in the afternoon from 12:00 – 17:00 as per the agreement with Cooperative 1 and Cooperative 2 and irrigation scheduling was done according to time, although this differed for each planting block. Farmer E informed the research group that during his work at the ARC he had used a number of soil water sensors, including capacitance sensors and neutron probes, but expressed that he felt these were an unnecessary expense for the business. Farmer E held the similar opinions to Farmer A and the members of Cooperative 1 that the soil at the site did not hold moisture well. Weeding was done by hand, although weed pressure was not observed to be a problem, likely due to weed lifecycles being disrupted during the regular harvesting of the leafy herbs and the lack of moisture outside of the dripper zone in the tunnel units where the cucumbers were grown. Farmer E employed temporary workers to plant, weed, and harvest and subcontracted the women's cooperative to grow herbs as discussed below. Farmer E was not willing the share the company's harvest or sales data, however he did express that he was proud to have secured profitable contracts with the restaurants in the Midrand area and had been able to secure a loan from a bank in order to buy his own refrigerated delivery vehicle.

Under the typology presented by Cousins and Chikazunga (2013) Farmer E would be considered a small-scale capitalist farmer. Although Farmer E uses low rates of mechanisation, a feature more typical of market-orientated smallholders, the nature of the business is more akin to that of a small-scale capitalist farming enterprise. The company produces solely for profit with greater capital intensity and all produce intended for market and no home consumption, utilises only hired labour, had been able to access finance through a formal financial institution in order to buy the delivery vehicle, and is Farmer E's only source of income.

Cooperative 2

Cooperative 2 consists of five women from the local community. None of the members of the Cooperative 2 spoke English and none of the research team spoke sePedi, and so communication was limited. Cooperative 2 receives annual donations of seed and fertiliser, typically in the form of bags of 2:3:2 (30), from CoT and solely produced coriander under shade net tunnels as part of a partnership with Farmer E. Additionally Cooperative 2 produced some vegetables such as beetroot for home consumption. Cooperative 2 made use of microjet sprinklers to irrigate, paid for by Farmer E as part of the agreement between the two parties. Irrigation was done in the afternoon from 12:00 – 17:00 as per the agreement with Cooperative 1 and Farmer E. All planting, harvesting, fertilisation, and irrigation scheduling decisions were made by Farmer E.

Under the typology presented by Cousins and Chikazunga (2013) Cooperative 2 would be considered a market-orientated smallholders in tight value chains. Although Cooperative 2 makes use of their own labour rather than any hired labour, a feature more typical of subsistence-oriented smallholders and market-orientated smallholders in tight value chains, Cooperative 2 produces almost entirely for a cash income through their sales to Farmer E. The major distinctions between the Cooperative 2 and Farmer E, which preclude Cooperative 2 from being viewed as small-scale capitalists, are that Cooperative 2 does not have access to the market directly and does not have access to finance through formal financial institutions due to the informal nature of the cooperative itself.

2.3.2 The Soshanguve Agri-park

Farmer F

Farmer F is the only farmer based at the Soshanguve Agri-park. A primary school teacher by profession Farmer F tendered for the position to farm the Soshanguve Agri-park in 2017 after Farmer E moved operations to the Rooiwal Agri-park, as mentioned above. Farmer F holds no formal agricultural training and attributes her decision to change careers to a passion for business and poor job satisfaction as a teacher, making several references to the frustrations of working in under-staffed state schools. Farmer F produces a mix of herbs, bell peppers, Swiss chard, cucumbers, cabbages (*Brassica oleracea* Capitata group L.), and tomatoes (*Solanum lycopersicum* L.), which she sells to local supermarkets and informal traders. Farmer F receives annual donations of seeds, fertilisers, and other inputs from CoT.

The tunnels and fields under shade netting are irrigated by microjet sprinklers, and the open fields irrigated with dragline sprinklers. As was the case with Cooperative 1 cooperative at the Rooiwal Agri-park, the microjet irrigation systems at the Soshanguve Agri-park were the result of continuous, improvised expansion as Farmer F could afford to expand or repair sections of the system, rather than infrastructure funding became available rather than planned system. Irrigation was scheduled according to time-length of application to each irrigation block, however during site visits the research team noted several indicators of substantial over-irrigation, including excessive ponding and the presence of algae on the soil surface of many fields.

In discussion, Farmer F shared similar experiences to those of the farmers at the Rooiwal Agri-park, particularly in respect to maintenance of essential equipment such as the borehole pump. Farmer F expressed frustration at not being permitted to perform maintenance herself, or to be reimbursed by CoT for emergency maintenance for which they had paid herself. When asked how they kept their crops going when the borehole was out of operation, Farmer F informed the research group that they paid a local water-tanker to bring in municipal water at a cost of R300 per 10 000 l tank.

Farmer F expressed that they were appreciative of CoT and GDARD's donations of fertiliser, seed, and other inputs, although it was evident that these donations were not always applicable and Farmer F felt that the money could have been better spent. Such donations in the time-period the research team worked with Farmer F included two brush-cutters, 20 litres of two-stroke oil, and a whiteboard. These donations were made despite the fact that the perimeter of the Soshanguve Agri-park is the only grassed area and was already easily cleared by hand with grass-whips, that 20 litres of two-stroke oil was an inconceivable amount for use in such a small area, and that Farmer F had no need for the white-board. Farmer F requested that these donations be returned and the money be used elsewhere, however they were told by CoT officials that this was not possible while simultaneously being told that there were no available funds to repair damages on the shade houses which had been caused by a hailstorm a month prior. Farmer F expressed their desire to save enough of their profits to buy their own land and move their operations there, so that they could be independent of the CoT. Farmer F was also concerned about the fact that no water quality or soil fertility testing was done at the Soshanguve Agri-park, however they did not have sufficient capital to pay for these tests themselves.

Under the typology presented by Cousins and Chikazunga (2013) Farmer F would be considered a small-scale capitalist farmer for similar reasons to Farmer E at the Rooiwal Agri-park. Farmer F uses low rates of mechanisation and capital intensity, which are features more typical of market-orientated smallholders in tight value chains, however they produce solely for profit with the business being their only source of income, utilises only hired labour, and has access to finance.

2.4 Irrigation water resources

The original intention of WRC project K5/2823//4 under which this dissertation fell prior to the knowledge that the Agri-parks were in operation was to conduct a water feasibility study for selected Agri-parks in Gauteng, under the assumption that the Agri-parks programme was in the planning stages (le Roux *et al.* 2022). At the time of the initial site visits on 25 July 2018 no long-term groundwater level data was available for either site despite both sites being solely reliant on groundwater for irrigation. The only indication of groundwater yields for the boreholes at the Rooiwal Agri-park were the water borehole certificates conducted on 1 May 2010 by SA Rock Drills cc (Table 2-5). No borehole certificate was available for the Soshanguve Agri-park.

Table 2-5: Summary of groundwater yield tests for the Rooiwal Agri-park

	Location	Static water level (meters from above)	Maximum constant yield (m^3 $hour^{-1}$)
Borehole 1	25.33.179°S; 28.13.95°E	9.6	12
Borehole 2	25.33.219°S; 28.13.96°E	11.7	0.7
Borehole 3	25.55.44°S; 28.23.41°E	7.1	5.6

Groundwater quality had been tested at the Rooiwal Agri-park (Appendix 2.2), although the results had not been analysed in order to inform management decisions. No water quality data were available from the Soshanguve Agri-park. This was of particular concern given the proximity of the Rooiwal Agri-park to the power station, wastewater treatment works, and old ash tailings dam, and the proximity of the Soshanguve Agri-park to the municipal dumpsite. As a result it was determined that an analyses of the water quality at both sites would need to be conducted in order to assess any risks posed by the irrigation water and to aid CoT in the management of the sites.

2.4.1 The Rooiwal Agri-park

Groundwater quality

In order to assess the suitability of the groundwater at the Rooiwal Agri-park, laboratory results from a 2017 CoT report (Appendix 2.2) were run through the South African Water Quality Guidelines Decision Support System (SAWQI DSS) to generate a 'Tier 1' fitness-for-use analysis. Groundwater quality data for Rooiwal (Table 2-6) indicates a relatively high concentration of salts, with an electrical conductivity (EC) of 176 mS m^{-1} and total dissolved solids of 1200 mg L^{-1}. Soil salinity may result in a decrease in yield, however, the Department of Water Affairs and Forestry (DWAF) reports that if the EC falls between 90 - 270 mS m^{-1} 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 (DWAF 1996). The SAWQI DSS predicted equilibrium root zone salinity (EC_e) of 331 mS m^{-1} (Table 2-6) was within the 'Acceptable' range. In terms of qualitative indication of impact on soil permeability, the groundwater is predicted to have a slight effect on surface infiltrability due to its sodium content and no impact on soil hydraulic conductivity.

Table 2-6: SAWQI DSS report on potential for root zone salinity results for Rooiwal groundwater

Fitness-for-use	*Root zone salinity (mS m^{-1})*	*Predicted equilibrium root zone salinity (mS m^{-1})*
Ideal	0 – 200	
Acceptable	200 – 400	331
Tolerable	400 – 800	
Unacceptable	> 800	

Overall, the quality of the groundwater at Rooiwal was assessed to be adequate for irrigation purposes. Concentration of NO_3^- (95 mg l^{-1}) of the groundwater samples taken at Rooiwal are above drinking water quality thresholds and therefore not fit for human consumption (Appendix 2.2). World Health Organization (2017) sets the maximum NO_3^- concentration at 50 mg l^{-1}, to protect against 'methemoglobinemia and thyroid effects in the most sensitive subpopulation, bottle-fed infants, and, consequently, other population subgroups'. Infants are particularly susceptible to developing methemoglobinemia due to their increased capacity to convert NO_3^- to nitrite (NO_2^-) (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). At high doses NO_3^- can competitively inhibit iodine uptake, and induce hypertrophic changes in the thyroid (Ward *et al.* 2005). Ward *et al.* (2005) further reported that NO_3^- is a precursor in the formation of N-nitroso compounds, of which many have been shown to be carcinogenic in multiple animal species. Studies on the impact on multiple human organ sites, including the oesophagus, stomach, colon, bladder, and lymphatic and hematopoietic systems, report mixed results. 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 NO_3^- 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 NO_3^- concentrations across studies or differences in exposure to other cofactors. Despite the proximity to the wastewater treatment facility, the groundwater samples did not contain any faecal coliforms.

According to DWAF (1996) NO_3^- concentrations above 30 mg l^{-1} '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. The groundwater quality was classified as 'Ideal' in most cases in terms of trace element accumulation (Table 2-7). The only trace elements of concern were fluoride (F) ('Unacceptable': 83 years to reach soil accumulation threshold at 1000 mm irrigation per annum), and selenium (Se) ('Tolerable': 125 years to reach soil accumulation threshold at 1000 mm irrigation per annum). The F^- concentration of 2.4 mg l^{-1} (Table 2-7) 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 Se concentration of 0.016 mg l^{-1} (Table 2-7) is within the 'Tolerable' fitness-for-use category for the SAWQI DSS, DWAF (1996) states that a concentration below 0.02 mg l^{-1} 'can be used over the long term', and 'does not result in the accumulation of Se 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 beryllium (Be), lithium (Li), mercury (Hg), and molybdenum (Mo).

The SAWQI DSS's 'Tier 1' fitness-for-use analysis categorised the high EC as 'Ideal' for irrigation purposes when irrigating a 'Generic Sensitive Crop with 1000 mm per annum', however yield reduction of 21% was predicted to occur (Table 2-8). The SAWQI DSS indicated that under the same conditions the boron (B), chloride (Cl), and Na levels were within the 'Ideal' range, and predicted that no decrease in relative crop yield would be attributed to these elements (Table 2-8). Leaf scorching as a result of Na^+ and Cl^- ions was predicted to be slight, and so fitness-for-use as irrigation water was deemed to be 'Acceptable' (Table 2-9).

Due to the high nitrogen (N) and potassium (K) concentrations in the groundwater, there is no need to apply additional fertilizer (Table 2-12). Removal of these nutrients from the system by the crop could also be seen as an environmental service, by reducing the nutrient load that may return to fresh waterways through runoff and leaching.

Table 2-7: SAWQI DSS report on the potential for trace element accumulation results for Rooiwal groundwater

Fitness-for-use	*Number of years of 1000mm irrigation before Trace Elements reach accumulation threshold in topsoil*	
Ideal	> 200 years to reach soil accumulation threshold	
Acceptable	150 to 200 years to reach soil accumulation threshold	
Tolerable	100 to 150 years to reach soil accumulation threshold	
Unacceptable	< 100 years to reach soil accumulation threshold	
Trace Element	Soil Accumulation Threshold (mg kg^{-1})	No of years to reach Soil Accumulation Threshold
Al	2500	71429
As	50	2000
Cd	5	1000
Cr	50	5000
Co	25	5000
Cu	100	4000
F	1000	83
Fe	2500	13158
Pb	100	5000
Mn	100	1333
Ni	100	20000
Se	10	125
U	5	1000
Va	50	Infinite
Zn	500	12500

Table 2-8: SAWQI DSS report on the potential for root zone effects results for Rooiwal groundwater

Fitness-for-use	*Relative crop yield (%)*	*Predicted relative crop yield (%) as affected by:*			
		Salinity (EC)	B	Cl	Na
Ideal	90 - 100		100	100	100
Acceptable	80 - 90				
Tolerable	70 - 80	79			
Unacceptable	<70				

Table 2-9: SAWQI DSS report on the potential for leaf scorching when wetted results for Rooiwal groundwater

Fitness-for-use	*Degree of leaf scorching*	*Degree of leaf scorching under sprinkler irrigation caused by:*	
		Cl^-	Na^+
Ideal	None		
Acceptable	Slight	Slight	Slight
Tolerable	Moderate		
Unacceptable	Severe		

Table 2-10: SAWQI DSS report on the potential for corrosion or scaling of irrigation equipment results for Rooiwal groundwater

Fitness-for-use	*Fitness for Use Category determined by the corrosion or scaling potential indicated by the Langelier Index*			
	Corrosion (Langelier Index)		Scaling (Langelier Index)	
Ideal	-0.5 to 0	Not Corrosive	0.0 to +0.5	0.0
Acceptable	-0.5 to -1.0		+0.5 to +1.0	
Tolerable	-1.0 to -2.0		+1.0 to +2.0	
Unacceptable	<-2.0		>+2.0	

Table 2-11: SAWQI DSS report on the potential for clogging of drippers results for Rooiwal groundwater

Fitness-for-use	*Fitness-for-Use Category determined by the potential of a constituent to cause clogging of drippers*									
	Suspended Solids (mg l^{-1})		pH		Mn (mg l^{-1})		Total Fe (mg l^{-1})		E.coli (10^6 per 100 mL)	
Ideal	<50	No data	<7.0		<0.1	0.0	<0.2	0.0	<1	0.0
Acceptable	50-75		7.0-7.5	7.1	0.1-0.5		0.2-0.5		1-2	
Tolerable	75-100		7.5-8.0		0.5-1.5		0.5-1.5		2-5	
Unacceptable	>100		>8.0		>1.5		>1.5		>5	

Table 2-12: SAWQI DSS report on the potential for nutrient removal results for Rooiwal groundwater

Fitness-for-use	*Contribution to estimated N P K removal by crop*	*% of estimated N P K removal at harvest and amount that is applied through irrigation*					
		N		P		K	
		Removal (%)	Applied (kg ha^{-1})	Removal (%)	Applied (kg ha^{-1})	Removal (%)	Applied (kg ha^{-1})
Ideal	0 - 10%			2	0		
Acceptable	10 - 30%						
Tolerable	30 - 50%						
Unacceptable	>50%	1900	950			600	60

Apies River water quality

Despite its proximity, the Apies River has not been considered as a potential water source to expand the irrigation capacity of the Rooiwal Agri-park. Water quality data from the Apies River between 2011/01/04 and 2018/01/03, taken at 25°27'34.56"S 28°15'51.48"E, was obtained from Department of Water And Sanitation (DWS) (Appendix 2.3) and median values were run through the SAWQI DSS to generate a 'Tier 1' fitness-for-use analysis.

Salinity of the water in the Apies River is relatively low with a median value of 69 mS m^{-1} for EC and 521.5 mg l^{-1} for TDS. According to the SAWQI DSS, the predicted EC_e of 152 mS m^{-1} was within the 'Ideal' range and lower than the groundwater. The SAWQI DSS predicted relatively low potential impacts on soil permeability, slight potential impacts on soil hydraulic conductivity, deemed 'Acceptable', and moderate potential impacts on surface infiltrability which was deemed 'Tolerable' (Table 2-14). Although not deemed 'Unacceptable', these potential impacts overall are greater than those posed by the groundwater (Table 2-6).

Apies River water quality data were not available for most trace elements, except for F. The SAWQI DSS indicated the F concentrations are much lower than those in the groundwater (Table 2-7) and within the 'Ideal' fitness-for-use category, potentially requiring 342 years to reach the soil accumulation threshold (Table 2-15).

Table 2-13: SAWQI DSS report on the potential for root zone salinity results for water from the Apies River

Fitness-for-use	*Root zone salinity (mS m^{-1})*	*Predicted equilibrium root zone salinity (mS m^{-1})*
Ideal	0 - 200	152
Acceptable	200 - 400	
Tolerable	400 - 800	
Unacceptable	> 800	

Table 2-14: SAWQI DSS report on the potential for soil permeability results for water from the Apies River

Fitness-for-use	*Degree of reduced Permeability*	*Qualitative indication of the impact on soil permeability as manifested by reduced:*	
		Surface Infiltrability	Soil Hydraulic Conductivity
Ideal	None		
Acceptable	Slight		Slight
Tolerable	Moderate	Moderate	
Unacceptable	Severe		

The SAWQI DSS indicated that Cl and Na 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 (Table 2-16). No information on the concentration of boron (B) in the groundwater was available, so the effects of B on the rootzone could not be reported by the SAWQI DSS. No leaf scorching is predicted to occur as a result of Na^+ and Cl^- ions, and so fitness-for-use as irrigation water was considered to be 'Ideal' (Table 2-17).

Due to the high N, P, and K of the surface water, there would be no need to apply additional fertilizer. Use of the Apies River water for irrigation purposes would supply over 100% of the crop requirements for all three nutrients (Table 2-18). Removal of these nutrients by the crop could be seen as an ecosystem service to reduce the nutrient load within the catchment.

As shown in Table 2-19, according to the Langelier Index, the water from the Apies River is not corrosive (fitness-for-use categor is 'Ideal') and will not cause scaling (fitness-for-use category is ‘Acceptable’). The high pH has the potential to cause clogging of the irrigation drippers (Table 2-20). No data were available for the impact of the Mn, total Fe, and *E. coli* content on dripper clogging.

Table 2-15: SAWQI DSS report on the potential for trace element accumulation results for water from the Apies River

Fitness-for-use	*Number of years of 1000mm irrigation before Trace Elements reach accumulation threshold in topsoil*	
Ideal	> 200 years to reach soil accumulation threshold	
Acceptable	150 to 200 years to reach soil accumulation threshold	
Tolerable	100 to 150 years to reach soil accumulation threshold	
Unacceptable	< 100 years to reach soil accumulation threshold	
Trace Element	Soil Accumulation Threshold (mg/kg)	No of years to reach Soil Accumulation Threshold
F	1000	342

Table 2-16: SAWQI DSS report on the potential for root zone effect results for water from the Apies River

Fitness-for-use	*Relative crop yield (%)*	*Predicted relative crop yield (%) as affected by:*		
		Salinity (EC)	Cl^-	Na^+
Ideal	90 - 100		100	100
Acceptable	80 - 90			
Tolerable	70 - 80	76		
Unacceptable	<70			

Table 2-17: SAWQI DSS report on the potential for leaf scorching when wetted results for water from the Apies River

Fitness-for-use	*Degree of leaf scorching*	*Degree of leaf scorching under sprinkler irrigation caused by:*	
		Cl^-	Na^+
Ideal	None		
Acceptable	Slight	Slight	
Tolerable	Moderate		Moderate
Unacceptable	Severe		

Table 2-18: SAWQI DSS report on the potential for nutrient removal results for water from the Apies River

Fitness-for-use	*Contribution to estimated N P K Removal by crop*	*% of estimated N P K removal at harvest and amount that is applied through irrigation (High nutrient concentrations may impact development of sensitive crops)*					
		N		P		K	
		Removal (%)	Applied (kg ha^{-1})	Removal (%)	Applied (kg ha^{-1})	Removal (%)	Applied (kg ha^{-1})
Ideal	0 - 10%						
Acceptable	10 - 30%						
Tolerable	30 - 50%						
Unacceptable	>50%	225	112	332	33	1526	153

Table 2-19: SAWQI DSS report on the potential for corrosion or scaling of irrigation equipment results for water from the Apies River

Fitness-for-use	*Fitness for Use Category determined by the corrosion or scaling potential indicated by the Langelier Index*			
	Corrosion (Langelier Index)		Scaling (Langelier Index)	
Ideal	-0.5 to 0	Not Corrosive	0 to +0.5	
Acceptable	-0.5 to -1.0		+0.5 to +1.0	0.84
Tolerable	-1.0 to -2.0		+1.0 to +2.0	
Unacceptable	<-2.0		>+2.0	

Table 2-20: SAWQI DSS report on the potential of a constituent to cause clogging of drippers results for water from the Apies River

Fitness-for-use	*pH*	
	Standard	Result
Ideal	<7.0	
Acceptable	7.0 - 7.5	
Tolerable	7.5 - 8.0	
Unacceptable	>8.0	8.6

2.4.2 The Soshanguve Agri-park

Ground water quality

A sample of the irrigation water was taken during the initial site visit on 28 July 2018 and sent to a private testing facility for analysis. The laboratory report was run through the SAWQI DSS to generate a 'Tier 1' fitness-for-use analysis. The predicted equilibrium root zone salinity (EC_e) of 77 mS m^{-1} (Table 2-21) was within the 'Ideal' range according to the SAWQI DSS. In terms of qualitative indication of impact on soil permeability, the groundwater is predicted to have a slight effect on both surface infiltrability and soil hydraulic conductivity (Table 2-22).

Table 2-21: SAWQI DSS report on the potential for root zone salinity results for Soshanguve groundwater

Fitness-for-use	*Root zone salinity (mS m^{-1})*	*Predicted equilibrium root zone salinity (mS m^{-1})*
Ideal	0 – 200	77
Acceptable	200 – 400	
Tolerable	400 – 800	
Unacceptable	> 800	

Table 2-22: SAWQI DSS report on the potential effects of groundwater on soil permeability for Soshanguve groundwater

Fitness-for-use	*Degree of reduced Permeability*	*Qualitative indication of the impact on soil permeability as manifested by reduced:*	
		Surface Infiltrability	Soil Hydraulic Conductivity
Ideal	None		
Acceptable	Slight	Slight	Slight
Tolerable	Moderate		
Unacceptable	Severe		

The ground water showed 'Unacceptable' levels of three of the six trace elements tested (Table 2-23). The trace elements of concern were F ('Unacceptable': 57 years to reach soil accumulation threshold at 1000 mm irrigation per annum), Mn ('Unacceptable': 91 years to reach soil accumulation threshold at 1000 mm irrigation per annum), and Mo ('Tolerable': 0 years to reach soil accumulation threshold at 1000 mm irrigation per annum). Despite the F and Mn levels being classified as 'Unacceptable' by the SAWQI DSS, both fell within the lower end of their respective "maximum acceptable concentration for fine-textured neutral to alkaline soils" (DWAF 1996). Of concern is the potential of Mo to reach accumulation threshold in topsoil in less than a single season, although DWAF (1996) states that Mo concentrations in irrigation water must be interpreted in conjunction with soil concentrations of Mo as well as in relation to Cu and sulphate (SO_4^-) concentrations. While Mo is highly mobile in the soil and so easily leached out of the profile, DWAF (1996) states that the risk associated with Mo uptake by crops is related only to the adverse effects to livestock, the guidelines also emphasise that is highly unlikely that Mo can be economically removed from irrigation water. The only option is the precipitation of insoluble salts at a pH of between 8.5-11.5. With a pH of 8.4 (Table 2-27) the water is already on the lower-end of the spectrum and this could ensure that furthering lowering the pH to precipitate Mo could be economically viable, should Mo toxicity to the crop become a threat. The three other trace elements, Cu, Fe, and Zn, were all found to be within the 'Ideal' range (Table 2-23). There is some concern that if three of the six trace elements were found to be 'Unacceptable', other trace elements not tested may almost present a risk. These include aluminium, arsenic, Be, cadmium (Cd), chromium, cobalt, lead (Pb), Li, Hg, nickel (Ni), uranium (U), and vanadium (V). The groundwater was predicted to have little to no effect on root zone salinity (Table 2-24) and no potential for leaf scorching (Table 2-25).

The SAWQI DSS indicated that, based on the Langelier Index, the groundwater was within the 'Ideal' range for both corrosion ('Not Corrosive') and scaling (0.29) (Table 2-26). In terms of the potential to clog drippers, Mn and Fe were within the 'Ideal' range (Table 2-27). However, at pH 8.4 was classified as unacceptably high with the potential to cause clogging of drippers (Table 2-27). Lowering irrigation water pH is typically done through the addition of liquid acids such as phosphoric acid, sulfuric acid, and hydrochloric acids. Soil acidifiers such as reduced nitrogenous fertilisers may also be used, however inorganic N levels were also within the 'Unacceptable' region (Table 2-27) and their use may increase the risk of eutrophication of the Soutpanspruit.

Table 2-23: SAWQI DSS report on the potential for trace element accumulation results for Soshanguve groundwater

Fitness-for-use	*Number of years of 1000mm irrigation before Trace Elements reach accumulation threshold in topsoil*	
Ideal	> 200 years to reach soil accumulation threshold	
Acceptable	150 to 200 years to reach soil accumulation threshold	
Tolerable	100 to 150 years to reach soil accumulation threshold	
Unacceptable	< 100 years to reach soil accumulation threshold	
Trace Element	Soil Accumulation Threshold (mg kg^{-1})	No of years to reach Soil Accumulation Threshold
Cu	100	286
F	1000	57
Fe	2500	>1000
Mn	100	91
Mo	5	0
Zn	500	>1000

Table 2-24: SAWQI DSS report on the potential for root zone effects results for Soshanguve groundwater

Fitness-for-use	*Relative crop yield (%)*	*Predicted relative crop yield (%) as affected by:*			
		Salinity (EC)	Boron (B)	Chloride (Cl)	Sodium (Na)
Ideal	90 - 100	99	100	100	100
Acceptable	80 - 90				
Tolerable	70 - 80				
Unacceptable	<70				

Table 2-25: SAWQI DSS report on the potential for leaf scorching when wetted results for Soshanguve groundwater

Fitness-for-use	*Degree of leaf scorching*	*Degree of leaf scorching under sprinkler irrigation caused by:*	
		Chloride (Cl)	Sodium (Na)
Ideal	None	None	None
Acceptable	Slight	Slight	Slight
Tolerable	Moderate		
Unacceptable	Severe		

Table 2-26: SAWQI DSS report on the potential for corrosion or scaling of irrigation equipment results for Soshanguve groundwater

Fitness-for-use	*Fitness for Use Category determined by the corrosion or scaling potential indicated by the Langelier Index*			
	Corrosion (Langelier Index)		Scaling (Langelier Index)	
Ideal	-0.5 to 0	Not Corrosive	0.0 to +0.5	0.29
Acceptable	-0.5 to -1.0		+0.5 to +1.0	
Tolerable	-1.0 to -2.0		+1.0 to +2.0	
Unacceptable	<-2.0		>+2.0	

Table 2-27: SAWQI DSS report on the potential for clogging of drippers results for Soshanguve groundwater

Fitness-for-use	*Fitness-for-Use Category determined by the potential of a constituent to cause clogging of drippers*									
	Suspended Solids (mg l^{-1})		pH		Manganese (Mn) (mg l^{-1})		Total Iron (Fe) (mg l^{-1})		E.coli (10^6 per 100 mL)	
Ideal	<50	No data	<7.0		<0.1	0.0	<0.2	0.0	<1	No data
Acceptable	50-75		7.0-7.5		0.1-0.5	0.2	0.2-0.5	0.4	1-2	
Tolerable	75-100		7.5-8.0		0.5-1.5		0.5-1.5		2-5	
Unacceptable	>100		>8.0	8.4	>1.5		>1.5		>5	

As at Rooiwal high N and K concentrations in the groundwater, there is no need to apply additional fertiliser, as use of the groundwater for irrigation purposes would supply over 100% of the crop requirements (Table 2-28). Although not as high as at Rooiwal, the same concerns with elevated N and K in the wider environment apply, and the removal of these nutrients from the system by the crop could be seen as an environmental service by reducing the nutrient load.

Table 2-28: SAWQI DSS report on the potential for nutrient removal results for Soshanguve groundwater

Fitness-for-use	*Contribution to estimated N P K removal by crop*	*% of estimated N P K removal at harvest and amount that is applied through irrigation*					
		Nitrogen (N)		Phosphorous (P)		Potassium (K)	
		Removal (%)	Applied (kg ha^{-1})	Removal (%)	Applied (kg ha^{-1})	Removal (%)	Applied (kg ha^{-1})
Ideal	0 - 10%			6	1		
Acceptable	10 - 30%						
Tolerable	30 - 50%						
Unacceptable	>50%	254	127			270	27

2.5 Discussion

2.5.1 The Agri-parks model

Reflecting on the Agri-park's guiding principles described in DRDLR (2016a), it is evident that these principles are not being adhered to in CoT and, in their current form, the CoT Agri-parks do not resemble the model described by DRDLR (2017b). Although no literature makes reference to a formal deviation from the original model to include metropolitan municipalities, for the remainder of this dissertation it will be assumed that the Agri-parks project has been extended to include the metropolitan municipalities and that CoT hosts one Agri-park as per the first guiding principal of the project laid out in DRDLR (2016a). Additionally there is disconnect between national, provincial, and local municipal governance regarding the terminology of the model, although no available literature refers to changes in the official definitions. The discrepancies in the terminology used by different tiers of government and respective literature could explain why, while there are a number of articles in the popular press and social media about the successes of the Agri-parks, these successes are not reflected in DRDLR annual reports (DRDLR 2015, 2016b, 2017a, 2018, 2019). The successes reported in the popular press reflect small advancements at a production unit level, rather than at the scale of what the Agri-parks programme was intended to achieve. Neither the Rooiwal nor the Soshanguve sites met the DALRRD's minimum requirements for a fully functional FPSU (Table 2-1) and were more akin to production units which would be serviced by a FPSU within an Agri-park catchment (Figure 1-2). The sites are also treated as separate projects rather than two parts of a single Agri-park, in contradiction to the interconnected model presented in Figure 1-2. In order to remain consistent with the definitions provided in DRDLR (2016a, 2016b), for the remainder of this dissertation the term 'Agri-park' will align with the original DRDLR (2016a) definition as 'a networked innovation system of agro-production, processing, logistics, marketing, training and extension services'. The Rooiwal, Soshanguve, Mamelodi, and The Innovation Hub 'Agri-parks' will be referred to as FPSUs which form part of a single CoT Agri-park in accordance with the original model (Figure 1-2), albeit in the early stages of development as discussed in more detail below.

The second of the Agri-parks project's guiding principles is that the Agri-parks must be farmer controlled (DRDLR 2016a). Currently the CoT Agri-park is managed in a top-down approach by CoT officials, with little participation from the farmers in either managerial or operational decisions. As discussed in Section 2.3, the most pressing frustration expressed by all farmers related to the maintenance of essential infrastructure by CoT. Although CoT officials denied negligence in upholding the maintenance obligations, officials made mention of constrained budgets and bureaucratic red tape that regularly delayed the process but were unwilling to give further details in this regard. Similarly, donations of agricultural inputs were not done in consultation with farmers and the types of donations currently being made do not address the farmer's needs. The provision of inappropriate inputs has the potential to strain relationships between farmers and government officials working in the project, as has already occurred at the Soshanguve Agri-park, and has negative environmental implications, as discussed under the section on the Agri-parks as an example of Sustainable Intensification (SI) below.

The third, ninth, and tenth guiding principles, that "Agri-parks must be the catalyst around which rural industrialization will takes place", must "maximise use of existing agro-processing, bulk and logistics infrastructure, including having availability of water, energy and roads", and "support growing-towns and revitalisation of rural towns… and promote rural urban linkages", all speak to Agri-parks as drivers of economic growth and job creation (DRDLR 2016a). According to both DRDLR (2020) and NCOP LREMRE (2019) the Agri-parks programme intended to contribute 300 000 new small-scale producers and 145 000 new jobs in agro-processing to the NDP by the year 2020. This equates to an average of 6 818 new small-scale producers and 3 295 agro-processing jobs per Agri-park. Despite these ambitious targets DARDLR estimated that by October 2019 a total of 10 566 smallholder farmers had 'benefitted' from the Agri-parks nationally (NCOP LREMRE 2019). At most, the Rooiwal and Soshanguve FPSUs have created approximately 30 jobs at any one time in 2018 (including temporary labour for harvesting and weeding), and the NCOP LREMRE (2019) report states that GDARD estimates that between 2015 and 2019 the Gauteng Agri-parks only benefitted 135 smallholder farmers and created 167 job opportunities. The market-orientated smallholders and small-scale capitalist farming groups at the Rooiwal and Soshanguve FPSUs all focus on the production and sale of fresh produce and during the time spent on the two sites Farmer F at the Soshanguve FPSU was the only farmer who engaged in some form of post-harvest agro-processing by preparing vegetables into ready-to-cook packs for clients. Although post-harvest agro-processing is not essential for small-scale farmers to become economical viable businesses, as illustrated by the growth of Farmer E through the production and sale of fresh herbs, there is strong evidence to show how post-harvest agro-processing boosts small-scale farmer incomes (Lin and Chang 2021). In addition the example of Cooperative 1 having to leave produce to rot in a field indicates a need to find additional markets outside of the sale of fresh produce, and agro-processing has been shown to be a successful mechanism to reduce food waste by extending the shelf-life of produce (Le Roux *et al.* 2018).

The fourth, fifth and seventh principles, that "Agri-parks must be supported by government to ensure economic sustainability" for a period of ten years, to "strengthen partnership between government and private sector stakeholders to ensure increased access to services (water, energy, transport) and production… while developing existing and create new markets to strengthen and expand value-chains", and that Agri-parks must "maximise access to markets to all farmers, with a bias to emerging farmers and rural communities" (DRDLR 2016a), speak to the economic viability of the Agri-parks project. At the time of writing there was no evidence of any plan to increase the economic self-sufficiency of the farmers at the Rooiwal and Soshanguve FPSUs, with little of the extensive support mentioned in the Agri-parks model, particularly at the FPSU level, being made available. As the NCOP LREMRE (2019) report concludes, 'these services should have been built into the planning phase at the beginning of implementation, and the correct funding channels identified'. The examples of Cooperative 1 having to leave produce to rot in the fields as a result of buyers reneging on contracts indicates there is a need for farmers within the Agri-parks project to receive business support to ensure financial viability. However, such support must be specific to the needs of each farmer. Farmer E had been able to grow their business and expand operations with limited donations to inputs and access to land and, although still dependent on input donations while based at Rooiwal, had expanded operations sufficiently to leverage capital and buy the company's own farm in 2019 (DALRRD 2019).

The sixth and eighth guiding principles of the Agri-parks project are to "maximise benefit to existing state land with agricultural potential in the provinces" and "and "maximise the use of high value agricultural land", (DRDLR 2016a). However, there is a need to more clearly define what is meant by 'use' and 'benefit' in the context of the Agri-parks model and in light of the other guiding principles. In DRDLR (2017b) the FPSU is described as a rural smallholder farmer outreach and capacity-building unit for the facilitation and provision of agricultural inputs, extension support and training, mechanisation support, local logistics support, post-harvest processing, business development and training, and financial services. Currently only agricultural inputs and some facilities for post-harvest processing are offered at the Soshanguve and Rooiwal FPSUs. The NCOP LREMRE (2019) report states that 'there is no synergy between the presentations received from National and Provincial sources', and that 'there have been almost no operational expense budget allocations made available to GDARD by the DRDLR'. While these are both failures in the execution of policy, two important questions are later raised: 'what is going to become of the half-developed FPSUs now not prioritized, and how will the funding already allocated and spent classified to audit processes?' (NCOP LREMRE 2019).

2.5.2 The Agri-parks as an example of Sustainable Intensification

Reflecting on the premises of SI laid out by Garnett *et al.* (2013), that increased production must be a necessity and that this must be achieved through higher yields on existing land rather than opening up new land, the CoT Agri-park is moving in the right direction even if the pace is limited. Based on the historical Google Earth imagery it was evident that agricultural activity had increased from the historical lows. Both the Rooiwal and Soshanguve FPSUs still have substantial infrastructure, such as tunnel structures and fertigation systems, which is currently not being used to its full potential. It logically follows that it is both inherently more sustainable and economically sound to repair these production systems and bring existing FPSUs into the maximum production possible before investing in any other component of the Agri-parks model or starting the construction of other sites from nothing. This development should have been paired with initial ecological assessments such as water quality and quantity and soil fertility to better inform the decisions. Assessment of water quality at both sites revealed that while groundwater quality was largely fit for irrigation use, monitoring is needed to keep track of specific heavy metals. However, these tests were conducted as a result of this current study and do not reflect a desire of the CoT Agri-park management to evaluate environmental impact of the project. This is particularly concerning in the context of the Rooiwal FPSU where, due to the proximity of the Rooiwal power station and wastewater treatment facility, higher levels of pollutants are expected. Such assessments are the foundation of monitoring an agricultural site's sustainability and therefore need to be conducted by the FPSUs management going forward. Farmers at both the Rooiwal and Soshanguve FPSUs indicated a desire to have water and soil testing conducted, limited only by insufficient access to capital in their personal capacity, and therefore it is likely that had the farmers been included in the FPSU's management decisions such testing would have been conducted from the onset.

Sustainable increases in production must also include an assessment of yields, to be measured against both historical and contemporary regional averages. Currently yield data is not collected at either the Rooiwal or Soshanguve FPSUs and so it is not possible to provide a quantitative analysis of farmer performance. However, it is well established that the yields within tunnel production systems exceed that of open-field production. As production under the tunnel structures at both the Rooiwal and Soshanguve FPSUs is more akin to open-field production than true tunnel production, there is potential to make substantial increases in yield by restoring the existing infrastructure to a functional state. Open field cultivation at the Rooiwal FPSU also has the potential to be expanded, as can been done in the past (Appendix 2.1). Such an expansion does not inherently mean an expansion of the irrigated area, as rain-fed cultivation of the current fallow land would be an improvement. Although the farmers at the Rooiwal FPSU cited limited water supply as one of their greatest challenges, the proximity of the Rooiwal wastewater treatment facility and Apies River present themselves as potential alternative sources of irrigation water, to either supplement or reduce reliance on ground water extraction. The water quality of the Apies River is suitable for use as irrigation water, albeit with high NO_3^- and phosphate levels. If the wastewater treatment facility discharge is the source of the elevated NO_3^- and PO_4^{2-} levels, then a strong argument could be made to utilise this discharge water directly for irrigation purposes. This would not only allow for the expansion of the area under irrigation at the Rooiwal FPSU and reduce reliance on groundwater, but also provide an ecosystem service of removing NO_3^- and phosphates from the system. These possibilities require further investigation, but regardless of the outcome irrigation water usage at both the Rooiwal and Soshanguve FPSUs should be quantified.

Currently irrigation water usage is measured at neither the Rooiwal nor Soshanguve FPSUs, and this has implications for irrigation scheduling. Although all the farmers mentioned that insufficient water was one of their largest challenges, there was evidence to suggest that all farmers were in fact over-irrigating at times. Tools such as the Chameleon soil water sensor (Stirzaker 2014) and the Wetting Front Detector (Stirzaker 2003) have been successfully used by smallholder irrigators across Africa to irrigate more efficiently and reduce the negative effects of over-irrigation (Stirzaker et al. 2017), and could provide a potential simple, low-cost solution in the Agri-parks context.

Monitoring should also inform the decision making process related to agricultural inputs. Agricultural inputs such as fertilisers are a key tool in the SI of smallholder agriculture, but inputs should be context-specific informed by the appropriate evidence (e.g. soil and water quality testing) in order to ensure the inputs being provided will be beneficial. As the analysis of the Rooiwal groundwater quality revealed, the elevated N and K levels meant that no additional N and K applications were necessary in order to meet the needs of most crops and that the annual donations of 2:3:2 (30) fertiliser made to the farmers was an unnecessary input. This highlights the need for appropriate testing and monitoring to be incorporated into the decision making processes of the project, to be used in conjunction with farmer's feedback.

Lastly, as discussed in Tittonell and Giller (2013), the largest production gains in SI projects are often made through the adoption of better practices. Throughout the site visits all the farmers displayed a passion for farming and a sense of pride in their work. Despite not receiving the support described in the Agri-parks model, these farmers have made alternative arrangements by investing in their own drip irrigation systems and producing their own compost in an effort to improve their production systems. However the hesitations towards the use of herbicides and the appeal to 'naturalness' indicates a need for agricultural science communication accompanied with training and agricultural extension to equip the farmers with the knowledge that will enable them to produce at maximum capacity.

2.6 Conclusions

Currently there is little evidence to suggest that the Agri-parks project could be considered an example of SI and little of the extensive support network described in the literature has been provided to the few farmers within the project. As there are already farmers cultivating sites within the FPSUs the immediate focus should be on equipping and upskilling existing farmers in order to bring production up to full capacity using the existing infrastructure. This requires farmers to be included in the management decisions in order to ensure their needs are catered for in an appropriate manner and decisions around management plans should be informed by appropriate environmental monitoring including irrigation water quality and soil health. Agricultural extension and business support should be provided to the farmers on a case-by-case basis in order to provide context-specific assistance to boost production and ensure financial stability of each farmer. Lastly, greater cooperation between different tiers of governance, and different departments, is urgently required in order to address the discrepancies and ensure that the Agri-parks project adheres to the original guiding principles.

Chapter 3: Technology transfer through field trials at the City of Tshwane Agri-park

3.1 Introduction

As part of the technology transfer requirements of WRC project K5/2823//4 under which this dissertation fell, separate field trials were to be established at the Rooiwal and Soshanguve Farmer Production Support Units (FPSU). Farmers were consulted to identify which of the challenges each farmer felt was the most pressing concern, and an appropriate tool and management practice with the potential to overcome said problem was identified. Farmers were to be included in the field trial process through the use of the Mother-Baby trial approach, however this was not possible due to the unforeseen complications described in the relevant sections below. The unsuccessful trials in Sections 3.2 and 3.3 were included in this chapter to provide context to some of the decisions made in Sections 3.4 and 3.5 as well as later chapters of this dissertation, as well as to provide evidence of the learning process undertaken for this MSc.

3.2 Irrigation water use efficiency in coriander at the Soshanguve Farmer Production Support Unit

3.2.1 Rationale

During initial consultation at the Soshanguve FPSU on 25 July 2018, Farmer F expressed that the major constraint to their production was insufficient water availability. As discussed in Chapter 2 irrigation water at the Soshanguve FPSU was supplied by a borehole on site, however, inadequate maintenance of pumping infrastructure had resulted in Farmer F having to buy municipal water from local water-tanker businesses on several occasions in order to irrigate. At the time, Farmer F scheduled irrigation according to time-length of application to each irrigation block rather than a more objective means. Irrigation water usage was not recorded, irrigation blocks were not uniform in size, and much of the site's irrigation system was the result of continuous, improvised expansion as infrastructure funding became available rather than planned expansion of the pre-designed system. Several indicators of substantial over-irrigation were observed, including excessive ponding and the presence of algae on the soil surface of the fields.

FullStop Wetting Front Detectors (WFDs) (Stirzaker 2003) and Chameleon soil water sensors (Stirzaker et al. 2014) were developed as simple, low-cost tools to aid farmers manage irrigation water resources more efficiently. The WFD is a funnel-shaped device buried in the soil profile with an indicator above the soil surface which is triggered as the wetting front moves down the profile and pools in the bottom of the funnel (Stirzaker *et al.* 2017). The Chameleon soil moisture sensor consists of an array of three capacitance sensors installed at different depths in the soil profile which give an indication of soil moisture through a series of coloured lights on a hand-held reader (Stirzaker *et al.* 2017). Both tools have been shown to assist farmers to increase water use efficiencies through more effective irrigation scheduling decisions (Stirzaker *et al.* 2017) and were identified as appropriate tools for Farmer F's context.

3.2.2 Materials and methods

Following consultation on 25 July 2018, Farmer F had prepared a 20 x 40 m section of the shade-house for a new planting of coriander (*Coriandrum sativum* L.) that was deemed an appropriate site to demonstrate the use of the WFDs and Chameleon sensors and quantify irrigation water usage. The research team was not involved in the site preparation as the intention of the study was to demonstrate the effectiveness of the WFDs and Chameleon sensors without altering any of the other agronomic practices employed by the farmer. On 2 August 2018, the area was divided equally into three blocks. In each block a capacitance sensor (Decagon ECH$_2$0 10HS, METER Group Inc., Pullman, U.S.A) was installed at depths of 0.25 m and 0.5 m, a WFD (Rural Integrated Engineering (Pty) Ltd., Pretoria, South Africa) installed at depths of 0.25 m and 0.5 m, and a Chameleon soil water sensor array (Rural Integrated Engineering (Pty) Ltd., Pretoria, South Africa) installed with the three soil water sensors buried at depths of 0.15 m, 0.25 m, and 0.5 m and the thermometer buried at 0.25

m. Capacitance sensors were connected to Em50 data loggers (METER Group Inc., Pullman, U.S.A) and set to record readings every 30 minutes. Farmer F was provided with training on the use of the WFDs and Chameleon soil water sensors to inform their irrigation scheduling and further requested to take daily readings from all sensors and record irrigation frequency and time length. The trial was to be run for 12 weeks and both a soil water balance and water footprint were to be conducted utilising the data obtained from the capacitance sensors and the yield data provided by Farmer F.

3.2.3 Discussion

On 17 August 2018, a miscommunication between Farmer F and a contractor resulted in the field being ploughed over. All WFDs, capacitance sensors, Chameleon sensors, and data loggers were destroyed, along with much of the shade-net structure as seen in Figure 3-1. At the time, Farmer F could not afford to repair the structure and so all new plantings were suspended until the City of Tshwane was able to conduct the necessary repairs. As a result, the trial could not be repeated.

During the 14-day period prior to the destruction of the equipment, Farmer F had irrigated for 30 minutes each day except for 14 August 2018. Prior to the start of the trial Farmer F reported that all her fields were irrigated for either 45 or 60 minutes every day. Farmer F attributed the shorter irrigation events, as well as the decision to not irrigate on 14 August, to the feedback that the WFDs and Chameleon sensors provided. Farmer F expressed that her experience using the WFDs and Chameleon sensors was positive and that she felt that these tools were a benefit to her production system, stating explicitly that she felt these tools should be provided to farmers as part of the Agri-parks support. Although the trial was not completed, the data (not shown) collected by Farmer F during the 14-day period showed that all Chameleon sensor arrays consistently gave blue and green responses across all sensors and all WFDs were triggered after each irrigation event. This indicated that over-irrigation was still occurring and further water savings could be made.

Figure 3-1: Damage at the Soshanguve FPSU test site 2018-12-12

3.3 Effect of mulching on water productivity and weed management at the Rooiwal Farmer Production Support Unit

3.3.1 Rationale

During initial consultation on 25 July 2018, the farmers of Cooperative 1 expressed that the major constraint to their production at the Rooiwal FPSU was insufficient water availability. As per the internal irrigation sharing agreement discussed in Chapter 2, Cooperative 1 was only permitted to irrigate in the mornings but recognised they could improve their irrigation efficiency to make better use of this allocation by investing in more efficient dripper irrigation lines to reduce their reliance on the dragline system. However, Cooperative 1 irrigated according to time length rather than a more objective means of irrigation scheduling. Additionally high weed pressure was observed at the Rooiwal FPSU and Cooperative 1 were often unable to keep their fields weed-free throughout the growing season, resulting in some fields being abandoned as weed pressure became too great.

Chameleon soil water sensors (Stirzaker et al. 2014) were identified as an appropriate tool to assist Cooperative 1 schedule irrigation more objectively. Due to the abundance of open veld in and around the Rooiwal FPSU, mulching with veld residues was identified as a potential intervention to reduce weed pressure and increase irrigation water use efficiency. Mulching with straw residues has shown to weed seed germination (Jodaugienė *et al.* 2006), decrease stand densities of weeds (Mtambanengwe *et al.* 2015), reduce weed infestations in vegetable crops (Zaniewicz-Bajkowska *et al.* 2009) while increasing infiltration rates (Adekalu *et al.* 2007) and water use efficiencies compared to non-mulched fields (Qin *et al.* 2015). However, the impact of such benefits is not universal and is highly dependent on agroecological context (Erenstein 2003).

A trial to demonstrate the effectiveness of the Chameleon soil water sensors, and to investigate the impact of different mulching intensities on the emergence and growth of weeds and the soil-water balance at the Rooiwal FPSU was proposed to Cooperative 1 at the end of August 2018. It was decided that the trial would be implemented according to a Randomised Complete Block Design (RCBD) in the next field that Cooperative 1 planted, irrespective of the crop choice. Between September and December 2018, Cooperative 1 experienced difficulties securing guaranteed markets, which led to several delays in the establishment of a new field suitable for the trial. It was decided that the trial would therefore begin at the beginning of January 2019, however, during the New Year’s period a rupture in the sewage line running under the fields of the Rooiwal FPSU resulted in raw effluent running into the fields. As a result, it was decided that the trial could not continue.

Figure 3-2: Leaking sewage line at the Rooiwal Agri-park on 2019-01-09

3.4 Effect of mulch on water productivity, weed pressure, and yields of Swiss chard: 2019 trial

3.4.1 Rationale

In light of the previous setbacks and the time frame of WRC project K5/2823//4 and this dissertation, the decision was taken to complete a trial under more controlled conditions at the University of Pretoria's Innovation Africa @UP campus. As discussed in Section 3.3, mulching with straw residues has shown to weed seed germination (Jodaugienė *et al.* 2006), decrease stand densities of weeds (Mtambanengwe *et al.* 2015), reduce weed infestations (Zaniewicz-Bajkowska *et al.* 2009), increase infiltration rates and reduce runoff (Adekalu *et al.* 2007) as well as increase water use efficiencies (Qin *et al.* 2015) under certain agroecological conditions (Erenstein 2003). In order to quantify the effects of different mulching treatments on the soil water balance, weed emergence and pressure, and the resulting effects on the yield of Swiss chard (*Beta vulgaris* subsp. *vulgaris* Flavescens Group cv. Fordhook Giant) in the CoT Metropolitan Municipality, a field trial replicating the production style and conditions of the smallholder farmers of the CoT Agri-park was established at the University of Pretoria's Innovation Africa @UP campus.

3.4.2 Materials and methods

A 20 x 40 m field (Figure 3-3) at the University of Pretoria's Innovation Africa @UP campus (25°44'58.12"S 28°15'36.74"E, 1371 meters above sea level) was identified as a suitable site. The field had lain fallow for two seasons was identified, as shown in. The field was ploughed on 5 February 2019 and tilled on 7 February 2019, and no other soil amendments or pre-emergent herbicides were applied as was the practice at the Rooiwal FPSU.

Figure 3-3: The research field prior to ploughing

The trial was set out following a RCBD of three 6 x 36 m blocks consisting of nine 6 x 4 m plots each as shown in Figure 3-4. In order to compensate for the edge effect and ensure that any impacts on yield and weed emergence were a direct result of the mulching treatment, a 1 m perimeter was excluded from each plot. Veld residues, to be used as mulch, were collected 200 m north of the trial from an old agricultural field that had been lain fallow for two years. The field was mowed on 12 March 2019 and the veld residues dried over a period of two days after which the residues were collected and weighed, averaging 210 g dry mass m^{-2}.

Nine treatments were assigned, as described in Table 3-1. Mulch treatments consisted of three ratios of veld residues, based on the average dry mass of residues per m^2 collected from the veld. In M_1 treatments veld residues were applied to the plots at a ratio of 1:1, receiving 210 g dry mass of veld residues dry mass per m^2. In M_2 treatments veld residues were applied to the plots at a ratio of 2:1, receiving 420 g dry mass of veld residues dry mass per m^2. In M_4 treatments veld residues were applied to the plots at a ratio of 2:1, receiving 840 g dry mass of veld residues dry mass per m^2. In order to compare the effectiveness of the veld residue mulch to plastic mulch, a treatment of 0.5 m wide 200-micron high-density polyethylene sheet mulch was included.

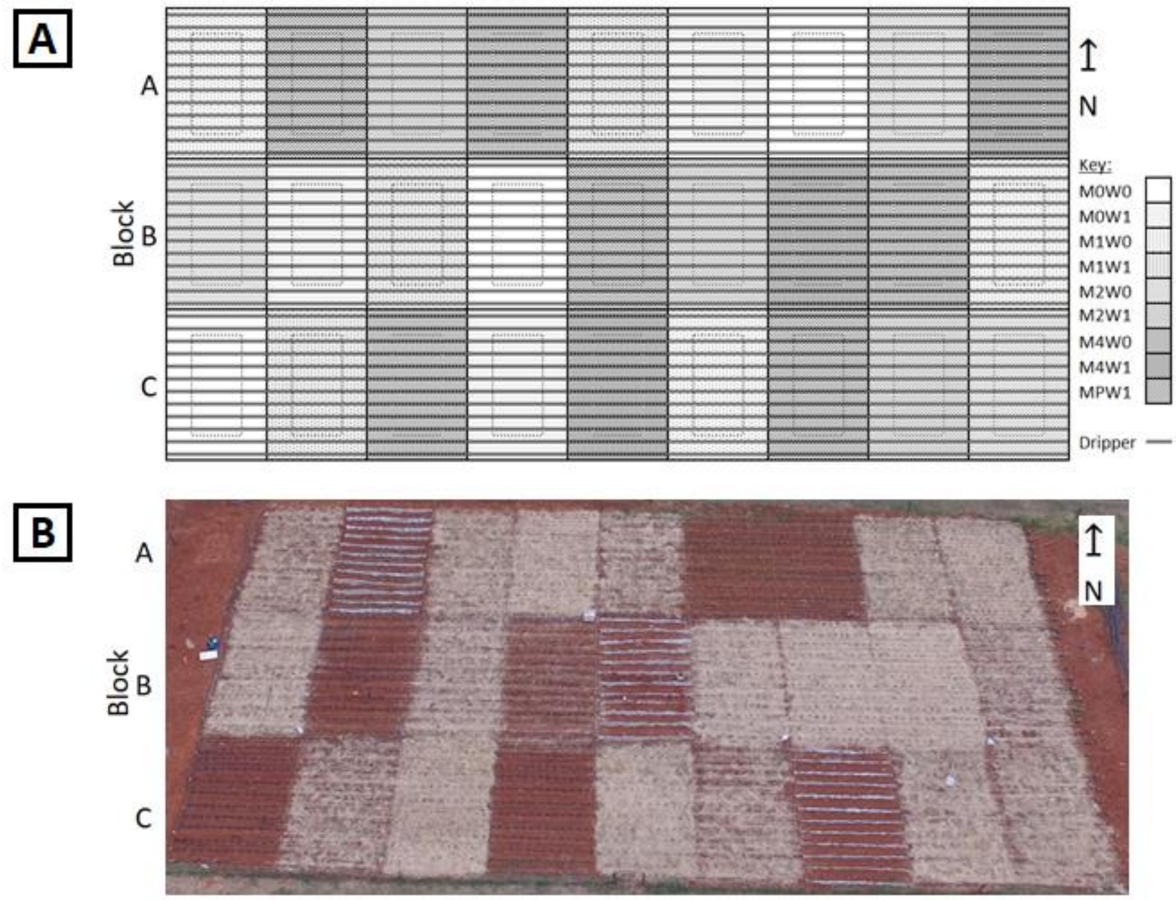

Figure 3-4: A) Layout of the trial B) Aerial photograph of trial

Drip irrigation specifications were selected to match that dripper lines used at the Rooiwal FPSU (2 l hr^{-1}, 0.3 m dripper spacing) and installed in the field at a 0.5 m row spacing. In order to quantify soil-moisture a capacitance sensors (Decagon ECH$_2$0 10HS, METER Group Inc., Pullman, U.S.A), WFD (Rural Integrated Engineering (Pty) Ltd., Pretoria, South Africa) and a suction cup (Irro Africa, Somerset West, South Africa) at depths of 0.25 and 0.5 m, and a Chameleon soil water sensor array (Rural Integrated Engineering (Pty) Ltd., Pretoria, South Africa) with the sensors at depths of 0.15, 0.25, and 0.5 m and the thermometer buried at 0.25 m, were installed in each plot of Block B. In order to quantify the impacts of mulching treatments on soil temperatures, locally produced thermocouples were installed in the M_0W_1,

M_2W_1, M_4W_1, and M_PW_1 treatments of Block B at a depth of 0.05 m. All equipment was installed along the shoulder of the respective row, aligned between two drippers.

Table 3-1: Mulching and weeding treatment combinations

Treatment Code	Treatment description
M_0W_0	No mulch No weeding
M_0W_1	No mulch Plot completely weeded every second week
M_1W_0	Mulch applied at a rate of 210 g dry mass of veld residues per m^2 No weeding
M_1W_1	Mulch applied at a rate of 210 g dry mass of veld residues per m^2 Plot completely weeded every second week
M_2W_0	Mulch applied at a rate of 420 g dry mass of veld residues per m^2 No weeding
M_2W_1	Mulch applied at a rate of 420 g dry mass of veld residues per m^2 Plot completely weeded every second week
M_4W_0	Mulch applied at a rate of 840 g dry mass of veld residues per m^2 No weeding
M_4W_1	Mulch applied at a rate of 840 g dry mass of veld residues per m^2 Plot completely weeded every second week
M_PW_1	0.5 m-wide 200-micron high-density polyethylene sheets Weeding not required as the no weeds can penetrate the polyethylene sheets

Swiss chard 'Fordhook Giant' was selected as this was a common crop grown at both the Soshanguve and Rooiwal FPSUs. Seedlings were produced in trays in the experimental farm's greenhouses, and planted out by hand at the two-leaf stage on 28 February 2019. As per Starke Ayres (2014), 2:3:4 was applied at a rate of 500 kg ha^{-1} (50 g m^{-2}). Fertiliser was applied to each plant individually rather than incorporated during field preparation, as is practice at the Rooiwal FPSU. The plants were irrigated daily for 45 minutes in order to facilitate establishment, after which irrigation was to be scheduled according to the readings obtained from the Chameleon soil water sensors.

The initial seedlings suffered severe transplant shock leading to a high mortality rate and on 19 March 2019 the field was replanted with the same cultivar from seed. However, poor germination occurred in the second planting with less than 40% of the seeds germinating successfully. Upon inspection, it was found that the dripper lines were shifting due to thermal expansion. This caused a misalignment between the drippers and the seeds during irrigation which lead to the seeds being on the margins of the horizontal wetting front rather than within the irrigated zone on the soil surface. This was determined to be the most likely cause of both the poor establishment of the initial planting and the poor germination in the second planting. Due to time constraints of the project, it was decided that the Swiss chard would not be replanted and that the trial would shift focus to the impact of the mulching treatments on weed pressure. Weeding treatments commenced from the initial planting date (28 February 2019) and were conducted by hand as was the practice at the Rooiwal FPSU. Weeds from each block were collected and identified to a species level, counted, and the total fresh mass of each species weighed using a triple-beam balance scale. Analysis of variance and Tukey's Honestly Significance Difference (Tukey's HSD) test was conducted using the Randomized Complete Block Anova function of the Real Statistics (Release 8.4) package for Microsoft Excel 2016.

3.4.3 Results

Analysis of variance of total weed biomass indicated that the differences between blocks were highly significant ($p < 0.01$, Appendix 3.1), with Block A producing a mean total weed biomass of 177.0 g fresh mass m^{-2}, Block B producing a mean total weed biomass of 47.2 g fresh mass m^{-2}, and Block C producing a mean total weed biomass of 82.2 g fresh mass m^{-2}. Tukey's HSD indicated that differences in total biomass of weeds between both Block A and Block B and between Block A and Block C were highly significant ($p < 0.01$, Appendix 3.2), but not significant between Block B and Block C ($p > 0.05$, Appendix 3.2). Due to the significant differences between blocks, data in Figure 3-5 are presented from each of the three blocks in order to illustrate the extreme variation, as well as the mean of the three blocks for each treatment. Analysis of variance indicated that the differences in total biomass of weeds between treatments were not significant ($p > 0.05$, Appendix 3.1).

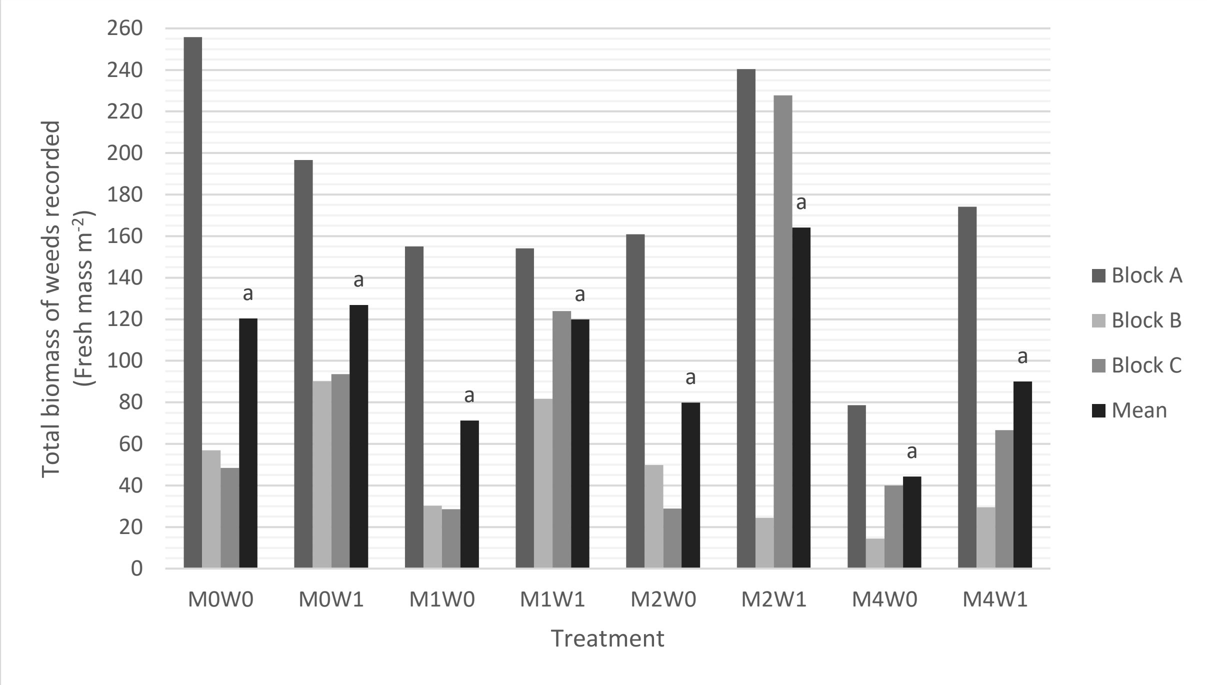

Figure 3-5: Total weed biomass recorded under no mulch and no weeding (M_0W_0), no mulch and biweekly weeding (M_0W_1), mulch at a rate of 210 g dry mass of veld residue per m^2 and no weeding (M_1W_0), mulch at a rate of 210 g dry mass of veld residue per m^2 and biweekly weeding (M_1W_1), mulch at a rate of 420 g dry mass of veld residue per m^2 and no weeding (M_2W_0), mulch at a rate of 420 g dry mass of veld residue per m^2 and biweekly weeding (M_2W_1), mulch at a rate of 840 g dry mass of veld residue per m^2 and no weeding (M_4W_0), and mulch at a rate of 840 g dry mass of veld residue per m^2 and biweekly weeding (M_4W_1). Treatment means with the same letters are not significantly different ($p > 0.05$).

Analysis of variance of mean weed population density indicated that the differences between blocks were highly significant ($p < 0.01$, Appendix 3.3), with a mean of 141.3 weeds per m^{-2} recorded in Block A, 48.1 weeds per m^{-2} recorded in Block B, and 71.6 weeds per m^{-2} recorded in Block C. Tukey's HSD indicated that the differences in mean weed population density between Block A and both Blocks B and C were highly significant ($p < 0.01$, Appendix 3.4), but differences between Block B and Block C were not significant ($p > 0.05$, Appendix 3.4). Due to the significant differences between blocks, data in Figure 3-6 are presented from each of the three blocks in order to illustrate the extreme variation, as well as the mean of the three blocks for each treatment. Analysis of variance indicated that the differences in mean weed population density between treatments were highly significant ($p < 0.01$, Appendix 3.3). Mean weed population densities under the unweeded (W_0) treatments were typically found to be lower than those recorded under weeded treatments (W_1, W_2, and W_4. Figure 3-6). The lowest mean weed population density was recorded under the M_4W_0 treatment at 23.4 weed weeds per m^{-2} (Figure 3-6), however, Tukey's HSD found this not to be significantly different from the mean weed population densities recorded under the other unweeded treatments (M_0W_0, M_1W_0, and M2W0. $p > 0.05$, Appendix 3.5). Mean weed population densities under the M_0W_0, M_1W_0, and M_2W_0 treatments were 72.9 weeds per m^{-2}, 39.6 per m^{-2}, and 47.4 per m^{-2}, respectively, (Figure 3-6) and differences between any combination of these unweeded treatments were not found to be statistically significant ($p > 0.05$, Appendix 3.5).

Mean weed population densities of the M_0W_1, M_1W_1, M_2W_1, and M_4W_1 treatments were found to be 130.5 weeds per m^{-2}, 148.3 weeds per m^{-2}, 119.2 weeds per m^{-2}, and 114.8 weeds per m^{-2}, respectively (Figure 3-6). Tukey's HSD indicated that differences between mean weed population densities were significant between the M_4W_0 treatment and M_2W_1 and M_4W_1 treatments ($0.01 < p < 0.05$, Appendix 3.5) and highly significant between the M_4W_0 treatment and both M_0W_1 and M_1W_1 treatments ($p < 0.01$, Appendix 3.5). Differences in mean weed population density were found to be significant between the M_1W_0 and M_0W_1 treatments ($0.01 < p < 0.05$, Appendix 3.5), highly significant between the M_1W_0 and M_1W_1 treatments ($p < 0.01$, Appendix 3.5), and significant between the M_2W_0 and M_1W_1 treatments ($0.01 < p < 0.05$, Appendix 3.5). Differences in mean weed population density between other treatment combinations were not found to be significant ($p > 0.05$, Appendix 3.5).

Analysis of variance of weed species richness indicated that the differences between blocks were significant ($0.01 < p < 0.05$, Appendix 3.6), with Block A recording a mean weed species richness of 43 species per plot, Block B recording a mean weed species richness of 37 species per plot, and Block C recording a mean weed species richness of 45 species per plot. Tukey's HSD indicated that the differences in weed species richness between Block B and Block C were significant ($0.01 < p < 0.05$, Appendix 3.7), but differences between Block A and both Block B or Block C were not significant ($p > 0.05$, Appendix 3.7). Due to the significant differences between blocks, data in Figure 3-7 are presented from each of the three blocks in order to illustrate the extreme variation, as well as the mean of the three blocks for each treatment.

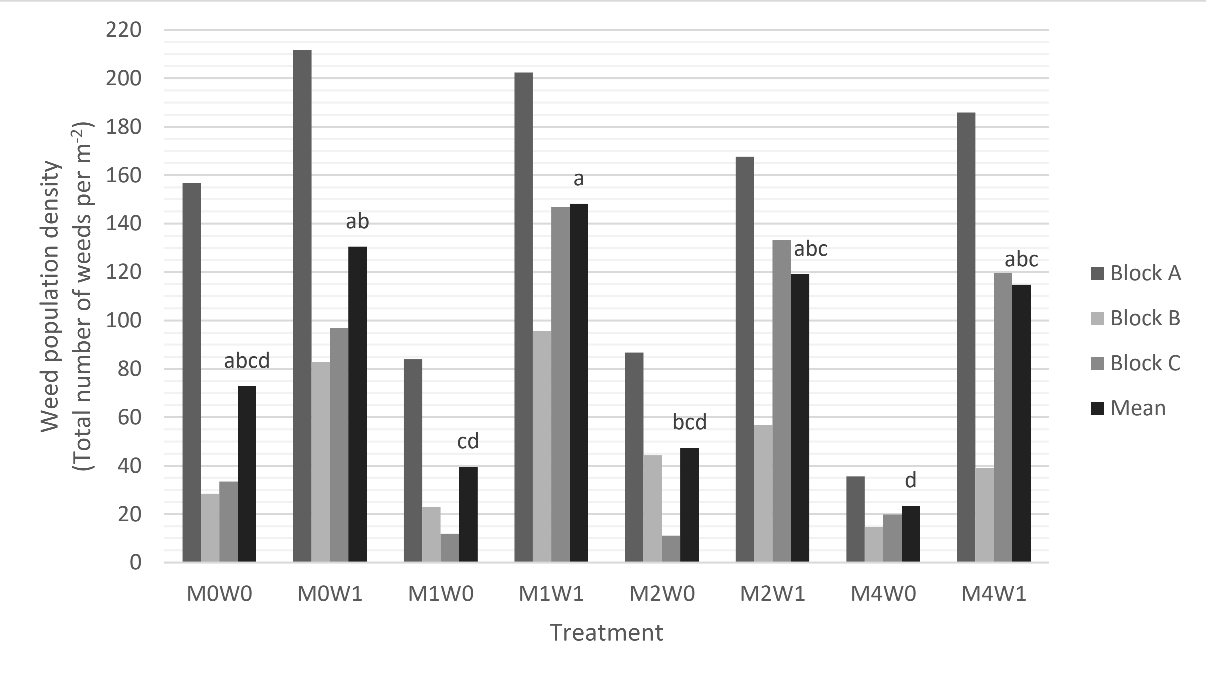

Figure 3-6: Mean weed population density recorded under no mulch and no weeding (M_0W_0), no mulch and biweekly weeding (M_0W_1), mulch at a rate of 210 g dry mass of veld residue per m^2 and no weeding (M_1W_0), mulch at a rate of 210 g dry mass of veld residue per m^2 and biweekly weeding (M_1W_1), mulch at a rate of 420 g dry mass of veld residue per m^2 and no weeding (M_2W_0), mulch at a rate of 420 g dry mass of veld residue per m^2 and biweekly weeding (M_2W_1), mulch at a rate of 840 g dry mass of veld residue per m^2 and no weeding (M_4W_0), and mulch at a rate of 840 g dry mass of veld residue per m^2 and biweekly weeding (M_4W_1). Treatment means with the same letters are not significantly different ($p > 0.05$).

Mean weed species richness was higher in the weeded (W_1) treatments than in the unweeded (W_0) treatments (Figure 3-7) and analysis of variance of weed species richness indicated that the differences between treatments were very highly significant ($p < 0.001$, Appendix 3.7). Mean weed species richness under the M_0W_1, M_1W_1, M_2W_1, and M_4W_1 treatments was found to be 65, 63, 70, and 56 weed species per plot, respectively, and mean weed species richness under the M_0W_0, M_1W_0, M_2W_0, and M_4W_0 treatments was found to be 22, 20, 19, and 18 weed species per plot, respectively (Figure 3-7). Tukey's HSD indicated that differences between all weeded (W_1) and unweed (W_0) treatments were highly significant ($p < 0.01$, Appendix 3.8) irrespective of mulching treatment. Differences in mean weed species richness between mulching intensities within the same weeding treatment were not found to be significant ($p > 0.05$, Appendix 3.8).

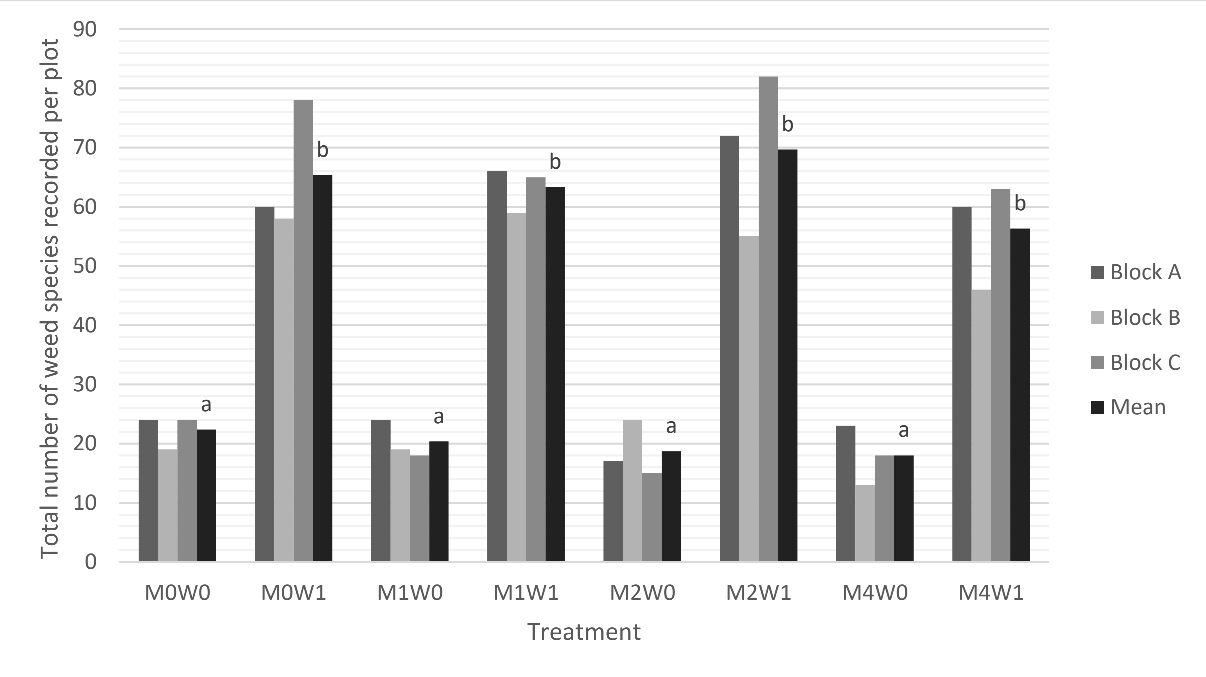

Figure 3-7: Total weed species richness recorded under no mulch and no weeding (M_0W_0), no mulch and biweekly weeding (M_0W_1), mulch at a rate of 210 g dry mass of veld residue per m^2 and no weeding (M_1W_0), mulch at a rate of 210 g dry mass of veld residue per m^2 and biweekly weeding (M_1W_1), mulch at a rate of 420 g dry mass of veld residue per m^2 and no weeding (M_2W_0), mulch at a rate of 420 g dry mass of veld residue per m^2 and biweekly weeding (M_2W_1), mulch at a rate of 840 g dry mass of veld residue per m^2 and no weeding (M_4W_0), and mulch at a rate of 840 g dry mass of veld residue per m^2 and biweekly weeding (M_4W_1). Treatment means with the same letters are not significantly different ($p > 0.05$).

3.5 Effect of mulch on water productivity, weed pressure, and yields of Swiss chard: 2022 trial

3.5.1 Rationale

Due to the repeated crop failure described in Section 3.4, the decision was taken to repeat the trial in order to quantify the effects of different mulching intensities and weeding practices on yield and water productivity of Swiss chard 'Fordhook Giant'. This trial follows the same rationale described in Section 3.4.

3.5.2 Materials and Methods

Field preparation

The 20 x 40 m fenced field (Figure 3-3) on the University of Pretoria's Innovation Africa @UP campus (25°44'58.12"S 28°15'36.74"E, 1371 meters above sea level) was selected as the site for the trial. The field had remained fallow since the previous trial in 2019. On 20 October 2022 the field was ploughed and rotovated and an area of 15 x 32 m marked and laid out according to a RCBD of three blocks of eight 4 x 5 m plots each. Drip irrigation (2 l hr^{-1}, 0.3 m dripper spacing) was installed on 2 November 2022 at 0.5 m row spacing and an aluminium neutron probe meter access tube was installed in the centre of each plot on the shoulder of the fifth row. Emerged weeds were treated on 5 November 2022 with a 2.5% solution of a generic glyphosate-based herbicide (360 g l^{-1} glyphosate concentrate as 480 g l^{-1} glyphosate isopropylamine salt) at a rate of 6 l ha^{-1}.

In order to reduce the chance of repeated crop loss described in Section 3.4, seedlings were identified as the preferred planting method. However, the application to procure Swiss chard seedlings was rejected by the University of Pretoria's Finance Department due to limited registered suppliers and the decision to sow seed directly was subsequently taken. Swiss chard 'Fordhook Giant' seeds were sown directly by hand on 14 November 2022. As per Starke Ayres (2014), 2:3:4 (30) fertiliser was applied at a rate of 500 kg ha^{-1} (50 g m^{-2}) at planting. The field was irrigated daily to facilitate germination and seedling establishment. A neutron probe meter (Model 503DR Hydroprobe, Neutron Depth Moisture Gage, Campbell Pacific Nuclear, California, U.S.A) was used to indirectly measure soil moisture on Mondays, Wednesdays, and Fridays.

Mulching treatments

Due to a shortage of available veld residues on the Innovation Africa campus at the time, bales of hay (*Eragrostis spp.)* were procured from a local farm for use as mulch. The eight weeding and mulching treatment combinations are described in Table 3-2 and were randomly assigned to plots within the RCBD. *Eragrostis* hay was weighed using a spring scale and laid out as mulch according to the assigned treatment from 10 – 12 November 2022.

Table 3-2: Mulch and weeding treatment combinations

Treatment Code	Treatment description
M_0W_0	No mulch No weeding
M_0W_1	No mulch Plot weeded clean every second week
M_1W_0	Mulch applied at 210 g dry mass m^{-2} No weeding
M_1W_1	Mulch applied at 210 g dry mass m^{-2} Plot weeded completely every second week
M_2W_0	Mulch applied at 420 g dry mass m^{-2} No weeding.
M_2W_1	Mulch applied at 420 g dry mass m^{-2} Plot completely weeded every second week
M_4W_0	Mulch applied at 840 g dry mass m^{-2} No weeding
M_4W_1	Mulch applied at 840 g dry mass m^{-2} Plot completely weeded every second week

Several days after the mulch was laid out, the presence of the harvester termite species *Hodotermes mossambicus* (Hagen) was detected in the field. 'Blue Death', a carbamate-based insecticide widely available through retail stores and commonly used by urban small-scale farmers in Gauteng (van der Linde 2000), was applied to the entrance tunnels of the colony to deter the termites from feeding within the field. However, the colony created numerous new tunnels averaging six new tunnel entrances per day across the field. Due to the size of the colony, reasonable application of a soil-drench insecticide was not feasible. Losses of mulch were substantial, as shown in Figure 3-8. The decision was taken to remove the mulching treatments from the trial and the remaining residues were removed from the field on 24 November 2022.

Figure 3-8: Impact of harvester termite (Hodotermes mossambicus) *foraging on mulch cover around one colony entrance over a 24-hour period*

Weeding Frequency

Due to the observed differences in weed emergence between plots under different mulching treatments, the decision was taken to remove all emerged weeds through chemical treatment. Between 28 - 30 November 2022 the field was sprayed with a 3.0% solution of a generic glyphosate-based herbicide (360 g l^{-1} glyphosate concentrate as 480 g l^{-1} glyphosate isopropylamine salt) at a rate of 8 l ha^{-1} using a knapsack sprayer. During spraying plastic cups were used to protect the Swiss chard seedlings, as shown in Figure 3-9. Each plot was sprayed individually with all of the seedlings in the surrounding plots protected with cups in order to prevent negative impacts on seedling growth from herbicide drift. Three days after spraying, weeds which had emerged close to the Swiss chard seedlings and were thus protected from herbicide application by the plastic cups were removed by hand.

Figure 3-9: Plastic cups used to protect seedlings from contact with the herbicide solution during spraying

The trial was laid out following a RCBD and the field was divided into six 5 x 16 m blocks with each block consisting of four 5 x 4 m plots. The four treatments are described in Table 3-3 and were randomly assigned within each block. Weeding was done by hand using a weeding trowel (Gardena, Ulm, Germany). Weeding treatments commenced from 30 November 2022. A Chameleon soil water sensor array (Rural Integrated Engineering (Pty) Ltd., Pretoria, South Africa) installed with the three soil water sensors buried at depths of 0.15 m, 0.25 m, and 0.5 m and the thermometer buried at 0.25 m was installed in each plot in Block C on the shoulder of the fifth row.

Table 3-3 : Weeding frequency treatments

Treatment Code	Treatment description
W_o	No weeding
W_1	Plot weeded completely once per 1-week cycle
W_2	Plot weeded completely once per 2-week cycle
W_4	Plot weeded completely once per 4-week cycle

Feeding activity of the harvester termites continued following the removal of the mulch, and termites were observed removing the remaining mulch residues as well as Swiss chard seedlings as shown in Figure 3-10. This resulted in significant seedling losses. The field was replanted between 10 – 12 December 2022 in areas where harvester termite activity had resulted in seedling mortality, and thinned between 24 – 26 December 2022 with the seedlings removed during thinning replanted in the remaining gaps within the field. The field was irrigated daily to facilitate germination of the seedlings while supporting the growth of established plants.

Figure 3-10: Harvester termite (<u>Hodotermes</u> <u>mossambicus</u>) dragging a section of a Swiss chard seedling towards the tunnel entrance of the colony, after cutting the seedling at the base and removing the leaves

The presence of the root rot fungal complex was detected in the field on 22 January 2023. Due to the soil borne nature of the disease complex chemical intervention is largely ineffective, particularly in established crops (Williamson-Benavides and Dhingra 2021). The decision was taken to equalise differences in plant size between plants of different planting dates, reduce irrigation to enhance the effect of weeds on crop regrowth, and harvest in two-week intervals until more than 10% of plants in any plot within a block succumbed to root rot. On 30 January, all plants were harvested by hand down to three leaves. Weed pressure was lower than expected, and the decision was taken to alter weeding treatments as described in Table 3-4.

Table 3-4: Adjusted weeding frequency treatments

Treatment Code	Original treatment	Number of weeks since last weeding prior to the adjusted regime	Adjusted treatment
W_o	No weeding	-	No weeding
W_1	Plot weeded completely once per 1-week cycle	1	Plot weeded completely once per 2-week cycle
W_2	Plot weeded completely once per 2-week cycle	2	Plot completely weeded once per 4-week cycle
W_4	Plot weeded completely once per 4-week cycle	4	Plot completely weeded once per 8-week cycle

Irrigation was scheduled according to readings obtained from the Chameleon sensor arrays to maintain consistent ‘green’ readings at 0.2 and 0.4 m depths in the control (W_1) plot. A neutron probe meter was used to indirectly measure soil moisture on Mondays, Wednesdays, and Fridays. Neutron probe meter readings were taken at 0.2 m intervals for a profile depth of 1.0 m in each plot, with three readings taken per depth and the average of the three readings used in the calibration equations below to determine volumetric water content (θ_v) in each plot. Calibration equations for the field were obtained from the Innovation Africa campus neutron probe meter technical assistant. Volumetric water content of the profile was determined using the calibration equations (Eqs. 3.1 – 3.5) where CR is the count ratio and n is the number of readings taken to determine the calibration equation. Mean θv under each treatment was plotted over time.

$$\theta_v = 0.169\ CR - 0.0344, r^2 = 0.9709, n = 8\ for\ 0.0\ to\ 0.2\ m\ depth \tag{3.1}$$

$$\theta_v = 0.153\ CR - 0.0612, r^2 = 0.9955, n = 8\ for\ 0.2\ to\ 0.4\ m\ depth \tag{3.2}$$

$$\theta_v = 0.143\ CR - 0.0486, r^2 = 0.8923, n = 8\ for\ 0.4\ to\ 0.6\ m\ depth \tag{3.3}$$

$$\theta_v = 0.123\ CR - 0.0087, r^2 = 0.7938, n = 8\ for\ 0.6\ to\ 0.8\ m\ depth \tag{3.4}$$

$$\theta_v = 0.142\ CR - 0.00278, r^2 = 0.7651, n = 8\ for\ 0.8\ to\ 1.0\ m\ depth \tag{3.5}$$

On 14 February the plots were revaluated. Several plots within three of the blocks were found to have mortalities greater than 10% due to root rot and were subsequently discarded from the trial. Plants in the remaining blocks were harvested by hand down to three leaves. Plants within a 1 m perimeter of each plot were excluded to remove the impact of the edge effect, and the total harvested fresh biomass of the remaining plants was recorded on an electronic scale (Precision Balance series, Labotec, Midrand, South Africa) within one hour of harvesting.

On 27 February the plots were revaluated. Several plots within the remaining three blocks were found to have mortalities of approximately 9% due to root rot and the early signs of a powdery mildew outbreak were detected. Plants were harvested of all leaves and total harvested fresh biomass of each plot recorded following the procedure described above.

Precipitation data was obtained from the Innovation Africa @UP campus weather station. Total precipitation and irrigation from initial planting (14 November 2022) to final harvest (27

February 2023) was used to determine the total water productivity (Eq. 3.6) and irrigation water productivity (Eq. 3.7) of each plot.

$$Total\ Water\ Productivity = \frac{Total\ harvested\ leaf\ fresh\ biomass}{Irrigation + precipitation\ during\ growing\ season} \tag{3.6}$$

$$Irrigation\ Water\ Productivity = \frac{Total\ harvested\ leaf\ fresh\ biomass}{Irrigation\ during\ growing\ season} \tag{3.7}$$

Analysis of variance and Tukey's HSD of the total harvested leaf fresh biomass and water productivity of the plots was conducted using the Randomized Complete Block Anova function of the Real Statistics (Release 8.4) package for Microsoft Excel 2016.

3.5.3 Results

The field received 331 mm of irrigation and 480 mm of rainfall between the initial planting on 14 November 2022 and the final harvest on 27 February 2023 (Figure 3-11). Heavy rainfall during the month of February resulted in a consistently wet soil profile, and readings from the Chameleon sensors remained blue throughout this period. As a result, no irrigation was required between 29 January and 27 February. Recurrent breakdowns of the neutron probe meter reduced the number of readings taken. Profile θ_v of W_0 treatments typically remained lower than other treatments (Figure 3-12) however, no discernible patterns between other treatments were observed during either of the two-week regrowth periods.

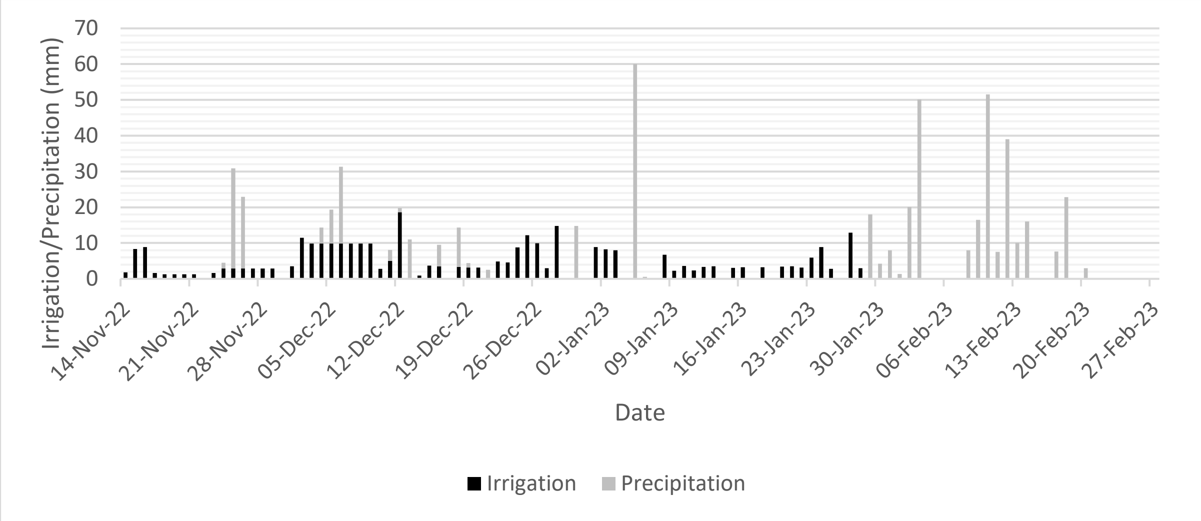

Figure 3-11: Irrigation and precipitation from initial planting (14 November 2022) until harvest (27 February 2023)

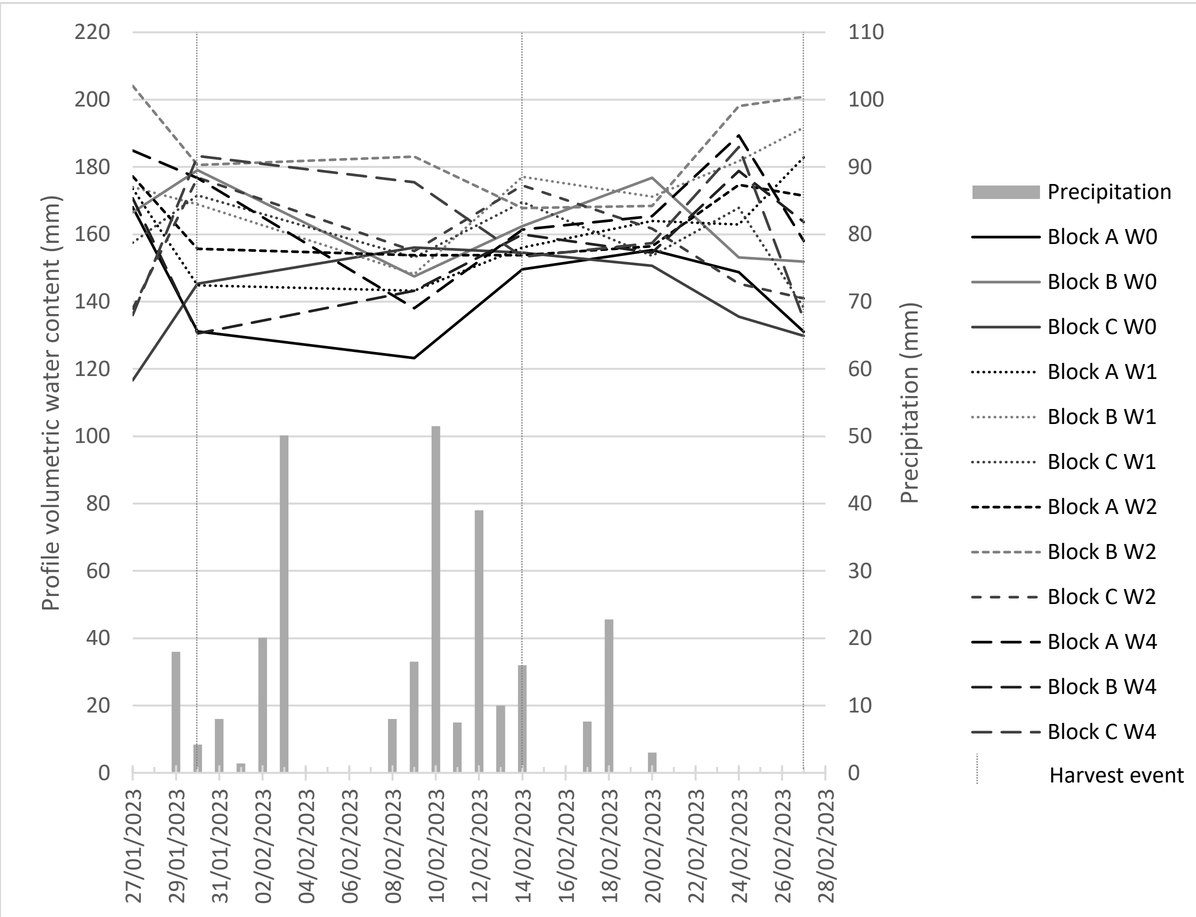

Figure 3-12: Profile ϑv during regrowth of an established Swiss chard field under different weeding frequencies following two harvest events

Analysis of variance of yields indicated differences between blocks were not significant ($p > 0.05$, Appendix 3.9), while differences between weeding regimes were found to be highly significant ($p < 0.01$, Appendix 3.9). Mean yields obtained under each treatment were 5.8 t ha^{-1} under the W_0 weeding regime, 24.5 t ha^{-1} under the W_1 weeding regime, 21.6 t ha^{-1} under the W_2 weeding regime, and 16.6 t ha^{-1} under the W_4 weeding regime (Figure 3-13). Tukey's HSD indicated that the differences between yield obtained in the unweeded (W_0) plots and yields obtained under the W_1, W_2, and W_4 weeding regimes were highly significant ($p < 0.01$, Appendix 3.10). Yields obtained in the W_1 treatments were not found to significantly different from the yields obtained in the W_2 treatments ($p > 0.05$, Appendix 3.10), but differences were highly significant when compared to the yields obtained in the W_4 treatments ($p < 0.01$, Appendix 3.10). Differences in mean yields obtained in the W_2 treatments and W_4 treatments were found to be significant ($0.01 < p < 0.05$, Appendix 3.10). Relative to the W_1 treatments, mean yield losses were 12% under the W_2 treatments, 32% under the W_4 treatments, and 76% under the unweeded treatments (W_0).

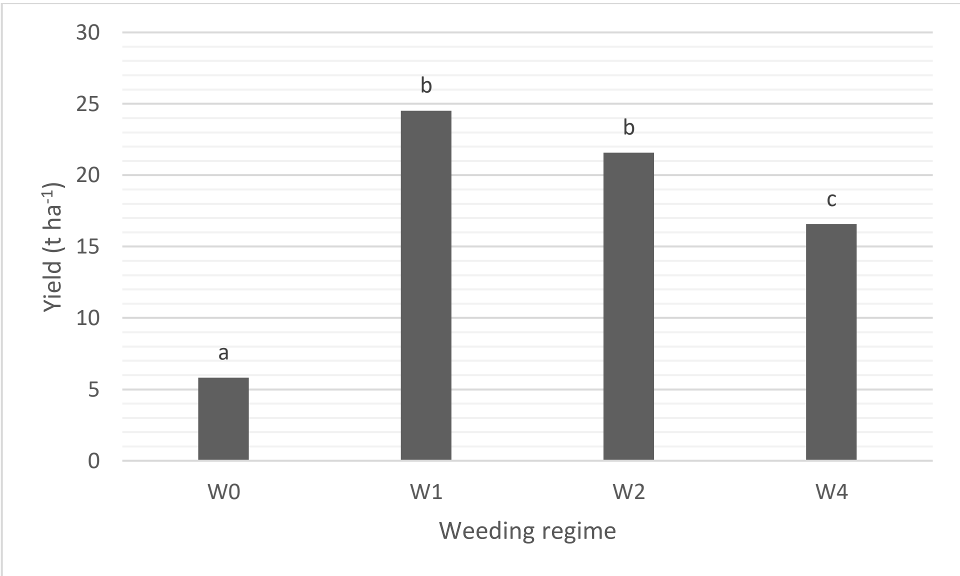

Figure 3-13: Mean Swiss chard yield under no weeding (W_0), weeding on a two-week weeding cycle (W_1), weeding on a four-week weeding cycle (W_2), and weeding on an eight-week weeding cycle (W_4). Treatment means with the same letters are not significantly different ($p > 0.05$).

Analysis of variance of mean total water productivity indicated that the differences between blocks were not significant ($p > 0.05$, Appendix 3.11), but differences between weeding regimes were highly significant ($p < 0.01$, Appendix 3.11). Mean total water productivity was 0.7 kg m^{-3} under the W_0 weeding regime, 3.0 kg m^{-3} under the W_1 weeding regime, 2.7 kg m^{-3} under the W_2 weeding regime, and 2.0 kg m^{-3} under the W_4 weeding regime (Figure 3-14). Tukey's HSD indicated that differences in mean total water productivity under the W_0 weeding regime and mean water productivities under the W_1, W_2, and W_4 weeding regimes were highly significant ($p < 0.01$, 0). Differences in mean water productivity of the W_1 weeding regime were not found to be significantly different from the mean water productivity of the W_2 weeding regime ($p > 0.05$, 0) but were found to be significantly different from the mean water productivity of the W_4 weeding regime ($0.01 < p < 0.05$, 0). Differences in mean total water productivity of the W_2 and W_4 weeding regimes were found to be significantly different ($0.01 < p < 0.05$, 0).

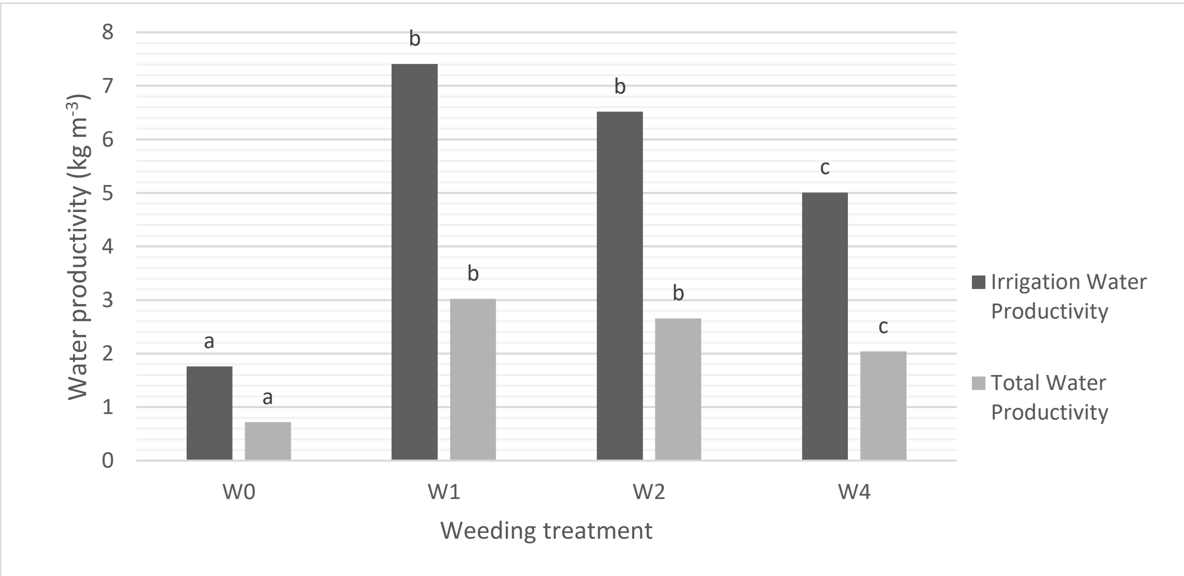

Figure 3-14: Mean total water productivity of Swiss chard under no weeding (W_0), weeding on a two-week weeding cycle (W_1), weeding on a four-week weeding cycle (W_2), and weeding on an eight-week weeding cycle (W_4). Treatment means of the two different water productivities with the same letters are not significantly different ($p > 0.05$).

Analysis of variance of mean irrigation water productivity indicated that the differences between blocks were not significant ($p > 0.05$, Appendix 3.13) but differences between weeding regimes were very highly significant ($p < 0.001$, Appendix 3.13). Mean irrigation water productivity was 1.8 kg m^{-3} under the W_0 weeding regime, 7.4 kg m^{-3} under the W_1 weeding regime, 6.5 kg m^{-3} under the W_2 weeding regime, and 5.0 kg m^{-3} under the W_4 weeding regime (Figure 3-14). Tukey's HSD indicated that differences in mean irrigation water productivity under the W_0 weeding regime and mean irrigation water productivities under the W_1, W_2, and W_4 weeding regimes were highly significant ($p < 0.01$, Appendix 3.14). Differences in mean irrigation water productivity of the W_1 weeding regime were not found to be significantly different from the mean irrigation water productivity of the W_2 weeding regime ($p > 0.05$, Appendix 3.14), but were found to be significantly different from the mean water productivity of the W_4 weeding regime ($0.01 < p < 0.05$, Appendix 3.14). Differences in mean total water productivity of the W_2 and W_4 weeding regimes were found to be significantly different ($0.01 < p < 0.05$, Appendix 3.14).

3.6 Discussion

3.6.1 Effect of mulch on water productivity, weed pressure, and yields of Swiss chard: 2019 trial

The extreme variability in the weed seedbank observed in the field, although similar to the weed pressure at the Rooiwal FPSU, is not typical of cultivated agricultural fields and as such results from this trial should be treated with caution. Weed biomass is a function of a number of factors, including weed population density and species composition. Given that the differences in both weed population density and total weed biomass between Block A and both Blocks B and C across treatments were highly significant, it is likely that the higher weed total biomass observed in Block A was largely the result of a greater active weed seedbank as a result of greater weed seed shed in previous seasons, although the cause of this is unclear. Differences in mean weed species richness between Block A and Block C were not found to be significant, however, this does not inherently indicate that species composition did not have some influence in the higher weed total biomass observed in Block A.

Neither weeding nor mulching had a significant effect on the total weed biomass produced, however, some interactions between mulching and weeding treatments had a significant effect on the number of weeds that emerged in each plot. Mulching at a rate of 840 g dry mass of veld residues per m^2 without weeding (M_4W_0) resulted in significantly fewer weeds than in the plots that were weeded regardless of the presence of mulch. This is to be expected as thicker mulch layers are associated with increased weed suppression (Ranaivoson *et al.* 2018). However, this effect was lost when regular weekly weeding was applied (M_4W_1 treatment) indicating that the process of hand weeding disturbed the mulch layer sufficiently to create gaps through which weed seeds were able to germinate and emerge successfully. Lower quantities of mulching residues had a more variable effect on the number of weeds. Mulching at a rate of 210 g dry mass of veld residues per m^2 without weeding (M_1W_0) resulted in significantly fewer weeds than in the unmulched weeded plots (M_0W_1). This quantity of mulch was insufficient to form a contiguous layer of mulch over the soil surface and so this affect is more likely the result of an effect other than mulch acting as a physical barrier for weed seedlings. Similarly, mulching at a rate of rate of 420 g dry mass of veld residues per m^2 without weeding (M_2W_0) resulted in significantly fewer weeds than in the plots than in the weeded plots with fewer mulch residues (M_1W_1). Mulching at a rate of rate of 420 g dry mass of veld residues per m^2 did create a contiguous layer of mulch. However, given that the significant differences were only between a lesser mulching intensity that was weeded, it is likely that the effect on the number of weeds is more likely associated with the disturbances the weeding practices create in both the mulch layer and the soil surface. Weeding had a significant effect on the weed species richness of the plots, with the mean species richness of weeded plots 321% greater than the mean species richness of unweeded plots. This is likely a result of disturbance of the soil surface as a result of weeding, which created more favourable conditions for weed seed germination. Weed species richness is an important factor in weed management as a greater number of weed species increases the diversity of weed lifecycles a farmer will need to disrupt in order to effectively control weeds.

Despite crop failure that prevented the demonstration of the water-saving benefits of mulching, an extensive body of research that supports mulching as a water-saving practice already exists (Kader et al. 2017). During a Focus Group Meeting at the Rooiwal FPSU on 25 February 2020, mulching as a water-conservation practice was discussed with the farmers. The farmers indicated that they had used mulching in the past, but the practice was stopped because in the farmers' opinion it made hand weeding difficult. Based on these discussions and the results of the trial it is likely that the farmers were not creating a contiguous layer of mulch that would have suppressed weed emergence. It is recommended that, where possible, farmers mulch at a rate of 840 g dry mass of veld residues per m^2 (M_4) in order to create a contiguous layer of mulch and limit disturbance of the mulch layer as much as possible. Where there is insufficient residues, or labour, to apply this quantity of mulch across an entire field, it is recommended farmers concentrate residues to the largest area possible without decreasing the rate below 840 g dry mass of veld residues per m^2, rather than spread the residues at a lower rate, as this would result in the greatest weed suppression possible.

Given the extreme weed pressure at the Rooiwal FPSU it is also recommended that an integrated weed management programme is implemented urgently in order to reduce further seed shed. As noted in Chapter 2, farmers at the Rooiwal FPSU had indicated a hesitation towards using herbicides. A site-specific integrated weed management programme for the Rooiwal FPSU, it must be accompanied with appropriate training and educational material about scientific best practices to enable farmers to make informed decisions that are best suited for their context.

3.6.2 Effect of mulch on water productivity, weed pressure, and yields of Swiss chard: 2022 trial

As with the previous field trials, the challenges experienced with this trial demonstrate the precarity of smallholder agricultural production and reinforce the need for integrated, context-specific agricultural extension and support services within the Agri-parks model. The benefits of mulching with straw and veld residues are well documented in the literature, however, such practices are not inherently feasible and their suitability should be assessed on a case-by-case basis. Veld residues were abundantly available from the Innovation Africa

@UP campus during the 2019 trial, however this was not the case for the 2022 trial and residues had to be brought in. The additional financial costs make this an unlikely solution for the Agri-parks model and, with the additional carbon emissions through transportation, will increase the net environmental impact of the production system, decreasing sustainability.

The presence of harvester termites was not noted at either the Soshanguve or Rooiwal FPSUs, however both sites fall within the specie's distribution range and the species has been recorded extensively across the City of Tshwane Metropolitan Municipality (iNaturalist 2023). The example of the harvester termites highlights the potential antagonisms between nature and agriculture that are often overlooked in discussions on agricultural sustainability. Increased on-farm biodiversity is typically viewed to be positive and, in indigenous ecosystems, harvester termites play a key role in the carbon cycle by collected aboveground biomass and transporting these residues deep into the soil profile (Symes and Woodborne 2011). However, while increasing carbon in agricultural soils is documented to have a number of benefits (Blanco-Canqui *et al.* 2013, Lal 2006), it is unclear if the crops would be able to access the organic carbon deposits left behind by termites due to the depth and fragmented nature of the colony structure. Additionally the persistent foraging activity following the removal of the mulch negatively impacted crop establishment necessitating replanting.

The over-irrigation necessary for seedling establishment likely contributed to the spread of the root rot fungal complex, which was further exacerbated by the high rainfall during the month of February. Although no discernible patterns in the changes in soil moisture between weeding regimes were observed during the two two-week regrowth periods, this is largely due to the persistent rain maintaining wet soil conditions. A large body of research has demonstrated that weeds negatively contribute to the soil water balance by increasing non-productive water losses through transpiration and under water-stressed condition will compete with crops for moisture.

In addition, weeds negatively affect crop development through a number of mechanisms as evident in the reduced yields observed in the plots with less frequent weeding. The mean yield gap between the control (W_1) and the unweeded plots (W_0) was 76%, thus achieving the same quantity of harvestable biomass would require 324% more land area and agricultural inputs, as all treatments received the same quantity of fertiliser and irrigation water. However, less frequent weeding regimes can improve productivity relative to no weeding. Mean yield gaps between the W_1 and the W2 and W4 weeding treatments were 12% and 32%, respectively, requiring 14% and 48% more land area and agricultural inputs to achieve the same quantity of harvestable biomass as the W_1 weeding treatments. In comparison to the unweeded (W_0) plots, the W_2 and W_4 treatments would theoretically require 27% and 35% of the land surface and agricultural inputs in order to achieve the same quantity of harvestable biomass.

Irrigation water productivities recorded for the W_1 treatment in this trial were comparable to those reported for Swiss chard in other studies, including the 7.58 kg m^{-3} reported by Mekonnen and Hoekstra (2011) and 7.47 kg m^{-3} reported by Maboko *et al.* (2018). This affirms that despite the challenges experienced throughout the trial, the data collected in the trial was not compromised. Increasing water productivities is a key component of sustainable intensification (SI) in the South African context where catchments are over-allocated and competition for water resources continues to increase (Le Roux *et al.* 2018). Increasing irrigation water productivity has a two-fold sustainability impact by decreasing both the amount of water applied and the energy required for pumping relative to the quantity of Swiss chard produced. Returning to the premisses of SI laid out by Garnett *et al.* (2013), increased production through higher yields is a necessity of SI in order to bolster food security while limiting environmental impacts of production. Agronomic practices which have a positive effect on yields, such as regular weeding, must be employed to their full extent.

3.7 Conclusions

The various circumstances that hindered the field trials at both Soshanguve and Rooiwal were unfortunate and beyond the control of both the farmers and the research group. Nonetheless, these disruptions are themselves a product of the daily challenges faced by the farmers in their production and if the Agri-parks programme is to uphold the original principles of maximising production and resource-use efficiency (DRDLR 2016) then basic practices such as the maintenance of irrigation infrastructure must be carried out regularly. These challenges also reflect the danger of centralising, rather than decoupling, institutional support through the Agri-parks model. Clearer communications channels are required when coordinating multiple parties in order to prevent the type of miscommunication that led to the ploughing of the research field at Soshanguve and to ensure repairs are carried out as quickly as possible on infrastructure under the jurisdiction of other governmental departments, such as the burst sewage line at Rooiwal.

Due to the complications, the field trials did not demonstrate the benefits of the WFDs and Chameleon sensors as intended. However, both Farmer F and the farmers of Cooperative 1 felt that these tools would be beneficial to farmers in the Agri-parks, and should be provided as part of the support provided by DRDLR. Farmer F specifically expressed that she felt such tools would have been a better investment than the provision of other equipment, as discussed in Chapter 2. Although the trial was not completed, the data (not shown) collected by Farmer F during the 14-day period showed that all Chameleon sensor arrays consistently gave blue and green responses across all sensors and all WFDs were triggered after each irrigation event. This indicated that over-irrigation was still occurring and further water savings could be made.

The trials conducted at the Innovation Africa @UP campus confirmed that regular weeding can have a positive impact on a crop's water productivity and reduce yield losses, and it is recommended that farmers be encouraged to weed at least every two weeks and that efforts are made to support the farmers in the Agri-parks programme to manage weeds effectively. The use of veld residues as a mulch showed more variable benefits with regards to weed suppression and although a body of research supports the benefits of mulching as a water-saving tool and weed suppressant, the suitability of this should be assessed on a case-by-case basis (Erenstein 2003). In order for the Agri-parks programme to fit the premises of SI laid out by Garnett *et al.* (2013) agronomic practices that have a positive impact on yields, such as regular weeding, must be employed to their full extent. More support is required to assist the farmers in the Agri-parks programme with managing weeds and water resources more effectively than is currently available, and it is in the interest of the programme for the DRDLR to intervene and provide the necessary extension and support services as per the Agri-parks model (DRDLR 2017b).

Chapter 4: Beta-testing of a social media-based agricultural science learning programme

4.1 Introduction

In order to create an integrated and inclusive rural economy in South Africa, the National Development Plan recommends improving and extending skills development in the agricultural sector, and investigating whether extension and other agricultural services are appropriately located at a provincial level (National Planning Commission 2012). This is to include "training a new cadre of extension officers to respond to the needs of smallholding farmers and contribute to their integration into the food value chain", as well as investigating "innovative means for agricultural extension and training by the state, in partnership with industry" (National Planning Commission 2012). However, despite the ever-increasing importance of social media within society and the existence of the number of virtual communities of farmers on these platforms, little research has been conducted on the potential of social media as a means of providing agricultural extension and training in South Africa.

Social media offers users the opportunity to connect and interact with tens of millions of other users remotely over vast geographic distances. Social media has been used to form online communities for knowledge sharing and social interaction across various sectors, including all aspects of the agricultural value chain. Research from Kenya indicates 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). Similarly, research from Nigeria recommends that agricultural extension training should encourage e-learning programmes using various social media platforms (Thomas and Laseinde 2015), while agricultural extension officers in India and Bangladesh are increasingly turning to social media to disseminate information to farmers within their constituencies (Indhuja *et al.* 2019, Kamruzzaman *et al.* 2019). Despite the opportunities for agricultural scientists to remotely connect with vast numbers of farmers across wide geographic spaces and agroecosystems, no available research has tested the practicalities of using social media as a platform for hosting an agricultural science e-learning programme.

In order to investigate the potential of Facebook as a platform to host free e-learning programmes prepared in a university environment for smallholder farmers, a programme on the fundamentals of weed science was created. This topic was selected due to the substantial impact of weeds and weed management on all aspects of production, and its importance in the context of smallholder farmers in SSA.

4.2 Materials and Methods

Facebook was selected as the most appropriate social media platform on which to run a learning programme for two reasons. Firstly, unlike most other social media platforms which only allow users to post one or two types of multimedia, Facebook allows users to make Posts as text, pictures, videos, links to external web pages, and other options either alone or in combination. Secondly, from previous experience it was known that a large number of online communities of smallholder farmers were already active on Facebook through the platform's Groups function.

Terminology in this section is used as presented in the data files downloaded from the Facebook Insights portal. The Facebook Insights portal is accessible to the administrators of a Facebook page and provides an extensive list of data and analytics for the page from which the social media performance of a page and its content can be gauged. Descriptions of these terminologies have been compiled in Table 4-1. To determine interest in a social media-based learning programme, a poll was run on 19 September 2019 on the Ingesta: Farming for the Future Facebook page (www.facebook.com/IngestaFarming, herewithin referred to as 'the Ingesta Page' for brevity). A learning programme on the fundamentals of weed science was created, due in part to the importance of sound weed management in African smallholder agriculture and the observations of elevated weed pressure made at the Rooiwal Farmer

Production Support Unit. The learning programme consisted of 14 chapters (Appendix 4.1) with each chapter comprising of a different aspect of weed science. Chapters were prepared using Google Docs, as this platform allows users to insert Unicode emoticons as they appear on posts on the Facebook platform. An online readability tool (https://www.webfx.com/tools/read-able/check.php) was used to ensure that post readability did not exceed an average grade level of 12.

Each chapter contained no more than 1500 words, included supporting diagrams, figures, and pictures where applicable, and contained a link to a five-question multiple-choice online test (Appendix 4.2). The programme also included a 30 mark multiple-choice online test at the end (Appendix 4.4). Tests were hosted through Google Forms, and marked using the automated grading function.

On 3 October 2019, a post was made on the Ingesta Page announcing the launch of the learning programme. Participants were required to complete an enrolment form via a Google Form (Appendix 4.3) with the intention of collecting biographical information such as age, gender, and geographic location of the participants, agricultural experience and previous formalised agricultural training, land ownership, irrigation and cropping choices, and expectations of the learning programme.

The learning programme was run from 7 October to 27 October 2019. Chapters of the learning programme were posted daily on the Ingesta Page from 7 October to 20 October 2019 through the Facebook page automated scheduling feature. The decision to release the learning programme in chapters rather than releasing the entire programme at once was taken in order to reduce the chances of participants becoming overwhelmed by receiving the entire programme's content at once, and to ensure constant web traffic on the Ingesta Page throughout the programme. However, participants were permitted to join at any time throughout the period of the learning programme.

Table 4-1: Descriptions of Facebook terminologies compiled from the definitions provided in the data files accessible through the Insights portal, information available through the Facebook Help Centre, and the author's experience using the Facebook platform.

Term	Level	Description	Unit
Like	Page, Post, and Individual media within a Post	A way for Facebook users to show their appreciation for content on the Facebook platform. At a Page level, users Like a page by clicking on the Like button that will then ensure that the content published by the page will show up in the user's News Feed. At the Post level, users will Like a Post or the individual media within a post by clicking the Like reaction. When a user Likes a piece of content, it is displayed in their News Feed with their friends and followers as a Story.	Number of Likes
Lifetime Total Likes	Page	The cumulative Likes a Page has amassed throughout the history of the Page	Number of Likes
Follow	Page and User	A way for Facebook users to add the content of a Page or another user onto their News Feed.	
Reaction	Post, and Individual media within a Post	A way for users to express their feelings towards a piece of content on the Facebook platform, represented by one of a set of emoticons. Reactions were introduced in 2016 as an expansion of the original Like button. There are currently five reactions: • 'Like' denoted by an emoticon of a thumbs-up • 'Love' denoted by an emoticon of a heart • 'Haha' denoted by an emoticon of a laughing face • 'Wow' denoted by an emoticon of a gasping face • 'Sad' denoted by an emoticon of a face with a tear drop out the left eye • 'Angry' denoted by an angry face emoticon	Number of Reactions
Comment	Post, and Individual media within a Post	A message that posted in response to a Post, the individual media within a Post, or other Comments on the Post. Comments can be viewed by any user who has access to the content that they are associated with.	Number of Comments
Share	Page, Post, and Individual media within a Post	An action by a user to repost a piece of content from another user or a Page. A user can Share the content onto their own Timeline, onto another user's Timeline, into a Group the users is a part of, through a private message, or as a link onto a different platform. When users share content onto a Timeline or into Groups, the user has the option of adding their own status which will be displayed about the content the user has Shared. Content which is shared onto a Timeline will be visible to the friends and followers of the user on whose Timeline the content was Shared.	Number of Shares

Story*		Stories are a type of content which show the actions of users to the user's friends and followers. Actions include Liking a Page, Post, or individual media within a post, commenting on a Post, and Sharing content.	
News Feed		A list of content in the middle of the user's home page of the Facebook platform. Content includes Posts made up of status updates, photos, videos, and links posted by Pages and other accounts that the user follows as well as advertisements. The News Feed is one of the primary ways that users discover and interact with content on Facebook.	
Timeline		A personalised section of the Facebook platform which displays all the Posts, Shares, and other content posted by a user in inverse chronological order.	
Follower	Page and User	A user who has opted to view and interact with the content of a Page or the public content of another User within their News Feed.	Unique Users
Friend	User	A user who has mutually agreed to connect with another user. When users add each other as Friends on the Facebook platform, the users will be able to view and interact with each other's public and private content within each other's News Feeds, view private information on each other's profiles, and send private messages through the Facebook Messenger function.	Unique Users
Page		A profile of a business, organisation, movement, or public figure on the Facebook platform. Pages differ from the personal profiles of users in that they are typically have fewer privacy options and have a greater number of features to share information and promote a brand or ideology.	
Group		An online community of users and Pages on the Facebook platform who share a common interest. Groups are created and administrated by users through either the user's personal account or a Page that the user is an administrator of. The conditions of joining and remaining a part of the Group, as well as the privacy settings of the Group, are determined by the administrators of the Group.	
Engagement	Page or Post	User activity such as Reacting, Commenting, Sharing, or clicking on links on a Page or Post that indicates active interaction with the content or profile	
Engaged Users	Page or Post	The number of unique people who engaged in certain ways with your Page post, for example by commenting on, liking, sharing, or clicking upon particular elements of the post.	Unique Users
Post Details		An interface accessible to Page Administrators which provides an overview of a number of social media metrics of a particular Post. These metrics include Reach, Reactions, Comments, Shares, and Post Actions	

Total Reach	Page and Post	The number of users who had any content from or about the Page enter their screen, such as posts, check-ins, advertisements, social information from other users who interact with the Page, and more.	Unique Users
Organic Reach	Page and Post	The number of users who had any content from or about the Page enter their screen through unpaid distribution, such as Posts, Stories, check-ins, and social information from other users who interact with the Page, and more.	Unique Users
Viral Reach	Page	The number of users who had any content from or about the Page enter their screen with social information attached, such as a Story of when a friend Likes or Follows the page, engages with a Post, or Shares a photo from the Page and checks into the page.	Unique Users
Paid Reach	Page and Post	The number of users who had any content from or about the Page enter their screen through paid distribution such as an advertisement.	Unique Users
Engaged Users		The number of unique people who engaged in certain ways with your Page post, for example by commenting on, liking, sharing, or clicking upon particular elements of the post.	Unique Users
Post Details		An interface accessible to Page Administrators which provides an overview of a number of social media metrics of a particular Post. These metrics include Reach, Reactions, Comments, Shares, and Post Actions	

*At the time of the study stories, a more recent feature which gives users the ability to post a video or image as a status different to the traditional post structures, had not yet been launched on the Facebook platform

On 23 October, three days after the last chapter of the learning programme was posted, the link to the final test of the learning programme was posted on the Ingesta Page. The form contained both the 30 mark multiple-choice test and a series of questions on the participants' experience of the learning programme (Appendix 4.4). The form remained open for four days until 23:59 on 27 October 2019 in order to give participants time to prepare before and complete the test. Participants were permitted to attempt the final test at any time during this period. Marks from the 14 chapter tests (70 marks in total) and the final test (30 marks) were combined and participants were required to have achieved a minimum combined mark of 50% in order to successfully complete the learning programme. Participants were permitted to retake the chapter tests, with only the highest mark being recorded. However, only the mark from the first attempt of the final test was recorded. Participants who successfully completed the learning programme received a certificate of their participation (Appendix 4.5).

Due to the small number of farmers currently within the CoT Agri-park, it was decided that the learning programme would be open to the public to better understand the reach potential of social media in the context of agricultural science education. To promote the learning programme, as well as making the information contained in the chapters as widely available as possible, it was decided that the chapter posts would be shared by the Ingesta Page into Facebook groups catering to smallholder farmers in Africa. A total of 21 suitable groups were identified based on a combination of the group's activity, previous experience sharing posts from the Ingesta Page into the group, and permission for the Ingesta Page to post within the group.

Page- and post-level data from 9 September to 17 November 2019 were downloaded through the Ingesta Page's Insight's portal on 18 November 2019. The 70-day period included 28 days prior to the start of the learning programme, the 14 days that the learning programme chapters were posted, and 28 days following the last learning programme chapter post. The data were used to determine the impact of the learning programme on traffic and post engagement on the Ingesta Page, and to explore the potential applications of the data provided to Facebook page administrators in the context of researching social media-based agricultural science learning programmes. Lifetime Total Likes, daily Engaged Users, and daily Total Reach of the Ingesta Page were compared during the 70-day period. Total Reach, Organic Reach, Viral Reach, and Paid Reach at both page- and post-level were compared in order to understand the relationship between these different metrics. Total Reach, Organic Reach, and Paid Reach of the 14 learning programme chapter posts were compared and relationship between Total Reach and the proportion of Total Reach attributed to users who had Liked the Ingesta Page was plotted. Impressions, Engaged Users, and Stories of the 14 learning programme chapter posts were compared and the relationship between Total Engaged Users and the proportion of Engaged Users who had Liked the Ingesta Page was plotted. Additionally, post-level data including the number of Shares, Reactions, and Comments, was manually collected from the Post Details interface for each of the 14 learning programme chapter posts for comparison to the data provided through the 'Insight's' portal. In comparison to the Insight's portal, which provides data for download as a Comma Separated Value (CSV) file, the Post Details interface provides page administrators with a graphic summary of some of the metrics provided by the Insight's portal for each post. Through the Post Details interface it is possible to view Shared posts (where individual users' privacy settings allow), as well as all shared posts by the page itself, which was not possible through the CSV data files obtained through the Insight's portal. This allowed for further analysis of some of the interactions on the posts shared into groups. Engagement through Reactions, comments, and post Shares of the 14 learning programme chapter posts was compared and further analysed as proportion by users who had already Liked the Ingesta Page. Reactions to posts, number of Engaged Users per post, and the number of Stories created through user interactions on each of the 14 learning programme chapter posts were compared. Reactions to posts were classed as either positive or negative, with 'Like', 'Love', and 'Wow' reactions considered to be positive and 'Angry' and 'Haha' reactions considered to be negative. Significance in differences between the numbers of reactions per post and impressions per user were determined through t-testing. Post Shares, and the proportion originating through Posts made into Groups, was compared for each of the 14 learning programme chapter posts.

4.3 Results

Response to the learning programme had a dramatic effect on the Total Likes, daily Engaged Users, and daily Total Reach of the Ingesta Page, with the bulk of the activity occurring during the 14-day period of the learning programme during which the chapter posts were posted. This period is indicated by the third and fourth vertical lines in Figure 4-1, which denote the publishing of the first and fourteenth chapters of the programme. For the sake of figure clarity, the second to thirteenth chapter posts are the only posts made in the 70-day period not indicated with vertical lines. Between the 28 days prior to the announcement of the learning programme and 28 days after the publishing of the final chapter, the Ingesta Page amassed 2045 Likes. This was the highest activity level in the life history of the Ingesta Page.

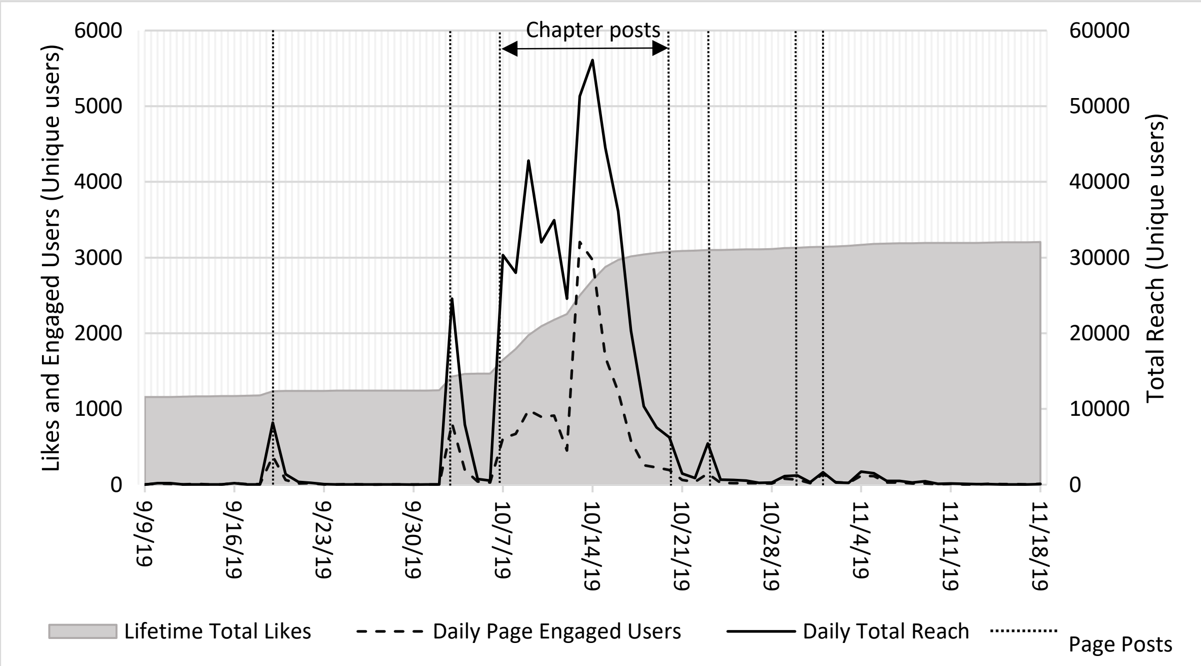

Figure 4-1 : Cumulative Likes, Engaged Users, and Total Reach of the Ingesta Page from 9 September to 18 November 2019

In terms of page-level Reach, the specifics of what Facebook constituents as 'reaching' a user are unknown. It is likely that Reach is a measure of the number of unique users on whose News Feed the algorithm has loaded information relating to a Page, either as a Post, an advertisement, or as Story created through the actions of a Friend of the user. However, it is unclear if there is a minimum threshold of how long the information needed to remain visible to the user. At page-level, Reach data is provided as Total Reach, Organic Reach, Viral Reach, 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 the 70-day period, daily page and post Paid Reach of all posts were consistently zero. The sum of daily Organic and Viral Reach of the Ingesta Page was, however, not equal to daily Total Reach indicating an overlap between Organic and Viral Reach at the Page-level in some areas (Data not presented). Post-level data does not include a Viral Reach component indicating that the user activities that contribute to Viral Reach do not pertain to posts, although it is unknown what these activities are. Mean daily Organic Reach of the Ingesta Page was found to be 96.23% of mean daily Total Reach of the Ingesta Page, while mean daily Viral Reach of the Ingesta Page was found to be 28.32% of mean daily Total Reach and 29.86% of mean daily Organic Reach of the Ingesta Page over the 70-day period. Statistical analysis revealed that there was no significant difference ($p = 0.49$) between daily Total and Organic Reach of the Ingesta Page; 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 Engaged Users of the Ingesta Page 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 4-1. The Post containing the poll had a Total Reach of 585 unique users, of which 338 voted (332 Yes and 6 No votes). The second spike in daily Engaged Users and Viral Reach of the Ingesta Page is attributed to the Post announcing the learning programme, denoted by the second vertical line in Figure 4-1. 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 (Table 4-2). Although the learning programme posts were shared into Groups specifically focused on agriculture in SSA, eight individuals living outside of the region enrolled, indicating the presence of, and active participation by, international members even within region-specific Groups.

Table 4-2: Geographical location data of the enrolees of the learning programme

South Africa		**Other African Countries**		**non-African Countries**	
Province	Number	Country	Number	Country	Number
Eastern Cape	18	Botswana	4	Czech Republic	1
Free-State	8	eSwatini	1	India	1
Gauteng	53	Ghana	3	Israel	1
Kwa-Zulu Natal	38	Kenya	13	Singapore	1
Limpopo	23	Lesotho	3	Spain	1
Mpumalanga	6	Namibia	1	UK	1
Northern Cape	6	Nigeria	1	USA	2
North-West	8	Somalia	2		
Western Cape	13	Tanzania	1		
		Uganda	1		
		Zambia	10		
		Zimbabwe	2		

Of the 223 enrolees, 143 (64%) of those that enrolled in the course indicated that they had not received any formal agricultural training before (Figure 4-2). All 224 candidates cited their reasoning for enrolling in the course as a desire to advance their own knowledge and skills to either become a farmer if they were not already farming or to be a more efficient farmer if they were already farming, indicating at least some level of self-motivation and commitment to personal development.

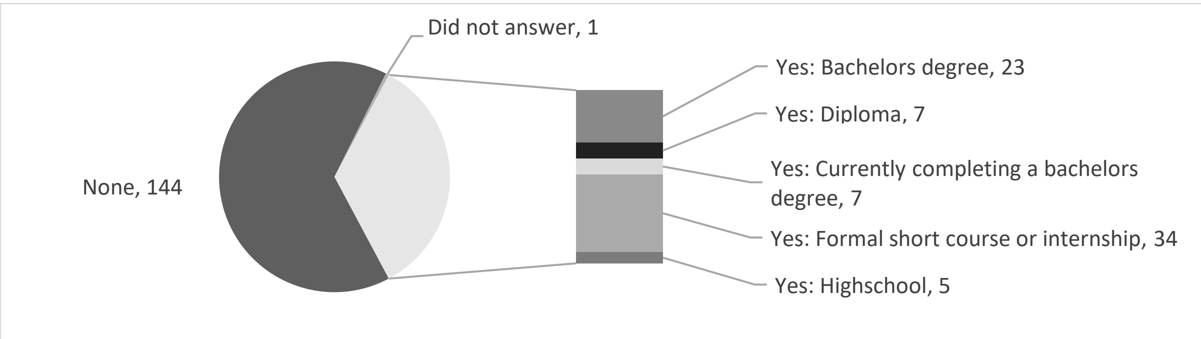

Figure 4-2 : Previous formal agricultural training of the enrolees of the learning programme

Of the 223 individuals who enrolled in the learning programme, 121 enrolees (54%) were already actively farming. Of the 121 enrolees already farming, 44 (36%) owned the land they farmed themselves, and 104 (86%) farmed an area less than 10 ha in size with 90 (74%) farming an area less than 5 ha in size (Figure 4-3).

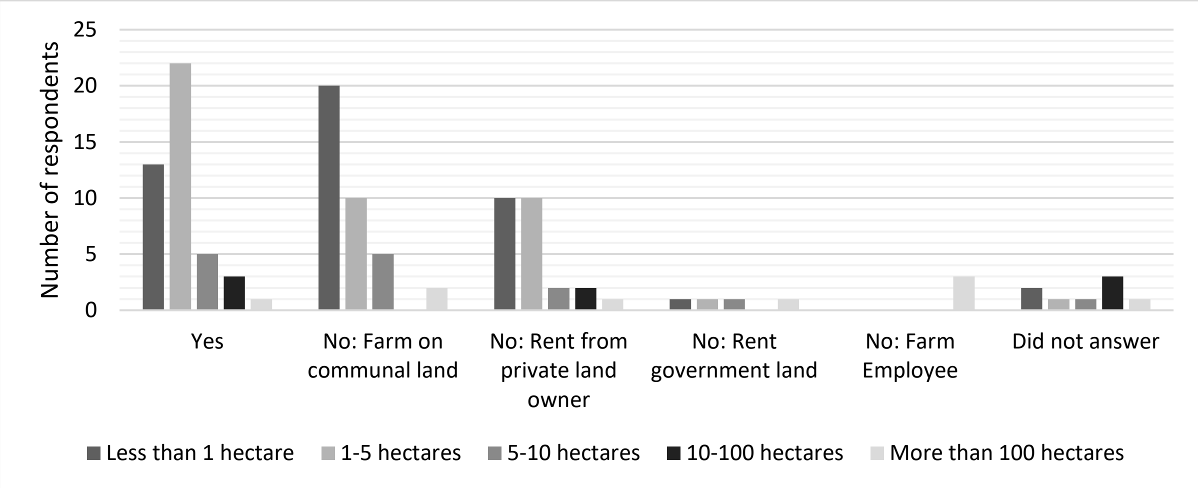

Figure 4-3: Land-ownership by area of the enrolees of the learning programme who were already farming

In terms of crop choice of the enrolees already farming, 81 (67%) indicated they grew at least one of a wide variety of vegetable crops, including various types of squash (*Cucurbita spp.*), brinjals (*Solanum melongena*), sweet potatoes (*Ipomoea batatas*), lettuce (*Lactuca sativa*), beetroot (*Beta vulgaris* subsp. *vulgaris* Conditiva Group), Swiss chard (*Beta vulgaris* subsp. *vulgaris* Flavescens Group), cabbage (*Brassica oleracea* var. *capitata*), okra (*Abelmoschus esculentus*), broccoli (*Brassica oleracea* var. *italica*), onions (*Allium cepa*), bell peppers (*Capsicum annuum*) , and tomatoes (*Solanum lycopersicum*) (Figure 4-4). Other notable crops of relatively high value included fruits (12%) such as avocados (*Persea americana*), strawberries (*Fragaria × ananassa*), blueberries (*Vaccinium spp.*), papayas (*Carica papaya*), cacao (*Theobroma cacao*), peaches (*Prunus persica*), and coconuts (*Cocos nucifera*), and herbs (7%) such as basil (*Ocimum basilicum*) and rosemary (*Salvia rosmarinus*). Just under a third (32%) of enrolees indicated they grew cereals, typically maize (*Zea mays*). The majority (58%) of enrolees already farming indicated that they utilised some form of irrigation with the largest fraction (21%) indicating they used drip irrigation (Figure 4-5). However, a number of different irrigation methods were reported as seen in Figure 4-5.

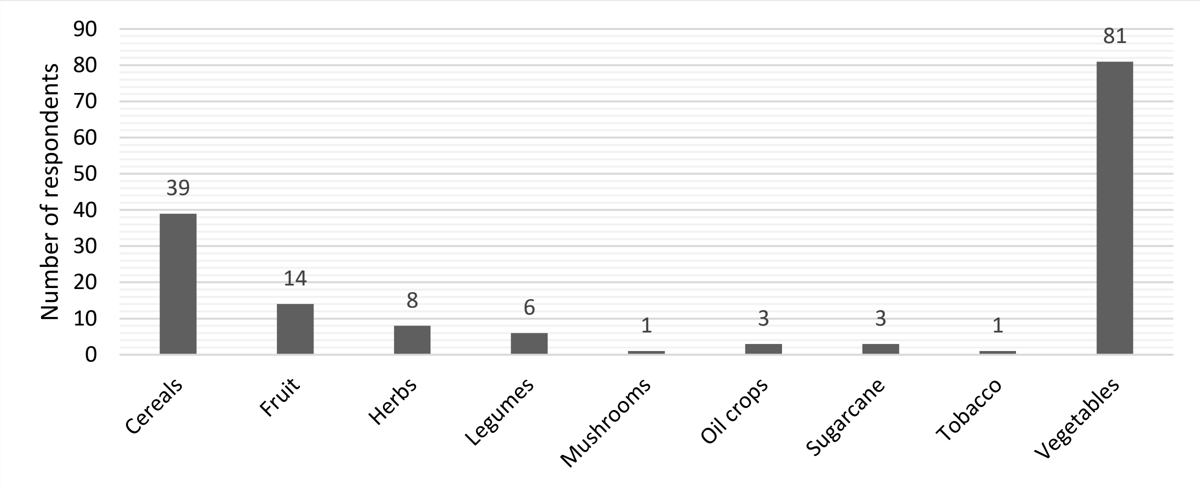

Figure 4-4: Crops grown by the enrolees of the learning programme who were already farming

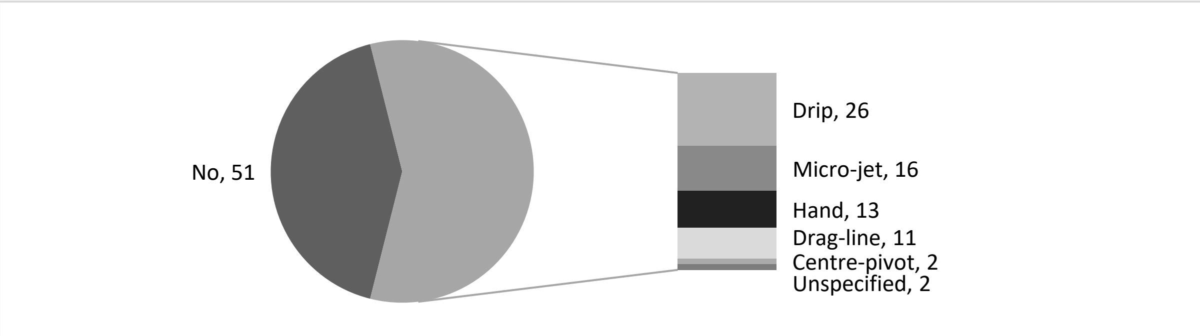

Figure 4-5: Irrigation methods used by the enrolees of the learning programme who were already farming

There was a sharp decline in participation over the course of the learning programme and of the 223 individuals who enrolled, 72 individuals completed the first test and 37 completed the final test (Figure 4-6). The median number of chapter tests completed was three and the mode one, with all tests receiving submissions by individuals who did not complete any other chapter tests. A total of 34 individuals completed the full programme, of which 25 were South African representing eight provinces (Table 4-3). The additional three submissions for the final test were from individuals who had not completed any of the chapter tests. Seven individuals completed more than 70% of the chapter tests, but did not complete the final test.

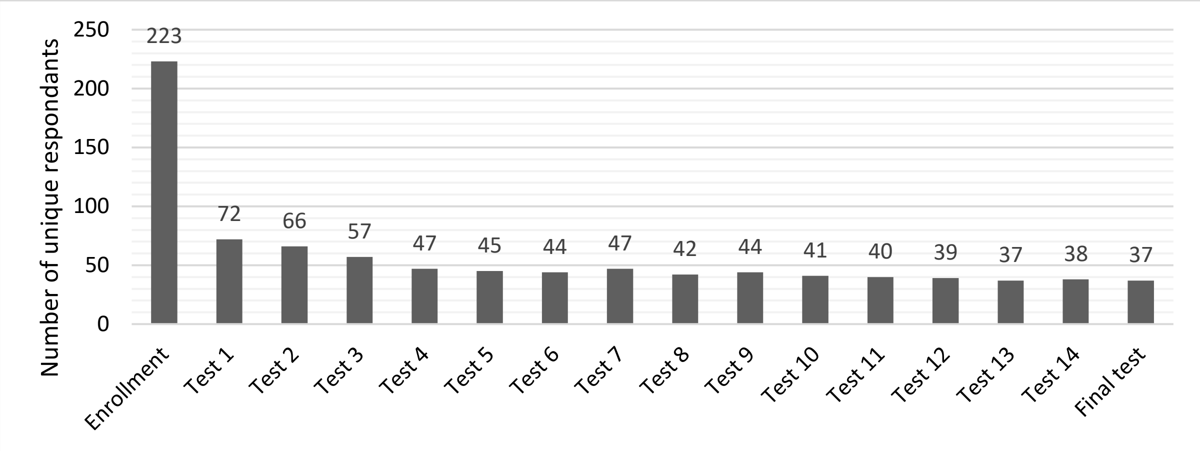

Figure 4-6: Number of unique submissions for each Google Form used for the learning programme

Table 4-3: Location data of individuals who successfully completed the learning programme

South Africa		Other African Countries		Non-African Countries	
Province	Number	Country	Number	Country	Number
Eastern Cape	2	eSwatini	1	USA	1
Free-State	2	Ghana	1		
Gauteng	5	Kenya	3		
Kwa-Zulu Natal	9	Lesotho	1		
Limpopo	5				
Mpumalanga	1				
Northern Cape	6				
North-West	1				
Western Cape	1				

Of the 34 individuals who completed the programme, 17 were already farming, with 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 ha 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. 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. 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 4-7).

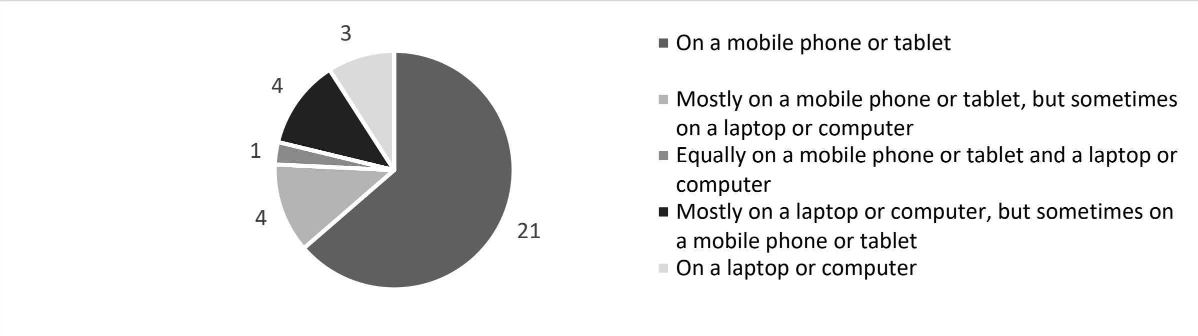

Figure 4-7: Devices used to access the learning programme by individuals who completed the learning programme

In terms of the content, 90% of the individuals who completed the learning programme found the programme either easy or very easy to understand (Figure 4-8) and 91% indicated that the length of the chapters was 'just long enough' (Figure 4-9). The two most popular options for learning programme length and chapter publishing frequency was a chapter published every day with either a total of five chapters or less or between 10 and 15 chapters, securing 10 votes each (Figure 4-10).

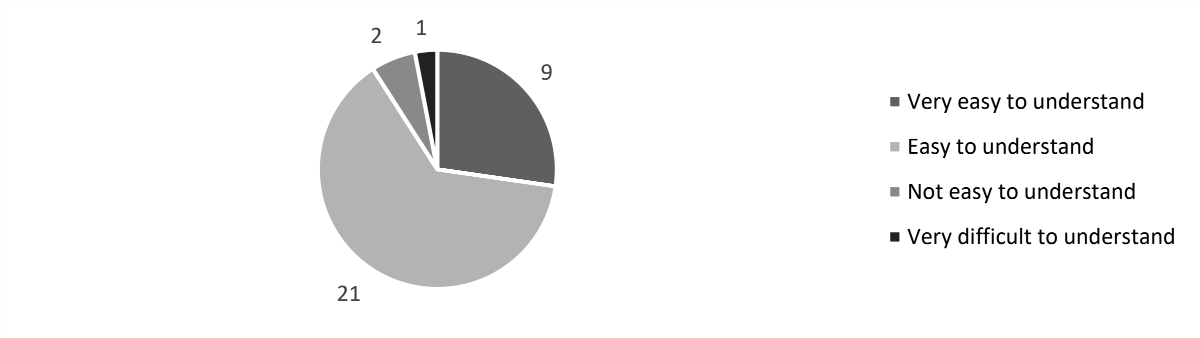

Figure 4-8: Opinion on ease of understanding of the learning programme's content by individuals who completed the learning programme

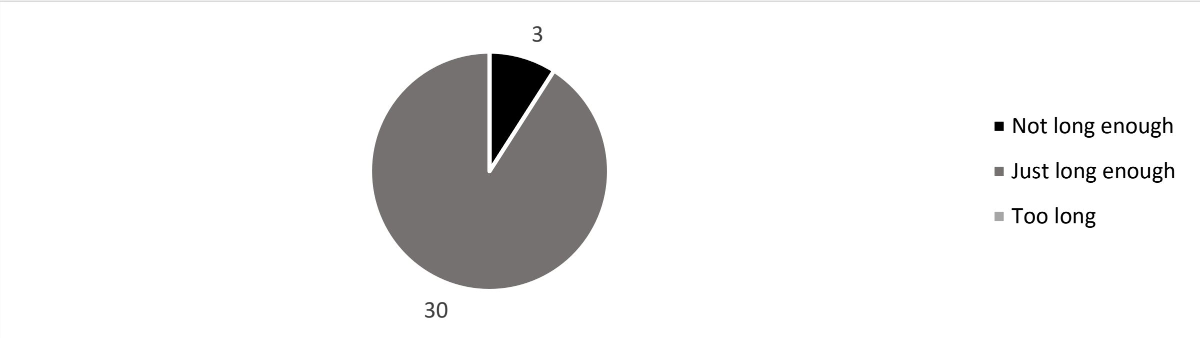

Figure 4-9: Opinion on the length of the learning programme's chapters by individuals who completed the learning programme

Two of the 34 participants who completed the learning programme indicated that they had difficulties 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 which had helped them stay up to date with the course. 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.

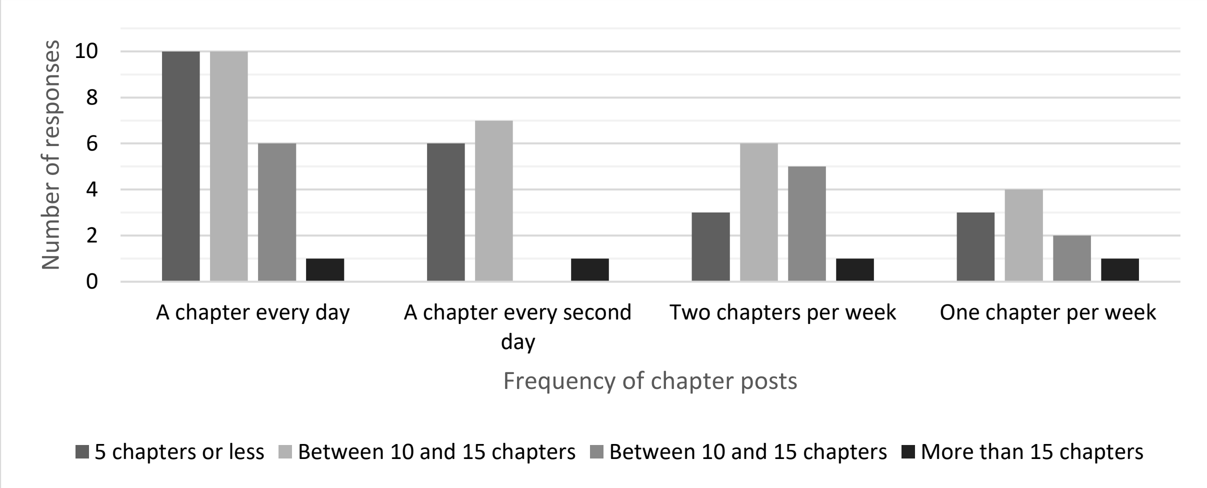

Figure 4-10: Opinion on the total length, and chapter publishing frequency of future learning programmes by individuals who completed the learning programme

Two of the 34 participants who completed the learning programme reported experiencing difficulties viewing the pictures, both of which accessed the learning programme solely through a mobile device. One participant indicated that they found it difficult to refer to the relevant picture between the long text, while the other indicated that when they had a test open, if they went back to a picture in the chapter while the had the test open 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 would have missed if it was just a picture with no caption". Two participants, who both solely used a mobile device to access the programme, stated 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 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. 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", they 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. The most common response type (Five participants) related to irrigation management and efficiency.

Social media 'performance' of the chapter posts was highly variable. As mentioned, at post-level Reach data is provided as Total Reach, Organic Reach, and Paid Reach. No paid promotions had been used on the Ingesta Page, and as a result Paid Reach was zero for all chapter Posts. There was no differences between Total Reach and Organic Reach of any of the chapter Posts, and Total Reach of Posts ranged from 1 021 (Chapter 12) to 22 460 (Chapter 7) unique users with a median of 1 834 unique users (Table 4-4). On average, chapter Posts made 1.54 Impressions per user who had liked the Ingesta Page, and 1.19 Impressions per user who had not liked the Ingesta Page. However, this difference was not found to be significant ($p = 0.33$).

The relationship between Total Reach of each of the 14 chapter Posts and the proportion of Total Reach attributed to users who had already liked the Ingesta Page was found to be a strong negative power ($R^2 = 0.94$, Figure 4-11). This relationship is expected as Posts with higher Total Reach should reach wider audiences of users who had not previously been exposed to the Page's content. However, Total Reach was found to be a poor predictor of the proportional reach of users who had liked the Ingesta Page, displaying a weak positive power relationship ($R^2 = 0.3943$). This indicates that creating Posts that achieve higher Total Reach will not inherently translate into reaching a larger portion of the users who had Liked the page.

Table 4-4: Reach and Impressions of the learning programme chapter Posts

	REACH				IMPRESSIONS		
CHAPTER	Total Reach	Reach to users who had already Liked the Ingesta Page	% of Total Reach attributed to users who had Liked the Ingesta Page	Total Reach as a % of Total Page Likes	Total Impressions	Number of Impressions on users who had already Liked the Ingesta Page	Total Impressions as a % of Total Page Likes
1	2234	687	30.75	41.69	2984	1025	34.35
2	1539	512	33.27	28.54	2122	888	41.85
3	2190	759	34.66	38.43	3010	1304	43.32
4	4785	1043	21.80	49.83	6234	1726	27.69
5	1711	591	34.54	27.11	2300	948	41.22
6	1742	651	37.37	28.87	2181	937	42.96
7	22460	1103	4.91	44.10	26847	1795	6.69
8	1925	627	32.57	23.21	2526	954	37.77
9	11824	923	7.81	32.09	14338	1398	9.75
10	2249	866	38.51	29.17	2911	1291	44.35
11	1510	770	50.99	25.52	2001	1122	56.07
12	1021	555	54.36	18.24	1355	814	60.07
13	1368	915	66.89	29.89	1806	1270	70.32
14	1725	890	51.59	28.89	2351	1318	56.06
MEDIAN	1834	765	34.60	29.03	2439	1196	42.40

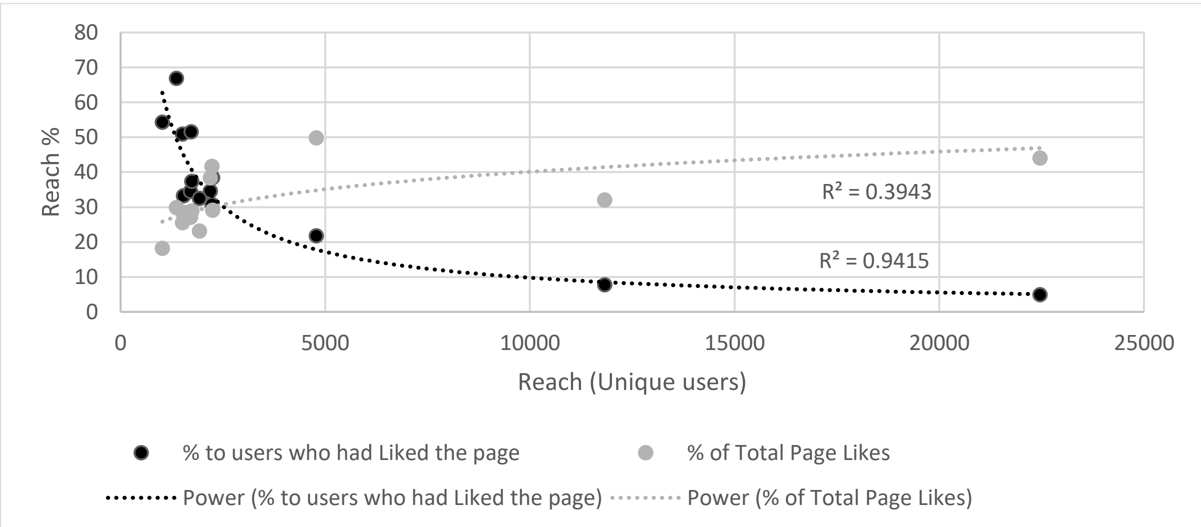

Figure 4-11: Relationship between Total Reach and the proportion of users who had already liked the Ingesta Page included in the Total Reach

The number of Engaged Users per Post displayed high variability, from 119 unique users (Chapter 14) to 6 040 unique users (Chapter 7), with a median of 753 unique users (Table 4-5). A total of 1733 Stories were created about the chapter Posts through direct user actions, including 276 Stories by the Ingesta Page through Sharing of the chapter Posts into Groups. Excluding Post Shares by the Ingesta Page, the Stories per Post created by user Sharing ranged from seven Stories from two unique users (Chapter 13) to 49 Stories from 34 unique users (Chapter 7), with a median values of 18 Stories and nine unique users (Table 4-6). Although Chapter 13 had the lowest number of Stories created through Sharing, as well as the lowest number of unique users who created Stories through Sharing, it had the highest mean number of Stories created through Sharing per unique user who Shared the Post (3.5 stories per unique users, Table 4-6). Chapter 12 had the lowest mean number of Stories created through Sharing per unique users who Shared (1.1 stories per unique user), while the median was 1.8 stories per unique user (Table 4-6). Stories created by user Reactions ranged between 20 Reactions from 20 unique users (Chapter 12) and 249 Reactions from 242 unique users (Chapter 7), with medians of 65 Reaction Stories and 63 Unique users (Table 4-6). The mean number of Reactions per unique user ranged between 1.0 and 1.2 (Table 4-6). The number of Stories per Post created by user Comments ranged from zero Stories (Chapter 11) to 41 Stories (Chapter 7) with a median of six Stories (Table 4-6). Chapter 7 also had the highest mean number of Comments per unique user who commented at 2.4 Comments per unique user, while the median was 1.5 Comments per unique users who commented (Table 4-6).

There was a strong negative power relationship between Total Engaged Users and the proportion who had Liked the page (R^2 = 0.93, Figure 4-12). Although the Chapter 7 Post (6 040 Engaged Users) appears to be an outlier in Figure 4-12, the strong negative power relationship remains true (R^2 = 0.88) if this data point is excluded. Through a comparison between the Post Stories data (Table 4-6) and the Post Engagement data (Table 4-7) manually collected from the Post Details interface of each Post, it was found that Post Stories from Shares and Comments on Posts are equal to the number of Shares and Comments (Including Comments in reply to other Comments) by users. Post Stories created from user Reactions also equal the total Reactions on the Post, however, if a user changed their Reaction both of these Reactions were counted rather than the new Reaction being substituted for the old

Reaction. This indicates that Facebook's algorithm generated Stories out of all actions all users take, rather than excluding some types of actions or users. In total, 1103 positive Reactions and eight negative Reactions were recorded on the chapter Posts. All eight negative Reactions, 824 (75%) of the positive Reactions, as well as 77 of the 129 Comments (60%) were recorded on Shares of the chapter Post, indicating that sharing had a substantial impact on reaching a wider audience beyond the users who had liked the Ingesta Page. However, 486 of the 495 shares (98%) occurred on the original Posts instead of shared Posts, indicating that the spread of the learning programme was largely done be those users who had first-hand access to the original Post. While Chapter 7 accrued the highest number of positive Reactions (34 on the Post and 212 on Shares, 12 and 26% of the respective totals), it also received four of the eight (50%) total negative Reactions.

Table 4-5: Engaged Users of the chapter Posts

Chapter	**Engaged Users**		
	Total	Number who had Liked the Ingesta Page	% who had Liked the Ingesta Page
1	721	159	22.05
2	672	156	23.21
3	1041	195	18.73
4	947	160	16.90
5	785	124	15.80
6	337	83	24.63
7	6040	418	6.92
8	1141	138	12.09
9	1066	204	19.14
10	1173	220	18.76
11	417	128	30.70
12	125	56	44.80
13	199	85	42.71
14	119	61	51.26

Table 4-6: Stories created about chapter Posts through user actions

Chapter	Post Stories									
	Number of Stories created				Number of unique users who created a Story about the Post				Mean number of Stories per number of unique story-creating users	
	Sharing		Reacting	Commenting	Sharing		Reacting	Commenting	Sharing	Commenting
	Total	Excluding shares by the page			Total	Excluding shares by the page			Excluding shares by the page	
1	46	31	83	17	18	17	77	9	1.8	1.9
2	36	21	70	4	8	7	67	4	3.0	1.0
3	39	24	122	14	10	9	114	7	2.7	2.0
4	36	18	84	15	17	16	75	10	1.1	1.5
5	36	19	60	9	10	9	58	5	2.1	1.8
6	29	13	45	2	10	9	42	2	1.4	1.0
7	65	49	249	41	35	34	242	17	1.4	2.4
8	32	18	71	10	12	11	68	5	1.6	2.0
9	46	30	121	2	16	15	114	2	2.0	1.0
10	29	14	57	2	9	8	55	2	1.8	1.0
11	26	13	53	0	6	5	47	0	2.6	0.0
12	28	9	20	3	9	8	20	3	1.1	1.0
13	22	7	36	7	3	2	31	5	3.5	1.4
14	25	10	38	3	8	7	34	2	1.4	1.5
Total	495	276	1109	129	171	157	1044	73	-	-

Posts sharing the learning programme chapter Posts into groups accounted for 510 of the 824 (62%) positive Reactions the learning programme chapter Posts received, and two of the eight (25%) negative Reactions (Table 4-8). Through the Post Details interface it was possible to see which of the users that Reacted to the Post had previously Liked the page. Due to the small number of negative Reactions, these were not analysed. However, the percentage of positive Reactions on the original learning programme chapter Posts and the Posts in the groups by users who had Liked the page was found to be highly significant ($p < 0.01$). This confirmed that Sharing Posts into Groups could be a viable way of interacting with an audience that is interested in the content of the Page but does not yet know about the Page.

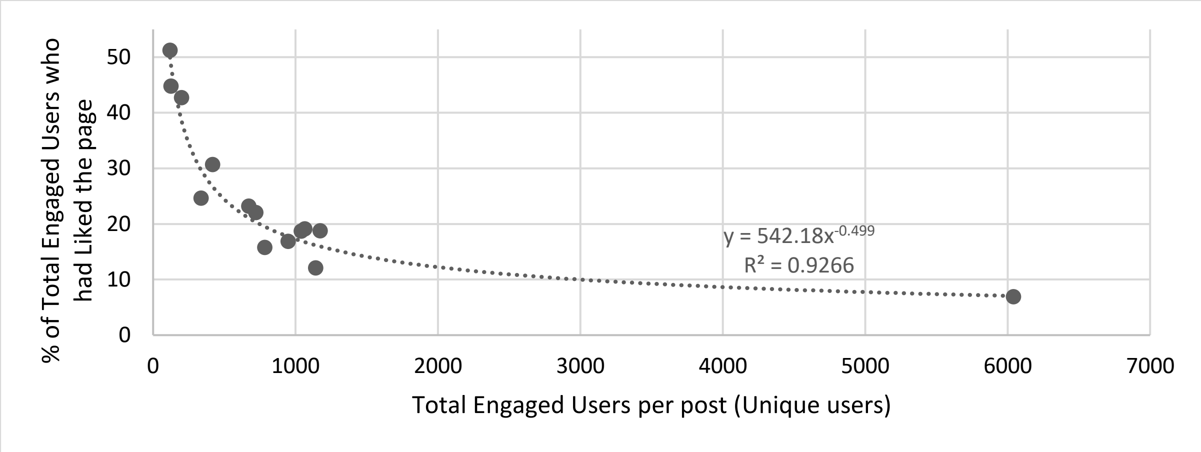

Figure 4-12: Relationship between Total Engaged Users per Post and the proportion of Engaged Users who had Liked the Ingesta Page

Table 4-7: Learning Programme chapter Post Engagement on original Posts and Shared Posts

Chapter	On Post				On shares				Total			
	Reactions				Reactions				Reactions			
	Positive	Negative	Comments	Shares	Positive	Negative	Comments	Shares	Positive	Negative	Comments	Shares
1	28	0	12	46	55	0	5	0	83	0	17	46
2	21	0	0	36	48	1	1	4	69	1	4	36
3	26	0	5	39	96	0	9	0	122	0	14	39
4	31	0	14	33	53	0	1	3	84	0	15	36
5	13	0	3	36	48	0	6	0	61	0	9	36
6	16	0	1	27	29	0	1	2	45	0	2	29
7	34	0	6	65	212	4	35	0	246	4	41	65
8	16	0	2	32	54	1	8	0	70	1	10	32
9	27	0	0	46	93	1	2	0	120	1	2	46
10	16	0	2	29	40	1	0	0	56	1	2	29
11	16	0	0	26	37	0	0	0	53	0	0	26
12	5	0	2	24	15	0	1	4	20	0	3	28
13	12	0	3	22	24	0	4	0	36	0	7	22
14	18	0	2	25	20	0	1	0	38	0	3	25
Total	279	0	52	486	824	8	77	9	1103	8	129	495

Sharing into Groups proved to have a positive effect on the overall number of Shares on the learning programme chapter posts, with shares from Posts Shared into Groups accounting for 83 of the 276 (30%) of the total Post Shares. Percentage of Total Shares from Groups ranged from 0% (Chapter 12) to 53% (Chapter 5), with a median value of 24%.

Comments on original Posts and Posts Shared into Groups were almost exclusively either positive Comments about the content of the learning programme, questions about the learning programme, or users tagging other users. One negative Comment in a Group Post, which questioned the validity of the information in the chapter was received. The individual did not respond when questioned which information they did not believe. Comparing data on Comments, however, proved to be more complex than comparing data on Reactions and Shares as further addressed in the discussion section. Out of the 14 chapter Posts, three received negative feedback. Chapter 1 received one 'Hide Post', Chapter 5 received five 'Unlike Page', and Chapter 12 received one 'Hide All' (Data not shown). However all three Posts recorded one unique user each and it is unclear how Chapter 5 recorded five of the same type of feedback from a single user.

Table 4-8: User Reactions to original learning programme chapter Posts and Posts sharing the chapter Posts into groups

Chapter	Original chapter Posts			Group Posts							
	Total	By users who Liked the page	% by users who had liked the page	Total		By users who liked the page			% by users who had liked the page		
	Positive	Positive	Positive	Positive	Negative	Positive	Negative	Total	Positive	Negative	Total
1	28	18	64.29	42	0	16	0	16	38.10	-	38.10
2	21	17	80.95	35	0	13	0	13	37.14	-	37.14
3	26	19	73.08	74	0	24	0	24	32.43	-	32.43
4	29	18	62.07	36	0	5	0	5	13.89	-	13.89
5	13	10	76.92	32	0	9	0	9	28.13	-	28.13
6	16	10	62.50	21	0	8	0	8	38.10	-	38.10
7	33	15	45.45	99	1	25	0	25	25.25	0.00	25.00
8	16	12	75.00	31	0	7	0	7	22.58	-	22.58
9	27	23	85.19	53	0	13	0	13	24.53	-	24.53
10	16	14	87.50	23	1	3	1	4	13.04	100.00	16.67
11	15	13	86.67	27	0	6	0	6	22.22	-	22.22
12	5	3	60.00	10	0	2	0	2	20.00	-	20.00
13	12	8	66.67	18	0	6	0	6	33.33	-	33.33
14	17	15	88.24	9	0	5	0	5	55.56	-	55.56

Table 4-9: Proportion of total Shares attributed to shares from Posts in Groups of the learning programme chapter Posts*

Chapter	Total	Group Posts	%
1	31	8	25.8
2	21	9	42.9
3	24	12	50.0
4	18	4	22.2
5	19	10	52.6
6	13	2	15.4
7	49	9	18.4
8	18	4	22.2
9	30	14	46.7
10	14	3	21.4
11	13	2	15.4
12	9	0	0.0
13	7	3	42.9
14	10	3	30.0
Total	276	83	30.1

**Excluding Post Shares by the Ingesta Page*

4.4 Discussion

It is recognised that the learning programme's small dataset was likely influenced by a number of factors which, to varying degrees, are unique to the Ingesta Page and its audience, the culture of the Groups Posts were shared to and other virtual spaces the Posts reached, and even the time of year the programme was published. However, in the context of investigating the potential and practicality of a social media-based learning programme aimed at smallholder farmers in SSA, the data gathered acts a baseline for measuring and working with other such learning programmes in the future. As an initial study, the learning programme was considered a success.

4.4.1 Practicalities and administration of the learning programme

A number of lessons were learnt in running a social media based learning programme, as well as what is possible to measure using the data provided by Facebook to Page administrators. However, the rate of technological innovation, particularly in the sphere of social media, does mean that some of these lessons may be outdated if viewed in isolation, but it is envisioned this study will form part of an ever-growing body of work that uses virtual platforms to make agricultural information that is relevant to the African context more accessible.

The majority of the work needed for this study was the creation of the learning programme content itself. Collaborating with organisations experienced in creating agricultural learning material, such as production guides and training manuals, would be beneficial. Based on experience working with undergraduate students at the University of Pretoria, such learning programmes could also easily be adapted from undergraduate agricultural science student's assignments and practicals. This could provide universities with a novel way of increasing university-community engagement while giving real-world impact to students' work. Once the content exists, it will also be substantially easier to modify and update the information to include in learning programmes in the future.

Facebook's Publishing Tools interface for page administrators was found to be simple to utilise and allows Posts to be scheduled for automated posting in advance. This reduced the workload of running the learning programme by not requiring the posting of learning programme chapters to be done manually every day. However, it was discovered that the only way to add captions to scheduled Posts is to save and schedule the Post, and then add captions through Post editing. 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 workload through the automatic collection of data into Google Sheets spreadsheets. Although

Google Forms is specifically mentioned here, any of the multiple online form and test hosting platforms could be used as a substitute.

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, despite participants being asked to provide their full name as part of every form, some participants only provided a first name. Although there were no duplicate names in this particular cohort, this was flagged as a potential problem going forward. Although all learning programme Posts emphasised that the only requirement to participate in the learning programme was to complete the enrolment form, comments and responses indicated that some participants expected to receive a notification that they had successfully enrolled. Assigning a student number to enrolees could function as a way to notify enrolees they have successfully enrolled while aiding in the tracking of participation, particularly if this system can be automated. It would also be beneficial to emphasise in such a notification that enrolees must turn on Facebook's Page notification option, to remind them automatically whenever content is posted through the Page. Both options could potentially reduce the large difference seen between the number of enrolees and the number of individuals that completed the learning programme, however, more work is needed to understand the full array of factors that affect this.

According to respondents, the chapter length and posting frequency was adequate, and the number of positive responses indicated that the programme was a positive learning experience for the participants. However, as the research group is made up of agronomists rather than education and extension specialists, there is perhaps further room for improvement through consultations with experts in the technology transfer field as well.

4.4.2 Reception, reach, and accessibility

The spike in Total Likes on the Ingesta Page, as well as the increased activity seen during the learning programme indicates that the interest in formalised learning programmes is higher than the interest in the less-structured information Posts that were posted on the Ingesta Page in the past. The responses on the enrolment form show that interest in agricultural science learning programmes is also not limited to people who are already farming. This raises the question of whether there is also potential for such learning programmes to be a means of raising public understanding of the science behind the agrofood system, as well as a method to change youth perceptions of the industry with the aim of recruiting the next generation of young scientists and agriculturalists. There were also several requests by agricultural science students asking for the learning programme to be held again at a later stage, as at the time they were busy preparing for their own exams.

Based on the responses to the question of land ownership, area farmed, irrigation usage, and crop choice it is evident that the learning programme reached, and was completed by, smallholder farmers of various economic means. While not asked directly, the responses also paint a picture of a spread of economic brackets. This is a positive indicator for social media learning programmes as a means to make agricultural information accessible to all spheres of society.

Although the sample size of final participants was relatively small, the presence of individuals from both different regions of SSA as well as eight of South Africa’s nine provinces further reinforces the potential of social media to connect remotely to communities across vast geographic spaces. This would allow academic and research institutions running learning programmes to have impacts in communities beyond their usual reach and scope of work, potentially aiding in increasing transboundary knowledge flows.

The high usage of mobile devices to access the learning programme is consistent with the research on internet access in SSA (Kabbiri *et al.* 2018), and this raises several points that must be kept in mind when designing future learning programmes. Firstly, while Facebook allows Page administrators to preview Posts in both desktop and mobile mode, this feature may not be available on other social media platforms and every effort must be made to ensure the Posts are compatible with the social media platform's mobile app. The online form and test hosting platform used for the learning programme should also be compatible with mobile browsers and apps, which Google Forms proved to be well suited for. Diagrams and figures used in the learning programme need to be clear on smaller mobile device screens, and while measures were taken to ensure this was the case for this learning programme, two respondents indicated that they still needed to zoom in in order to read some text. The respondents stated that this is did not present a problem to them; however this might present an issue in the future particularly with individuals with visual disabilities.

A number of requests were made for the learning programme content to be sent through to participants in PDF format. This was specifically not done so that the learning programme's content could only be accessed through the social media Posts. However, the end goal of such learning programmes is to make information as accessible as possible, and if PDF files of the Posts can aid in this regard then it is recommended that they form part of the programmes. There is potential that this could reduce the social media performance of learning programmes by reducing the number of actions users take on the Posts, thereby reducing the spread of Posts in the social media sphere. Further work is therefore needed to understand these trade-offs.

Although only 10% of the final participants indicated that they found the content difficult to understand, further improvements can be made and this must be continually monitored in all learning programmes. Accessibility is not only important in terms the type of language used, but also in which language the learning programmes are presented in. This is particularly true in a multi-cultural society such as South Africa, where significant work is still needed to decolonise science and make scientific information readily available in indigenous languages (Ziegler and Lehner 2018).

While this study is too small to draw any conclusive observations on how the different weed science topics are received by society, there is an anecdote of interest. During the creation of the learning programme special attention was given to the chapters which focused on chemical control. This is due to the current public discourse surrounding the use of glyphosate and the negative attention given to herbicides in general (Bazzan and Migliorati 2020, Lock 2020), and it was feared that these Posts would be negatively affected by these biases. However, it was Chapter 7 and Chapter 9, which focussed on physical and cultural control, respectively, that drew the most negative attention and this is likely due to the negative perceptions held over the practice of ploughing and flaming. Both Posts contained pictures of these practices, and it is understandable how the images of these practices may provoke negative emotions by individuals who are unfamiliar with them. A future repetition of this learning programme will need to be conducted with these pictures removed to assess if it is merely the images of these practices that drove the increased Post interactions, or if users were also driven by the content in the Posts as well.

4.4.3 Social media performance

The social media 'performance' of the chapter Posts exceeded the research group's expectations. However, while this performance can provide data on how many citizens the information is reaching it is by no means a reflection of the impact of the learning programme itself. Posts with higher Reach are not inherently seen by a larger portion of the individuals who Liked the page. As these individuals took a conscious decision to support the page and see the page's content on their timeline through their page Like, they should be seen as the primary targets of programmes run through the Page. Furthermore as Reach is only a measure on information being loaded onto a user's News Feed, and not a measure of the user interacting with the information, it could be argued that Reach data does not provide a meaningful picture to researchers looking at through the lens of science communication and that the focus should instead be on Engagement.

One area where the research group would like to see improvement is Post comments, as ideally learning programme Posts should foster discussion regarding the information in the Comment section. Based on the mean number of Comments per user there is some indication that this happened on shared Posts not visible to the Page administrators, however more work is needed to get such discussions on the original Posts where researchers can contribute as well as analyse the discussion.

4.4.4 Other Facebook groups

Facebook Groups proved to have a positive effect on Post engagement and aided in sharing the information to users who had not already liked the Ingesta Page. While not looked at in this study it is likely that consistently sharing the learning programme chapter Posts into Groups also had a positive impact on enrolment into the programme. Groups are of immense value to such projects, providing insight and access to farmers of various means, training, and locations. However not all Groups were as receptive to the information in the learning programme chapter Posts, and it is therefore important to continually monitor which groups add value to the Page and its learning programmes. The dynamics of Groups are highly variable, and not all chapter Posts were approved for sharing by group administrators. This would have had a negative impact on the reach of Posts, however as these Group administrators are largely farmers and their decisions were seen as an extension of the Group's culture and this variability was ignored. The dynamics of such Groups are also constantly evolving, and it is therefore important for researchers to be familiar with the groups they wish to work with prior to selecting them as part of a study.

4.4.5 Working with Facebook

In terms of the data available to Page administrators, the information Facebook provides is extensive and proved to be useful in quantifying Post performance. However, as mentioned there are likely a number of external factors which played a role as well, and further repetitions of these learning programmes will be needed in order to fully understand these influences. The data Facebook provides through Page Insights was found to be largely sufficient, but it did prove to be beneficial to collect data manually from other interfaces. The privacy settings of users and Groups does limit which shared Posts are visible to Page administrators and this prevented the research group from examining comments on these Posts. Although this information would be useful for providing insight into how the public receives the learning programmes, it is not essential as this can still be gauged by total user Reactions on the original Post and individual Reactions the shared Posts which are visible.

A note of caution that there are discrepancies between the data presented on different interfaces. This particularly relevant with Comments, where some interfaces include replies to original Comments in the Post's Comment count while others do not. Facebook also alters the visibility of Comments on Posts through the All Comments and Most Relevant sorting options, but hidden Comments are still included in Comment counts. Reactions on Posts may also not align with the Reaction data in other interfaces, as when individual users change their Reactions as two separate reactions. Based on the calculations of the mean number of Reactions per unique user this was likely negligible, but could potentially have an impact when there are low numbers of specific reactions on Posts.

Facebook also allows users to "Follow" a page without "Liking" it. In both instances content published by the Page will appear on the user's News Feed, however there is no information available on whether content from Pages users have Liked is prioritised over Pages they have only Followed. Users who have followed the page but not Liked it are excluded from the data on proportion of Reactions and actions by users who have Liked the page. If there is no difference between how users are fed information from Pages they have Liked and Pages they have followed, then the data that only includes users who have Liked the page is not a true reflection of the proportion of Reactions and actions by users who have taken an active interest in wanting to see the Page's content.

4.5 Conclusions

Overall, the learning programme was considered a success as a pilot study. The dramatic increase in page activity indicates that there is a demand for informative agricultural science Posts, at least on Facebook. Facebook does lend itself as a more functional platform for hosting a learning programme, but further work is needed to understand how such learning programmes would compare on other social media platforms particularly as trends and platform popularity continue to change rapidly in the digital world. Social media performance data of the learning programme provides a benchmark for future studies to assess if performance and popularity can be improved in order to increase the Reach and 'viral potential' of Posts. It is recommended that further research explores the real-world impacts of a social media-based learning programme, with particular focus on changes in smallholder farmer decision-making processes and demonstrable increases in production efficiency and sustainability.

Chapter 5: Final remarks and conclusions

In its current form, the CoT Agri-park's sites do not meet the Department of Agriculture, Land Reform and Rural Development's (DALRRD) minimum requirements for a fully functional Farmer Production Support Unit (FPSU) and there is insufficient evidence to support the idea that the CoT Agri-park is a case study for the sustainable intensification (SI) of smallholder agriculture. This is of concern as the drive towards the Agri-parks model, where farmer support and agricultural extension is centralised, presents a substantial risk 'where the services previously offered in a decentralised farmer support model may become totally unavailable to farmers within an Agri-park catchment if the Agri-parks do not function as intended' (NCOP LREMRE 2019). The NCOP LREMRE (2019) report suggests a number of reasons for the delays in the progress of the Agri-parks programme in Gauteng, including insufficient funding, but makes extensive reference to the disjunction between national and provincial governmental departments, as described in Chapter 2. This disjunction between different tiers of government needs to be addressed if the Agri-parks programme is going to achieve the scale of development it was envisioned to, particularly as the lives of the smallholder farmers already farming within the CoT Agri-park's FPSUs continue to be directly impacted by delays in the development of the Agri-parks programme.

Returning to the four tenants of SI by Garnett et al. (2013), as described in Chapter 1, yield and resource-use efficiency are the two most important components needed to assess if a system has been intensified sustainably. Coupled with this, the guiding principles of the Agri-parks initiative state that the Agri-parks should maximise benefit to existing state and high value agricultural land (DRDLR 2016a), yet neither production data nor irrigation water usage is recorded at the Soshanguve and Rooiwal FPSUs. It is thus not possible to quantify if either yields or irrigation efficiency at either site have been increased under the Agri-parks banner in comparison to the projects which preceded the Agri-parks programme, and it is therefore paramount that this information is recorded going forward if sustainability and agronomic performance is to be measured in the Agri-parks.

If the rest of the guiding principles of the Agri-parks programme (DRDLR 2016a) are to be adhered to, specifically that the Agri-parks will be farmer-controlled and set to maximise the use of resources and infrastructure across the agricultural production chain, then greater autonomy should also be granted to farmers. This is not only in how the CoT Agri-park's FPSUs are managed, but also in what the farmers need as part of the ten years of governmental support. Farmers at both Rooiwal and Soshanguve recognised a need to invest in more efficient drip-irrigation systems, but had limited capital to do so themselves. The small number of farmers currently within the CoT Agri-park means it is unlikely they will be able to collectively source capital to invest in more efficient irrigation systems, as was the case with treadle pumps in Bangladesh described by Namara et al. (2010). As a result, the Agri-park farmers will remain reliant on government support until they are able to increase production to a level that enables them to be financially independent. Given that the CoT Agri-park farmers are still reliant on the donation of even basic inputs such as fertilisers from government institutions, and are thus no more financially independent than they were in 2018, financial independence is unlikely to occur soon.

As discussed in Chapter 2, the NCOP LREMRE (2019) report notes that DALRRD is now focusing on the development of FPSUs without making mention of the Agri-hubs and RUMCs. The report further notes that there are concerns as to where further funding for the Agri-parks will come from and which level of government is responsible for driving the programme (NCOP LREMRE 2019). Although the CoT Agri-park and its FPSUs are not noted as priorities for the DALRRD in any available literature, these FPSUs nonetheless exist and their future has real-world ramifications for the farmers that occupy the space. Despite neither Rooiwal nor Soshanguve meeting the DALRRD's minimum requirements for a functioning FPSU, both sites still host the infrastructure for intensified high-yielding tunnel production already. As most of the infrastructure is still in place, the seed-funding necessary to repair this infrastructure would likely be less than that required to start new FPSUs elsewhere. Repairing this infrastructure would enable farmers to increase production, raising the likelihood of them becoming economically self-sufficient. This would free up institutional resources, and potentially generate income for the Agri-parks programme, which could be utilised to expand the development of the sites into fully functional FPSUs according to the DALRRD's requirements. This development must, however, be done with the farmers forming part of the decision-making process to ensure that farmers do not continue to receive inadequate governmental donations as discussed in Chapter 2.

The DALRRD's requirements for a fully functional FPSU include designated extension officers, which will be necessary to ensure farmers receive sufficient support. It is recommended that software, such as the South African Water Quality Guidelines Decision Support System (SAWQI DSS), and tools, such as the Wetting Front Detectors (WFDs) and Chameleon soil water sensors, which have been demonstrated to assist smallholder farmers manage their resources more efficiently be considered as part of the Agri-parks support. Although these tools are comparatively cheap to more high-tech sensors, they are still expensive for smallholder farmers to invest in themselves. Similarly, although the SAWQI DSS software is open-access, a computer is required to run the software. For this reason, it is recommended that these tools form part of input packages provided to Agri-parks farmers, in order to increase resource use efficiency within the Agri-park, and that extension officers are trained to use the SAWQI DSS to generate and interpret reports for farmers as part of the knowledge support. Extension officers should also been aware of the site-specific challenges each FPSU has. Although the water-saving benefits of mulching are well established, the conclusions from the University of Pretoria's Hatfield Experimental Farm trial and the Rooiwal farmer field day have shown that mulching is not appropriate in this instance due to high weed pressure. The Rooiwal farmer's hesitation towards the use of chemical control measures reinforces that extension specialists should be training farmers on holistic scientific best-practices in order to over-come the challenges they face.

Given the current limited size of the CoT Agri-park, however, it is unlikely that it would be feasible for the municipality to appoint an extension officer whose sole role is to provide support for the CoT Agri-park. Social media presents itself as a viable platform for connecting Agri-parks farmers and extension specialists across the country. This study has demonstrated that it is possible to host social media-based learning programmes catering to providing fundamental agronomic knowledge to smallholder farmers across SSA, and this success has initiated further work by the WRC to understand if social media-based learning programmes lead to real-world action changes in smallholder farmer's irrigation practices. It is recommended that extension specialists and Agri-parks farmers are trained in the use of social media to connect and share information, to reduce the reliance on in-person consultation.

In conclusion, although the CoT Agri-park is currently not a case study for the SI of smallholder agriculture, the programme has the potential to become one if there is a co-ordinated effort from all tiers of government. This coordinated effort must focus on developing the programme as it is described in the original model and ensuring appropriate support is given to enable smallholder farmers to sustainably intensify their production.

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Appendix

Appendix 2.1 Historical images of the Rooiwal Agri-park site


Rooiwal Agri-park
2011-07-13
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2011-08-23
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2011-10-24
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2012-03-03
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2013-04-17
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2013-09-26
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2015-05-03
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2015-05-30
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2015-06-15
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2015-07-29
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2015-08-20
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2016-08-18
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2017-05-04
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2017-09-13
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2017-10-19
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2018-01-28
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2018-03-04
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2018-04-08
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2018-06-02
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2018-06-08
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2018-06-15
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
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Rooiwal Agri-park
2018-09-11
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2018-11-09
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2019-02-20
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2019-05-13
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Rooiwal Agri-park
2020-01-26
Legend
Boundary
Google Earth
© 2020 AfriGIS (Pty) Ltd.
© 2020 Google
Image © 2020 Maxar Technologies
400 m
N

Appendix 2.2 Water quality results for groundwater taken from the Rooiwal Agri-park (Rietvlei Water Laboratory, 2017)

Analysis	Units*	Standards Limits	Borehole 1	Borehole 2	Number of samples	Average	Water quality ˣ
Colour	mg l^{-1} Pt-Co	≥ 0.0 to ≤ 15.00	3.35	3.79	2	3.57	Excellent
Conductivity	mS m^{-1}	≥ 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^{-1}	≥ 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
Aluminium as Al	µg l^{-1}	≥ 0.0 to ≤ 300.00	<7.00	<7.00	2	7	Excellent
Antimony as Sb	µg l^{-1}	≥ 0.0 to ≤ 20	3.7	<2.7	2	3.2	Excellent
Arsenic as As	µg l^{-1}	≥ 0.0 to ≤ 10	<5.0	<5.0	2	5	Excellent
Barium as Ba	µg l^{-1}	≥ 0.0 to ≤ 700.00	2.59	3.63	2	3.11	Excellent
Boron as B	µg l^{-1}	≥ 0.0 to ≤ 2400	19	14	2	17	Excellent
Cadmium as Cd	µg l^{-1}	≥ 0.0 to ≤ 3.0	<0.50	<0.50	2	0.5	Excellent
Cobalt as Co	µg l^{-1}	≥ 0.0 to ≤ 499.00	<1.0	1.31	2	1.16	Excellent
Copper as Cu	µg l^{-1}	≥ 0.0 to ≤ 2000.00	<5.00	<5.00	2	5	Excellent
Iron as Fe	µg l^{-1}	≥ 0.0 to ≤ 300.00	17.77	58.09	2	37.93	Excellent
Lead as Pb	µg l^{-1}	≥ 0.0 to ≤ 10.00	<3.50	<3.50	2	3.5	Excellent
Manganese as Mn	µg l^{-1}	≥ 0.0 to ≤ 100.00	16.14	14.81	2	15.48	Excellent
Nickel as Ni	µg l^{-1}	≥ 0.0 to ≤ 70	<1.4	<1.4	2	1.4	Excellent
Selenium as Se	µg l^{-1}	≥ 0.0 to ≤ 40	19	13	2	16	Excellent

Total chromium as Cr	µg l^{-1}	≥ 0.0 to ≤ 50	<0.70	3.3	2	2	Excellent
Uranium as U	µg l^{-1}	≥ 0.0 to ≤ 30	<1.0	<1.0	2	1	Excellent
Vanadium as V	µg l^{-1}	≥ 0.0 to ≤ 200.00	<0.40	<0.40	2	0.4	Excellent
Ammonia as N	mg l^{-1}	≥ 0.0 to ≤ 1.50	<0.29	<0.29	2	0.29	Excellent
Calcium as Ca	mg l^{-1}	≥ 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^{-1}	≥ 0.0 to ≤ 300.00	115.98	116.42	2	116.2	Excellent
Fluoride as F	mg l^{-1}	≥ 0.0 to ≤ 1.5	2.4	2.4	2	2.4	Unacceptable
Magnesium as Mg	mg l^{-1}	≥ 0.0 to ≤ 70.00	20.1	20.3	2	20.2	Excellent
Magnesium Hardness as $CaCO_3$	mg l^{-1}	≥ 0.0 to ≤ 280	83	84	2	84	Excellent
NO_3^- as N	mg l^{-1}	≥ 0.0 to ≤ 11	95	95	2	95	Unacceptable
NO_2^- as N	mg l^{-1}	≥ 0.0 to ≤ 0.90	0.004	0.002	2	0.003	Excellent
NO_2^--NO3- Ratio		≥ 0.0 to ≤ 1.00	8.67	8.67	2	8.67	Unacceptable
Potassium as K	mg l^{-1}	≥ 0.0 to ≤ 50	5.9	6.1	2	6	Excellent
Sodium as Na	mg l^{-1}	≥ 0.0 to ≤ 200.00	60.46	61.26	2	60.86	Excellent
Sulphate as SO_4	mg l^{-1}	≥ 0.0 to ≤ 250.00	95.65	97.43	2	96.54	Excellent
Total Oxidised Nitrogen as N	mg l^{-1}	≥ 0.0 to ≤ 10	95	95	2	95	Unacceptable
Zinc as Zn	mg l^{-1}	≥ 0.0 to ≤ 5.0	0.011	0.0053	2	0.0082	Excellent
Total Hardness as $CaCO_3$	mg l^{-1}	≥ 0.0 to ≤ 660.00	728.26	734.59	2	731.43	Unacceptable
Confirmed E. coli	Count per 100ml	≥ 0.0 to ≤ 0.0	0	0	2	0	Excellent
Faecal Coliforms	Count per 100ml	≥ 0.0 to ≤ 1.0	0	0	2	0	Excellent

Total Coliforms	Count per 100ml	≥ 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
Alkalinity as $CaCO_3$	mg l^{-1} CaCO3	≥ 0.0 to ≤ 500.00	112.03	112.97	2	112.5	Excellent
Orthophosphate as PO_4	mg l^{-1}	≥ 0.0 to ≤ 1.0	<0.020	<0.020	2	0.02	Excellent
Silica as Si	µg l^{-1}	≥ 0.0 to ≤ 100.00	23.06	23.18	2	23.12	Excellent
*** Based on SANS 241:2015**							
ˣAccording to Rietvlei Water Laboratory							

Appendix 2.3 Apies River water quality for 2011-2018 (DWS, 2018)

Monitoring Variable	*Number of samples*	*Min*	*25% P*	*50% P*	*75% P*	*Max*	*Target**	*Target*ˣ
pH	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	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	116	-2.97	0.18	0.52	0.76	1.14	-2 to 2	

*(DWA, 1996) ˣ(SANS 241:2015)

Appendix 2.4 Historical images of the Soshanguve Agri-park site


Soshanguve Agri-park
22-05-2011
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
21-09-2011
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
16-10-2011
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
400 m
N


Soshanguve Agri-park
29-03-2013
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
06-04-2013
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
17-07-2014
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
28-07-2014
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
05-04-2015
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
02-06-2015
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
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Soshanguve Agri-park
16-10-2016
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
04-05-2017
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
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Soshanguve Agri-park
11-06-2017
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
N


Soshanguve Agri-park
14-09-2017
Legend
Boundary
Google Earth
Image © 2020 CNES / Airbus
100 m
N


Soshanguve Agri-park
13-12-2017
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
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Soshanguve Agri-park
12-03-2018
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
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Soshanguve Agri-park
03-04-2018
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
100 m
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Soshanguve Agri-park
20-05-2018
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
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Soshanguve Agri-park
02-06-2018
Legend
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Image © 2020 Maxar Technologies
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Soshanguve Agri-park
15-06-2018
Legend
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Image © 2020 Maxar Technologies
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Soshanguve Agri-park
25-08-2018
Legend
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Google Earth
Image © 2020 Maxar Technologies
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Soshanguve Agri-park
26-08-2018
Legend
Boundary
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Image © 2020 Maxar Technologies
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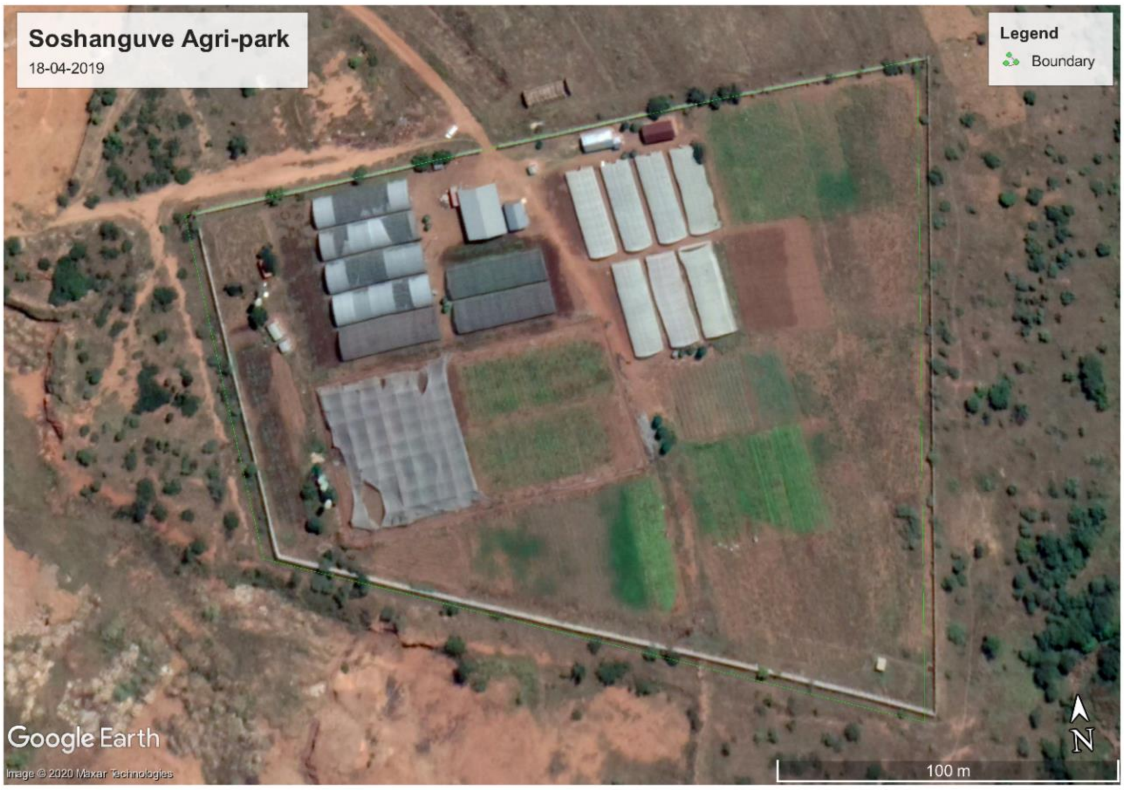
Soshanguve Agri-park
11-09-2018
Legend
Boundary
Google Earth
Image © 2020 Maxar Technologies
N
100 m



Appendix 3.1 Analysis of variance of weed fresh biomass

Sources	*SS*	*df*	*MS*	*F*	*P value*	*Adj SS*

Blocks	72160	2	36080.17	17.60736	***0.000151***	0
Groups	30129	7	4304.075	2.100417	0.112405	0
Error	28688	14	2049.153			
Total	130977	23				

Appendix 3.2 Tukey post-hoc test of weed fresh biomass between blocks

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*
A	B	129.8211	8.111535	70.58842	189.0538	***0.000143***	2.867861
A	C	94.74219	5.91972	35.50952	153.9749	***0.002466***	2.092937
B	C	35.07891	2.191815	-24.1538	94.31158	0.298907	0.774924

Appendix 3.3 Analysis of variance of weed population density

Sources	*SS*	*df*	*MS*	*F*	*P value*	*Adj SS*
Blocks	37644.06	2	18822.03	21.99174	***0.000048***	0
Groups	46551.06	7	6650.151	7.770065	***0.000623***	0
Error	11982.15	14	855.8682			
Total	96177.28	23				

Appendix 3.4 Tukey post-hoc test of weed population density between blocks

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*
A	B	746.125	9.017022	439.881	1052.369	***0.000048***	3.187999
A	C	558	6.743506	251.756	864.244	***0.000820***	2.384189
B	C	188.125	2.273516	-118.119	494.369	0.274992	0.803809

Appendix 3.5 Tukey post-hoc test of weed population density between treatments

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*

M0W0	M1W0	33.29167	1.971028	-50.992	117.5753	0.845990	33.29167
M0W0	M2W0	25.5	1.509723	-58.7837	109.7837	0.953812	25.5
M0W0	M4W0	49.5	2.930639	-34.7837	133.7837	0.473740	49.5
M0W0	M0W1	57.625	3.411679	-26.6587	141.9087	0.306080	57.625
M0W0	M1W1	75.375	4.462564	-8.90866	159.6587	0.095502	75.375
M0W0	M2W1	46.29167	2.740691	-37.992	130.5753	0.549634	46.29167
M0W0	M4W1	41.91667	2.481669	-42.367	126.2003	0.656186	41.91667
M1W0	M2W0	7.791667	0.461304	-76.492	92.07532	0.999969	7.791667
M1W0	M4W0	16.20833	0.959612	-68.0753	100.492	0.996343	16.20833
M1W0	M0W1	90.91667	5.382706	6.633011	175.2003	**0.030510**	90.91667
M1W0	M1W1	108.6667	6.433592	24.38301	192.9503	***0.008002***	108.6667
M1W0	M2W1	79.58333	4.711718	-4.70032	163.867	0.070587	79.58333
M1W0	M4W1	75.20833	4.452697	-9.07532	159.492	0.096639	75.20833
M2W0	M4W0	24	1.420916	-60.2837	108.2837	0.966072	24
M2W0	M0W1	83.125	4.921402	-1.15866	167.4087	0.054481	83.125
M2W0	M1W1	100.875	5.972288	16.59134	185.1587	**0.014401**	100.875
M2W0	M2W1	71.79167	4.250414	-12.492	156.0753	0.122808	71.79167
M2W0	M4W1	67.41667	3.991393	-16.867	151.7003	0.165390	67.41667
M4W0	M0W1	107.125	6.342318	22.84134	191.4087	***0.008986***	107.125
M4W0	M1W1	124.875	7.393204	40.59134	209.1587	***0.002398***	124.875
M4W0	M2W1	95.79167	5.67133	11.50801	180.0753	**0.021140**	95.79167
M4W0	M4W1	91.41667	5.412309	7.133011	175.7003	**0.029386**	91.41667
M0W1	M1W1	17.75	1.050886	-66.5337	102.0337	0.993691	17.75
M0W1	M2W1	11.33333	0.670988	-72.9503	95.61699	0.999620	11.33333
M0W1	M4W1	15.70833	0.930009	-68.5753	99.99199	0.996980	15.70833
M1W1	M2W1	29.08333	1.721874	-55.2003	113.367	0.913528	29.08333
M1W1	M4W1	33.45833	1.980895	-50.8253	117.742	0.842893	33.45833
M2W1	M4W1	4.375	0.259021	-79.9087	88.65866	0.999999	4.375

Appendix 3.6 Analysis of variance of number of weed species

Sources	*SS*	*df*	*MS*	*F*	*P value*	*Adj SS*
Blocks	333.25	2	166.625	3.840445	**0.04681194**	0
Groups	11839.83	7	1691.405	38.98422	***0.00000004***	0
Error	607.4167	14	43.3869			
Total	12780.5	23				

Appendix 3.7 Tukey post-hoc test of weed species richness between blocks

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*

A	B	6.625	2.844799	-1.99393	15.24393	0.145935	1.005788
A	C	2.125	0.912483	-6.49393	10.74393	0.798015	0.322611
B	C	8.75	3.757281	0.131069	17.36893	***0.046466***	1.3284

Appendix 3.8 Tukey post-hoc test of number of weed species between treatments

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*
M0W0	M0W1	43	11.30706	24.02336	61.97664	***0.000029***	6.528135
M0W0	M1W0	2	0.52591	-16.9766	20.97664	0.999924	0.303634
M0W0	M1W1	41	10.78115	22.02336	59.97664	***0.000050***	6.224501
M0W0	M2W0	3.666667	0.964168	-15.31	22.6433	0.996237	0.556663
M0W0	M2W1	47.33333	12.44653	28.3567	66.30997	***0.000009***	7.186009
M0W0	M4W0	4.333333	1.139471	-14.6433	23.30997	0.989882	0.657874
M0W0	M4W1	34	8.940467	15.02336	52.97664	***0.000376***	5.161781
M0W1	M1W0	45	11.83297	26.02336	63.97664	***0.000017***	6.831769
M0W1	M1W1	2	0.52591	-16.9766	20.97664	0.999924	0.303634
M0W1	M2W0	46.66667	12.27123	27.69003	65.6433	***0.000011***	7.084798
M0W1	M2W1	4.333333	1.139471	-14.6433	23.30997	0.989882	0.657874
M0W1	M4W0	47.33333	12.44653	28.3567	66.30997	***0.000009***	7.186009
M0W1	M4W1	9	2.366594	-9.97664	27.97664	0.702781	1.366354
M1W0	M1W1	43	11.30706	24.02336	61.97664	***0.000029***	6.528135
M1W0	M2W0	1.666667	0.438258	-17.31	20.6433	0.999978	0.253028
M1W0	M2W1	49.33333	12.97244	30.3567	68.30997	***0.000006***	7.489643
M1W0	M4W0	2.333333	0.613561	-16.6433	21.30997	0.999789	0.35424
M1W0	M4W1	36	9.466377	17.02336	54.97664	***0.000207***	5.465415
M1W1	M2W0	44.66667	11.74532	25.69003	63.6433	***0.000019***	6.781163
M1W1	M2W1	6.333333	1.665381	-12.6433	25.30997	0.925820	0.961508
M1W1	M4W0	45.33333	11.92062	26.3567	64.30997	***0.000016***	6.882375
M1W1	M4W1	7	1.840684	-11.9766	25.97664	0.883964	1.06272
M2W0	M2W1	51	13.4107	32.02336	69.97664	***0.000004***	7.742672
M2W0	M4W0	0.666667	0.175303	-18.31	19.6433	1.000000	0.101211
M2W0	M4W1	37.66667	9.904635	18.69003	56.6433	***0.000127***	5.718444
M2W1	M4W0	51.66667	13.586	32.69003	70.6433	***0.000003***	7.843883
M2W1	M4W1	13.33333	3.506066	-5.6433	32.30997	0.278495	2.024228
M4W0	M4W1	38.33333	10.07994	19.3567	57.30997	***0.000105***	5.819655

Appendix 3.9 Analysis of variance of number of yields under different weeding frequencies

Sources	*SS*	*df*	*MS*	*F*	*P value*	*Adj SS*

Blocks	6.565488222	2	3.282744111	1.088144794	0.3951709	0
Groups	607.7338336	3	202.5779445	67.14935075	***0.0000523***	0
Error	18.10095933	6	3.016826556			
Total	632.4002811	11				

Appendix 3.10 Tukey post-hoc test of yields under different weeding frequencies

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*
W0	W1	18.70144	18.649217	13.791733	23.611155	***0.000049***	10.767130
W0	W2	15.75083	15.706846	10.841122	20.660544	***0.000133***	9.0683519
W0	W4	10.75533	10.725297	5.8456220	15.665044	***0.001128***	6.1922532
W1	W2	2.950611	2.9423709	-1.9591001	7.860322	0.259403	1.6987782
W1	W4	7.946111	7.9239201	3.0363998	12.855822	***0.005545***	4.5748774
W2	W4	4.9955	4.9815491	0.085788	9.905217	**0.046623**	2.8760942

Appendix 3.11 Analysis of variance of total water productivity under different weeding frequencies

ANOVA

Sources	*SS*	*df*	*MS*	*F*	*P value*	*Adj SS*
Blocks	0.099808	2	0.049904	1.088145	0.3951709	0
Groups	9.238741	3	3.07958	67.14935	***0.0000523***	0
Error	0.27517	6	0.045862			
Total	9.613719	11				

Appendix 3.12 Tukey post-hoc test of total water productivity under different weeding frequencies

Q TEST

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*
W0	W1	2.305817	8.105568	0.913036	3.698598	***0.00494***	4.679752
W0	W2	1.942018	9.620711	0.953721	2.930315	***0.00203***	5.55452
W0	W4	1.326092	9.458589	0.639674	2.01251	***0.00222***	5.460919
W1	W2	0.363799	4.262732	-0.05405	0.781644	0.08459	2.46109
W1	W4	0.979725	6.116783	0.195533	1.763918	**0.01927**	3.531526
W2	W4	0.615926	6.428148	0.146806	1.085046	**0.01533**	3.711293

Appendix 3.13 Analysis of variance of irrigation water productivity under different weeding frequencies

ANOVA

Sources	*SS*	*df*	*MS*	*F*	*P value*	*Adj SS*
Blocks	0.599417	2	0.299709	1.088145	0.3951709	0
Groups	55.48499	3	18.495	67.14935	***0.0000523***	0
Error	1.652585	6	0.275431			
Total	57.73699	11				

Appendix 3.14 Tukey post-hoc test of irrigation water productivity under different weeding frequencies

Q TEST

group 1	*group 2*	*mean*	*q-stat*	*lower*	*upper*	*p-value*	*Cohen d*
W0	W1	5.650751	18.64922	4.167253	7.13425	***0.00005***	10.76713
W0	W2	4.759207	15.70685	3.275709	6.242705	***0.00013***	9.06835
W0	W4	3.249787	10.7253	1.766289	4.733285	***0.00113***	6.19225
W1	W2	0.891545	2.942371	-0.59195	2.375043	0.25940	1.69878
W1	W4	2.400964	7.92392	0.917466	3.884462	***0.00554***	4.57488
W2	W4	1.50942	4.981549	0.025922	2.992918	**0.04662**	2.87610

Appendix 4.1 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.

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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.

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:

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

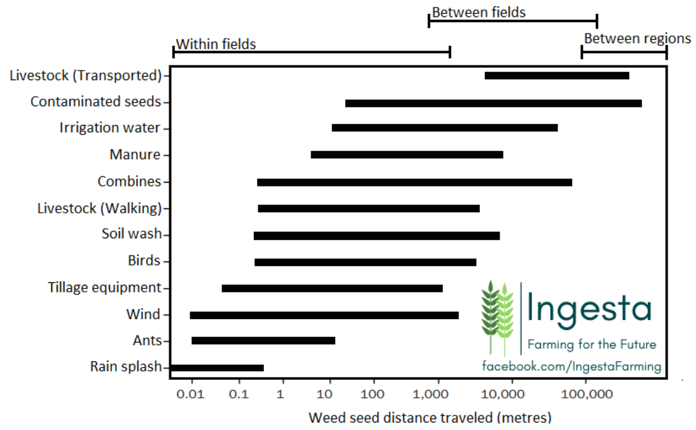
https://www.facebook.com/IngestaFarming/Posts/975465866130400

→ 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.

Weed seed dispersal



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.

The dynamics of the weed seedbank

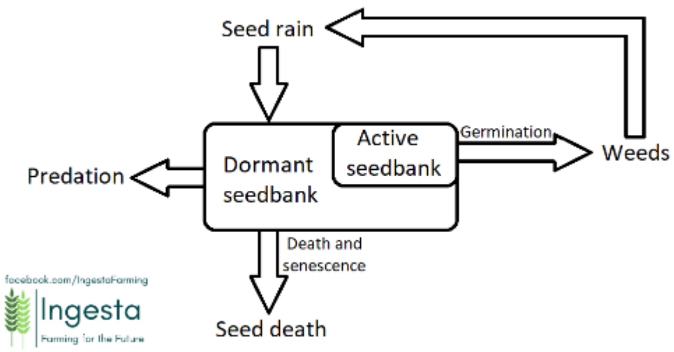


Figure 2: This figure shows the dynamics of the weed seedbank. The dormant seed bank refers to the seeds in the seedbank that are in a state of dormancy (Not yet ready to germinate). The active seedbank refers to the seeds that are ready to germinate as soon as the conditions are good. Seed rain is the 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

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:

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

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If you missed Chapter 1 you can access it here:

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If you missed Chapter 2 you can access it here:

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 succesfully 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

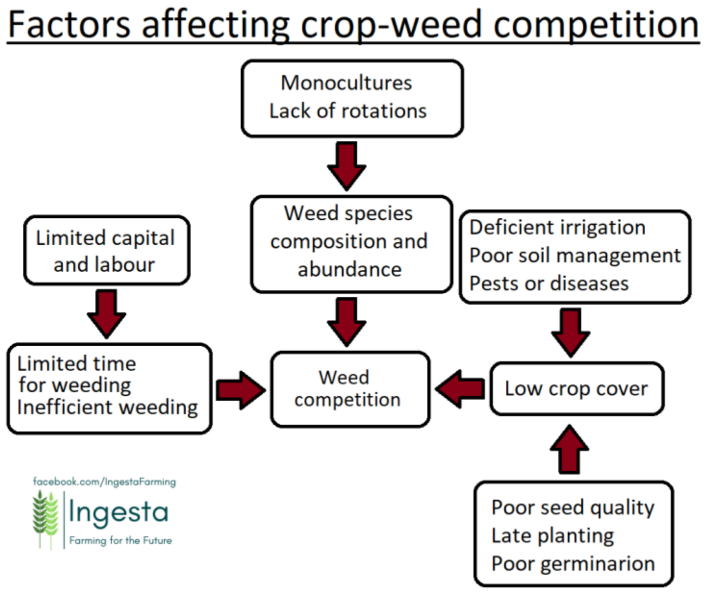

Figure 1: The factors that affect crop-weed competition in your field

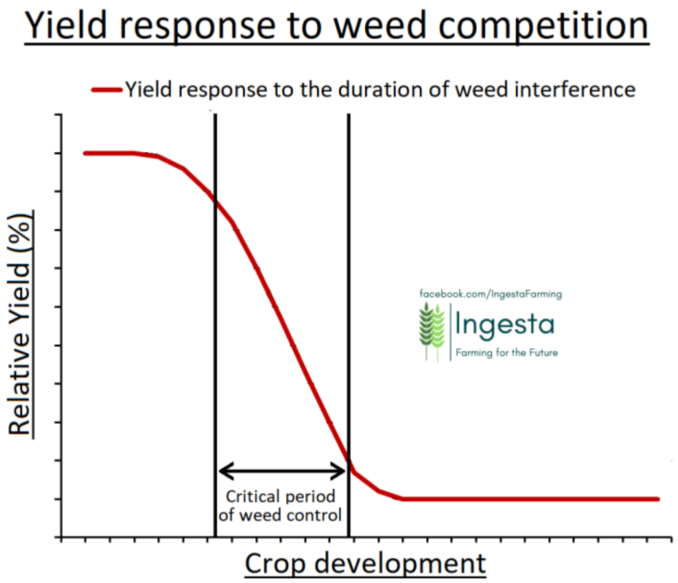

Figure 2: The red line shows us what would happen to our relative yield if we weeded the field at the start of the season, but then stopped weeding during the critical period of weed control. Here we see that relative yield decreases a lot. Even if we begin weeding again after the critical period of 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.

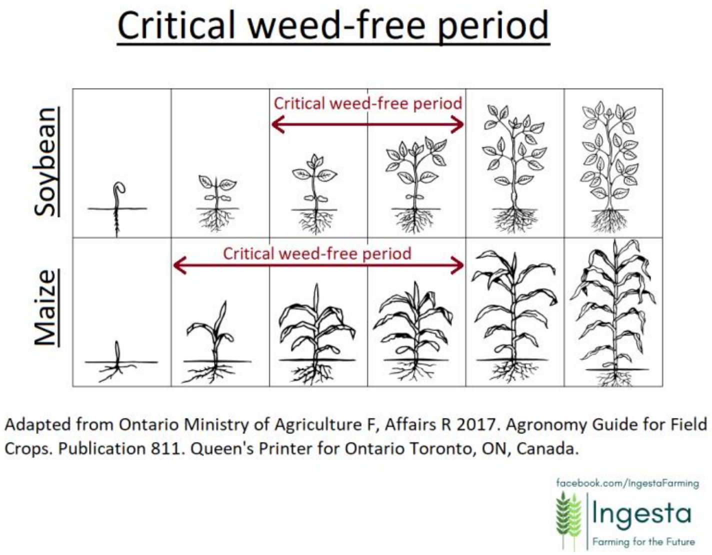

Figure 3: This diagram shows the critical weed-free period for maize and soybean. As discussed under Figure 2, controlling weeds during the critical weed-free period is very important for ensuring good yields. For example in maize, if weeding is delayed from the 3rd to the 5th leaf-stage (Total number 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).

https://www.facebook.com/IngestaFarming/Posts/977828725894114?__tn__=K-R

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 allelpathy 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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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).

4. Harrison, H.F. and J.K. Peterson, Evidence that sweet potato (Ipomoea batatas) is allelopathic to yellow nutsedge (Cyperus esculentus). Weed Science, 1991. 39(2): p. 308-312.

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 then 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

Prickly-pear (Figure 2)

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

Gum trees (Figure 3)

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

URL: https://www.facebook.com/IngestaFarming/Posts/979623045714682?__tn__=K-R

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.

• 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.

3. Stapleton, J., C. Elmore, and J. DeVay, Solarization and biofumigation help disinfest soil. California Agriculture, 2000. 54(6): p. 42-45.

4. Li, S., et al., Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dryland areas of China. Agricultural water management, 2013. 116: p. 39-49

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

URL: https://www.facebook.com/IngestaFarming/Posts/981505075526479?__tn__=K-R

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 1800's. 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.

→ Test:

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→ References:

1. Neser, S. and D. Annecke, Biological control of weeds in South Africa. Entomological Memoir, 1973.

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.

→ Test:

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→ References

1. Benson, J.M., Weeds in Tropical Crops: Review of Abstracts on Constraints in Production Caused by Weeds in Maize, Rice, Sorghum-millet, Groundnuts, and Cassava, 1952-1980. Vol. 32. 1982: Food & Agriculture Org.

URL: https://www.facebook.com/IngestaFarming/Posts/983046842038969?__tn__=K-R

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 90000mg/kg. This means that if your drink 90000mg, or 90g, per kilogram of body weight, you have a high chance of dying. This is the equivalent of a 50kg person drinking 4.5litres of water at once. Eugenol (Clove oil), an organic herbicide. Eugenol has an LD50 of 2700mg/kg, which is 135g for a 50kg person. In comparison Glyphosate, a common synthetic herbicide, has an LD50 of 5600mg/kg, which is 280g for a 50kg person. However, we also see chemical compounds like Vitamin D3, which has an LD50 of 37mg/kg, which is only 1.85g for a 50kg 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.

→ Test:

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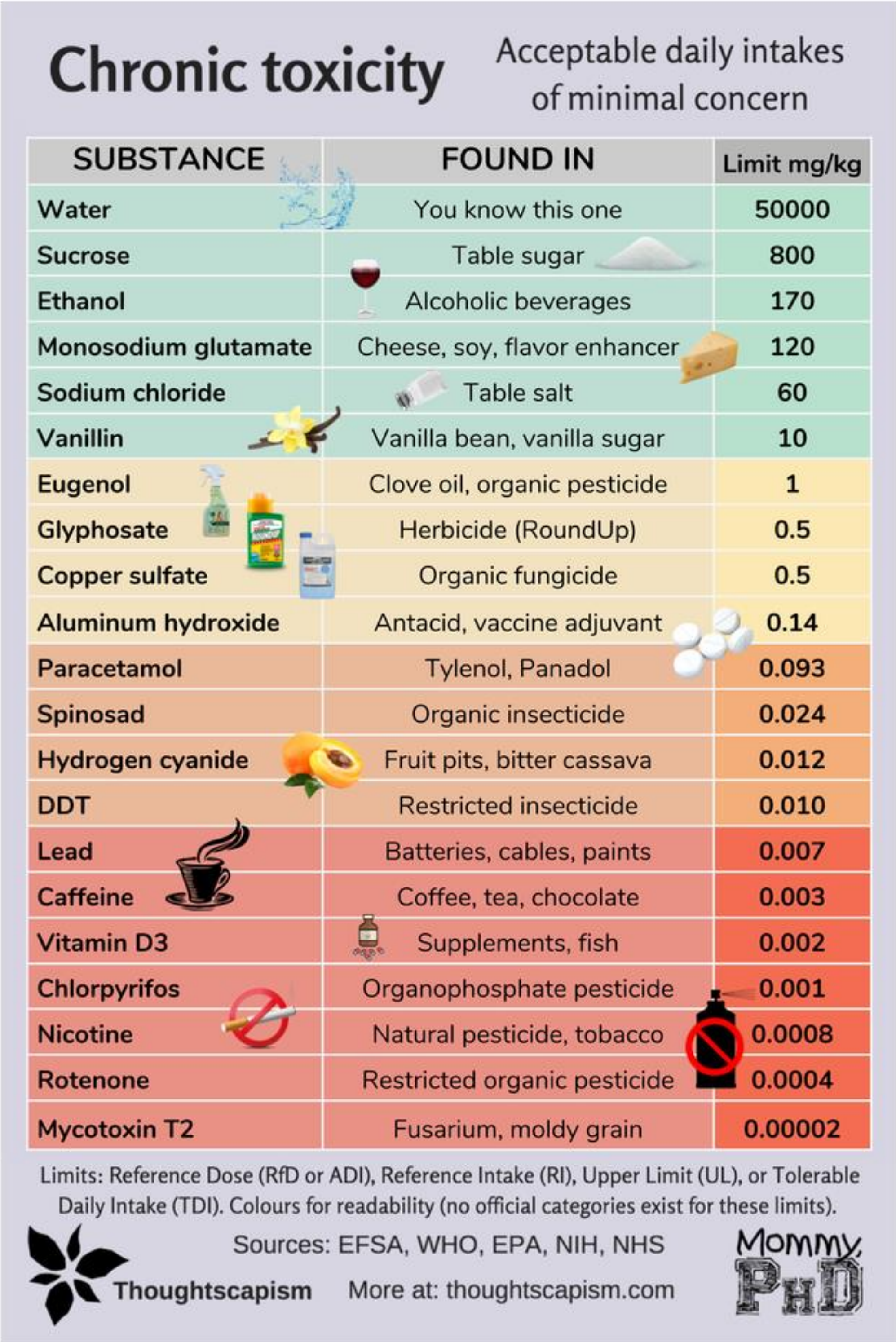
Acute toxicity Life-threatening one-time doses

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.

Thoughtscapism | Measures of Toxicity thoughtscapism.com | Sources: EFSA, WHO, EPA, NIH, NHS | Mommy PhD

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

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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.

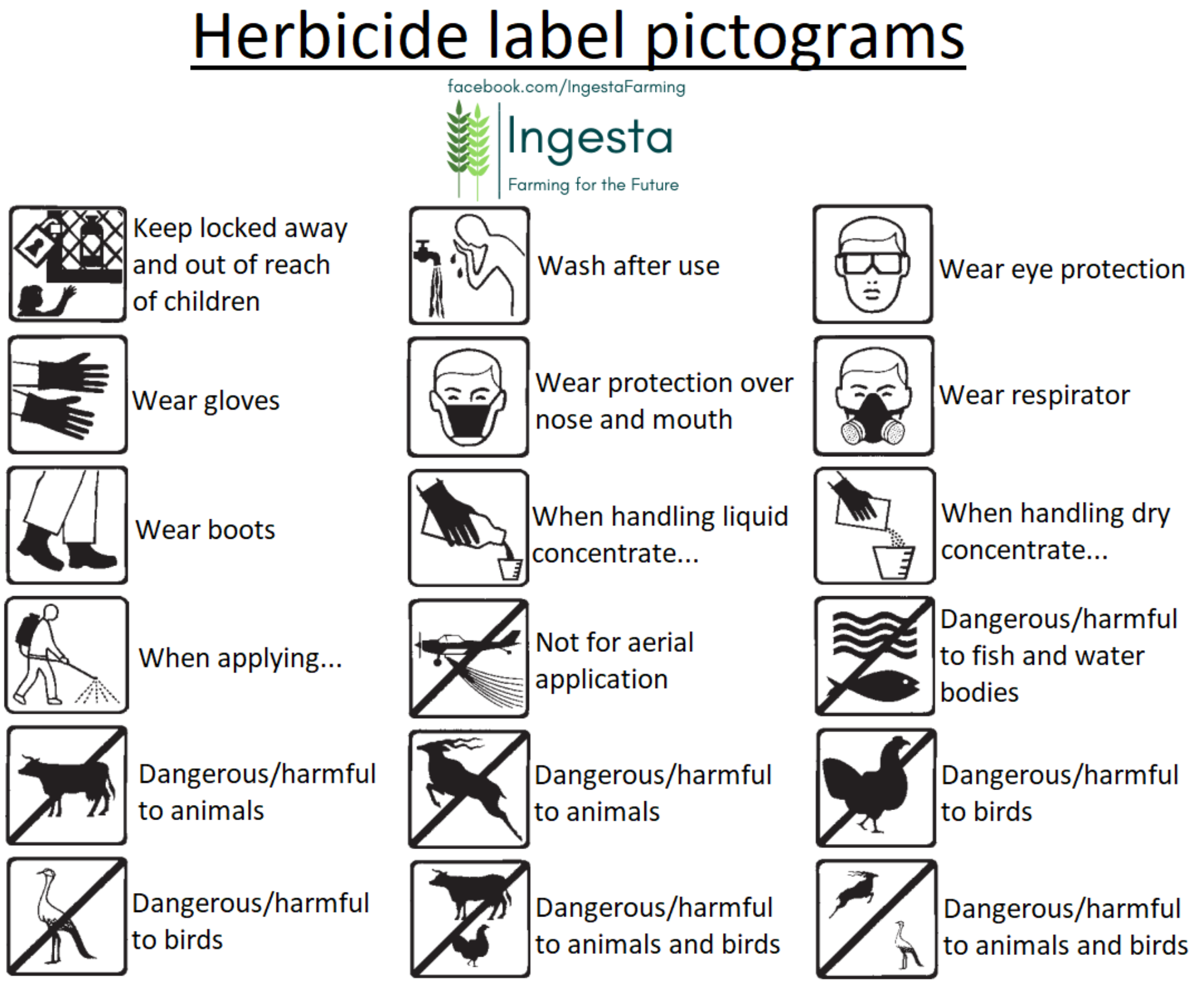

Figure 1: Common pictograms used on herbicide labels.

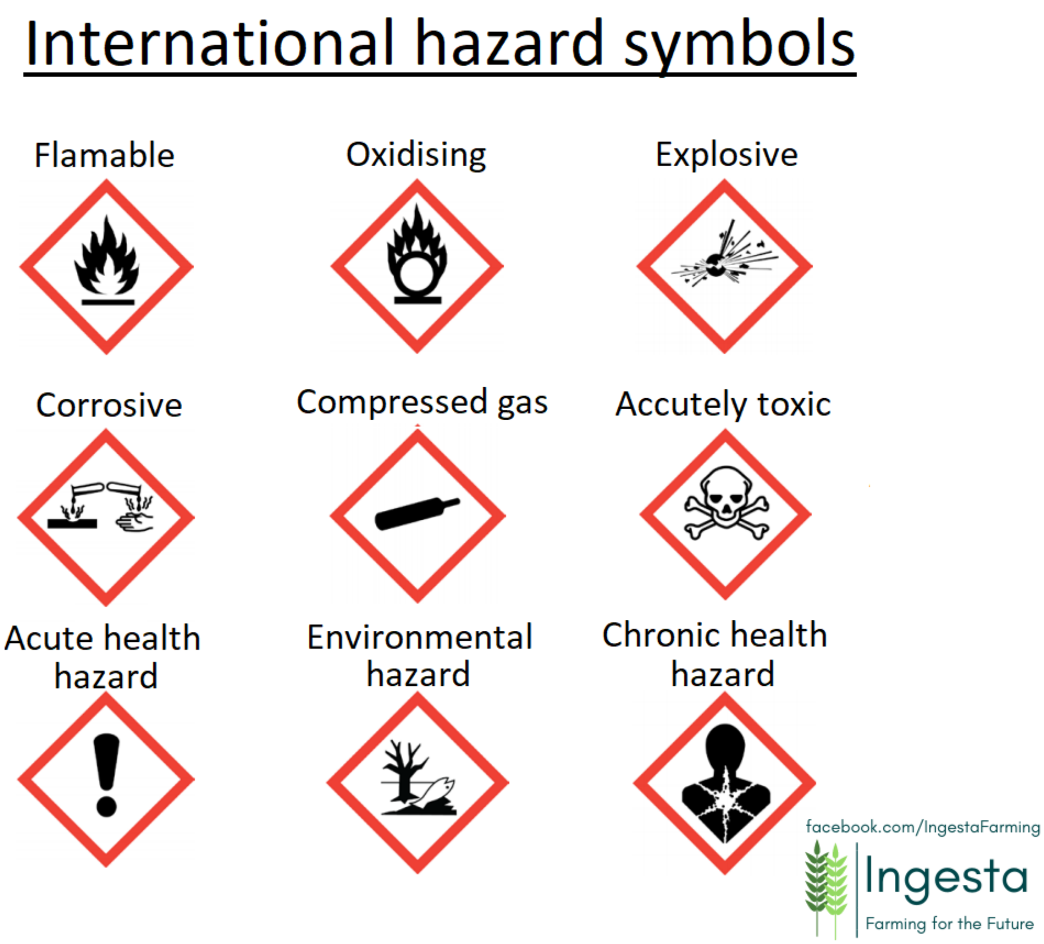

Figure 2: International hazard symbols

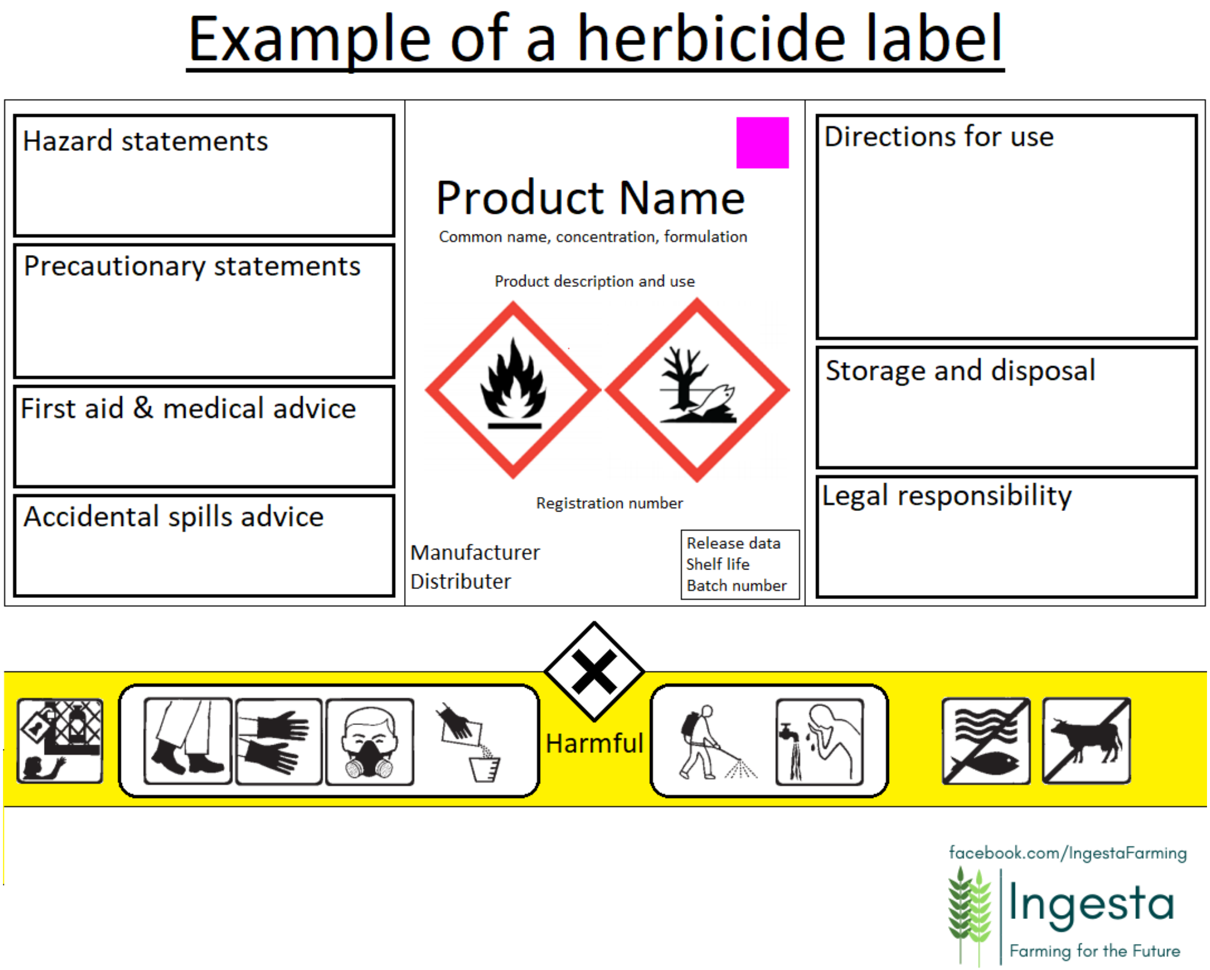

Figure 3: An example of a herbicide label. The purple square tells us that this is a herbicide. The two international hazard symbols tell us that this formula is flammable and that it is an environmental hazard, and so we must handle this product with care to ensure that no accidents occur. The yellow 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 miroorganisms (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 rootzone 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

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

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Please note that you will have to complete the tests for all 14 chapters to earn your certificate 🙂

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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:

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

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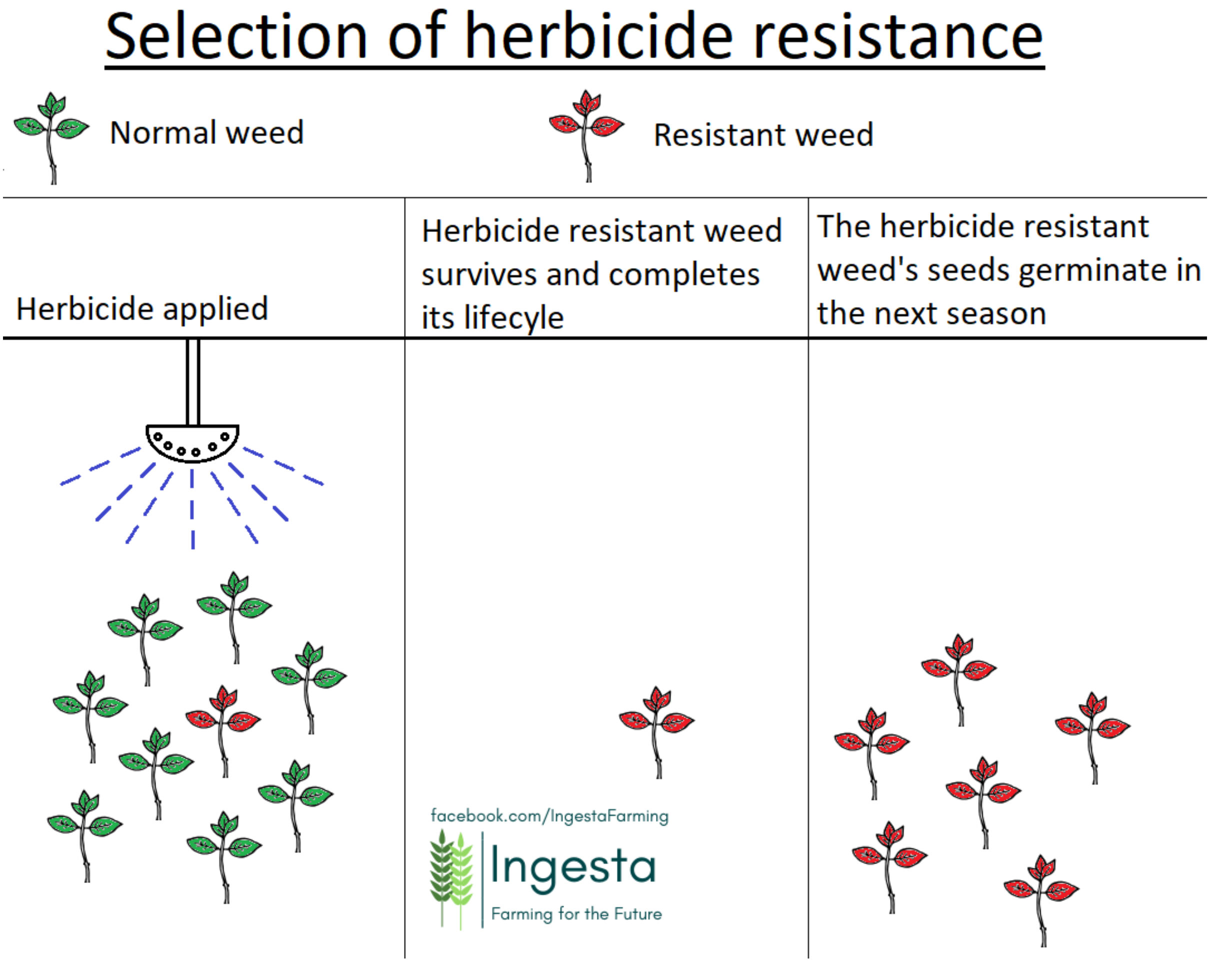

Figure 1: Herbicide resistance selection. As we can see in the resistant weed (Red weed) is not removed it will be able to produce seeds, which will increase the number of resistant weeds in the next season.

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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 is the best approach for designing our own integrated weed management programme.

→ What weeds are we controlling?

The first question we need to ask ourselves is what weeds are we 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 4.2 Learning programme chapter test memorandums

Chapter 1:

True or False: Weed seeds germinate in many different environments.
True ✓
False

True or False: Weeds do not grow quickly before producing flowers.
True
False ✓

True or False: Weeds will produce some seeds, even if growing conditions are not good.
True ✓
False

True or False: Weed seeds have adapted for both short- and long-distance dispersal.
True ✓
False

True or False: Weeds do not compete aggressively with other plants.
True
False ✓

Chapter 2:

True or False: Livestock can transport weed seeds into your fields from weeds that grew many kilometres away.
True ✓
False

True or False: Ants can transport seeds between fields.
True
False ✓

Which is a loss of seeds from the seedbank?
Predation ✓
Seed Rain
Dormancy

Which is the most efficient approach to manage the weed seedbank in the long run?
Prevention ✓
Increasing seed losses
Rotation
Reduction

Which approach will disrupt weed communities and change the weed species composition of the field?
Prevention
Increasing seed losses
Rotation ✓

Reduction

Chapter 3:

True or False: Competition only happens between plants of different species.
True
False ✓

True or False: At the beginning of the season competition is mainly for minerals and water and not for light.
True ✓
False

According to Figure 2, what is the most important time for controlling weeds in your field called?
The planting and weeding period
The crop growth weed-free period
The critical weed-free period ✓
The harvest and weeding period

True or False: Plants do not compete for water. They only compete for light and minerals.
True
False ✓

According to Figure 3, how much will maize yields decrease by if weeding is delayed from the 3rd to the 10th leaf-stage?
6.38%
10.72%
15.81% ✓
22.36%

Chapter 4:

True or False: Allelopathy is the same as competition.
True
False ✓

True or False: Allelopathy is always negative.
True
False ✓

What pest do marigolds help prevent in your fields?
Nematodes ✓
Snails
Mice
Grasshoppers

True or False: Yellow Nutsedge is a small plant, but can still have a negative effect on big crops such as maize.
True ✓
False

Weeds such as Common Purslane and Jute Mallow can be reduced by intercropping which crop on alternate ridges with maize?
Sweet potatoes
Onions
Cowpea ✓
Sunflowers

Chapter 5:

True or False: Australian Wattles can increase the risk of fire in some environments.
True ✓
False

How much water is lost to invasive weeds every year in South Africa?
Up to 6%
Up to 10%
Up to 16% ✓
Up to 20%
How do pine trees change the soil they grow in?
Cause soil compaction
Cause soil acidification ✓
Reduce the available nitrogen
Reduce the infiltration rate

True or False: All invasive aliens have the same impact on the environment.
True
False ✓

What category is the prickly pear (Figure 2)?
1a
1b ✓
2
3

Chapter 6:

True or False: Some weed seeds can survive being eaten by livestock, and will grow from the manure
True ✓
False

True or False: ComPosting kills weed seeds
True ✓
False

Why is total weed eradication difficult to achieve?
Because it requires killing all living seeds, plants and parts of plants that could grow again. ✓
Because it requires manual labour, and that is hard-work
Because it requires a lot of time, and we have other things we want to do instead
Because it requires sometimes we want to leave our weeds so we can admire their flowers

What is the economic threshold?

The number of weeds that will cause a yield loss equal to the economic cost of controlling the weeds. ✓
The number of weeds that you can afford to control.
The amount of money that you will make by controlling your weeds.
The amount of money you should save instead of spending it on weed management.

What is the first principle of weed management systems?
Slowing the growth of weeds ✓
Ploughing your field
Ensuring your weeds are healthy
Watering your weeds

Chapter 7:

What is the minimum amount of residues that are left during conservation tillage?
10%
20%
30% ✓
40%

What is the best type of physical weed control?
Tillage
Hand weeding
Mowing and grazing
Thermal control
Mulching
We cannot say because it depends on many factors that are specific to the production system ✓

How does soil solarisation control weeds?
It heats the soil which kills weeds and weed seeds ✓
It heats the soil and increases microbial activity
It cools the soil and slows weed growth
It cools the soil and increases soil fertility

What is a potential problem with using crop residue mulches?
They can reduce water availability
They can decrease soil organic matter content
The can decrease soil fertility
They can host pests and diseases, increasing disease pressure ✓

What is a benefit of using plastic mulches, other than weed control?
They can reduce evaporation water loss from the soil surface ✓
They decrease soil temperatures
The increase soil fertility
They look neat

Chapter 8:

What is a biological control agent?
People who are in charge of clearing weeds from an area
Insects or diseases that are used to increase the number of weeds in an area
Insects or diseases that are used to reduce the number of weeds in an area ✓
People who are in charge of planting more plants in an area

What is the objectives of biological control?
To increase the number of weeds in an area so that they compete with each other
To bring more insects into an area to increase the biodiversity
To remove all the weeds from the area
To reduce the number of weeds in an area to below a level that was cause economic losses ✓

Which is a characteristic of a biological control agent?
Is able to survive once the weed population has been reduced ✓
Can cause harm other species
Is not adapted to the local environment
Has its own predators or diseases

Biological control is best suited for:
High-input cropping systems
Situations where rapid killing of weeds is not necessary ✓
Where many weed species are dominant

Who lobbied the South African government to release the cochineal in 1932?
Farmers who wanted help clearing drooping prickly pear from their grazing land ✓
Farmers who wanted to see more insects on their land
Farmers who wanted to see more drooping prickly pear on their land
Farmers who wanted help clearing pine trees from their land

Chapter 9:

How is crop rotation a form of cultural control?
It increases our yields
It increases the number of crops we grow
It increases the biodiversity in our fields
It disrupts the lifecycles of the weeds in our fields ✓

True or False: Tillage and field preparation creates favourable growing conditions that will encourage weed seed germination.
True ✓
False

How is using cold-tolerant cultivars a form of cultural control?
They can be planted early in the season when temperatures may be too cold for weed germination ✓
They are frost-resistant which prevents damage to our crops during cold times
They can be stored in a fridge, ensuring a longer shelf-life for our harvest
They grow faster under cold conditions than they do under hot conditions

If Amaranthus is not controlled it can cause deficiencies of which nutrient?
Nitrogen ✓
Potassium
Phosphorous
Calcium

True or False: Increasing fertiliser applications without weed-control can increase yield losses cause by weeds
True ✓
False

Chapter 10:

True or False: 2,4-D is a broad-spectrum herbicide
True
False ✓

True or False: Over-reliance and misuse of herbicides can lead to herbicide resistance developing, which reduces the effectiveness of the herbicide in the future
True ✓
False

True or False: All chemicals are bad for us
True
False ✓

True or False: Organic herbicides are always safer than synthetic herbicides
True
False ✓

What is acute toxicity?
The amount of a chemical compound you would have to be exposed to at once to have a good chance of dying ✓
The maximum amount of a chemical compound a person can be exposed to every day, before long-term harm is caused
The probability of coming into contact with a harmful dose of a specific chemical compound

Chapter 11:

Which pictogram shows that we must wear eye protection when handling the herbicide?

 ✓

Which pictogram shows that we must keep the herbicide away from children?

 ✓




Which pictogram shows that we must wash ourselves after handling the herbicide?




 ✓

Which pictogram shows that we must wear gloves when handling the herbicide?






 ✓

Which pictogram shows that the herbicide is potentially dangerous to animals?


 ✓


Chapter 12:

What is absorption?
The process through which a herbicided will bond to the surface of soil particles
The process in which a herbicide becomes a gas
The movement of herbicides by water through the soil profile
The process in which a herbicide is taken up by plants or soil microbes ✓

True or False: Herbicide volatilisation occurs quicker from wet soils than from dry soils
True ✓
False

What is photodegredation?
When the chemical compound is broken down by water
When the chemical compound is broken down by phytochemicals
When the chemical compound is broken down by reactions with soil particles
When the chemical compound is broken down by the ultraviolet light in sunlight ✓

True or False: Herbicides are only effective if they remain active and available
True ✓
False

What is the name of the mobile app that can be used to plan when to apply herbicides?
AgriHub
AgriCloud ✓
SpraySaver
CropDuster

Chapter 13:

What is the mechanism of action?
The plant's response to being exposed to the herbicide chemical compound
The geochemical processes that are affected by the herbicide chemical compound
The biochemical or biochemical process that is affected by the herbicide chemical compound ✓
The plant's response to harsh environmental conditions

If a herbicide's mechanism of action is to stop photosynthesis, what is its mode of action?
The plant becoming weak because it is growing too fast
The plant starving because it can no longer produce sugars to feed itself ✓
The plant growing too fast because it is producing too many sugars
The plant becoming stressed because it can no longer take up water

True or False: We can mix any herbicides together
True
False ✓

What is herbicide resistance?

An individual weed is able to survive being exposed to a dose of a herbicide that would normally kill a weed of that species ✓
The weed species has a mechanism that prevents the uptake of the herbicide chemical compound
An individual weed is able to survive being exposed to a dose of a herbicide because it was not sprayed with enough herbicide
The weed species has the ability to process the herbicide chemical compound without suffering any negative effects

True or False: Using the same herbicide every season increase the chance of resistance developing
True ✓
False

Chapter 14:

What is the first question we ask ourselves when planning an integrated weed management programme?
Where are the weeds coming from?
What weeds are we controlling? ✓
How can we control weeds early on in the season?
How do we control weeds that have already established?

Why can perennial weeds be more difficult to control than annual weeds?
They produce more seeds than annual weeds
There are always more perennial weeds than annual weeds
The grow faster than annual weeds
They have evolved survival strategies such as bulbs or the ability to regrow from roots ✓

True or False: It is not beneficial for us to help our neighbours control the weeds in their fields
True
False ✓

Why is it important to use a secondary form of weed control after herbicide application?
To show our neighbours we know many different types of weed control methods
To use all the weed control equipment we have
To make sure we are always busy during the growing season
To remove any resistant weeds that might have survived ✓

True or False: Investing in good weed management this season reduces the amount of weeding we will need to do next season
True ✓
False

Appendix 4.3 Learning Programme Enrolment Form

Section 1: Biographical information

Email:

First Names:

Surname:

Phone number:

Date of birth:

Gender:

- Female
- Male
- Non-binary
- Prefer not to say
- Other:

Country of residence

- South Africa
- Other:

Section 2: South Africa

Province:

- Gauteng
- Mpumalanga
- Kwa-Zulu Natal
- Eastern Cape
- Western Cape
- Northern Cape
- North-West
- Limpopo
- Free-State

Closest town or city to where you live:

Section 3: Other countries

Closest town or city to where you live:

Section 4: Are you a farmer?

Do you farm?

- Yes
- No

Section 5: Active Farmers

Do you own the farm?

- Yes
- No, I farm on communal land
- No, I rent the land from a private land owner
- No, I rent the land from the government
- Other:

How much land do you farm?

- Less than 1 hectare
- 1-5 hectares
- 5-10 hectares
- 10-100 hectares
- More than 100 hectares

What crops do you farm with?

Do you use irrigation?

- No
- Yes, drip irrigation
- Yes, microjet sprinklers

- Yes, centre-pivot
- Yes, drag-line sprinklers
- Other:

Section 6: Agricultural training

Have you had any formal agricultural training? If yes, please provide details

Why do you want to enrol in this learning programme?

What do you hope to learn from this programme?

Appendix 4.4 Learning programme final test and feedback form, with memorandum marks

Email:

First Names:

Surname:

1) Why is it important to control weeds before they produce seeds?
   - To reduce the number of weed flowers we see on our farm
   - To reduce the number of seeds being added to the weed seedbank ✓
   - To reduce the number of weeds we have to control
   - To reduce the number of seeds the wild birds are eating

2) How does the invasive prickly pear affect grazing?
   - The prickly-pear produces fruit which is better for livestock than grass
   - The prickly-pear uses a lot of water, which decreases grazing
   - The prickly-pear increases soil fertility, which improves grazing
   - The prickly-pear displaces grasses and prevents access to grazing areas ✓

3) How do eucalyptus trees threaten our natural water resources?
   - Eucalyptus trees invade natural ecosystems, and use large amounts of water ✓
   - Eucalyptus trees fix nitrogen from the atmosphere, polluting water resources
   - Eucalyptus trees release allelopathic chemicals into our water
   - Eucalyptus trees produce a lot of biomass which blocks our rivers

4) Why is whole-farm weed control important?
   - Weeds from along fence lines and road edges will attract pests to our fields
   - Weeds from along fence lines and road edges will cause nutrient deficiencies in our fields
   - Weeds from along fence lines and road edges will add seeds to our field's weed seedbank if left to seed ✓
   - Weeds from along fence lines and road edges will cause damage to our equipment if left to seed

5) How does tillage affect the number of weed seeds that germinate successfully?
   - During tillage small seeds get buried deeper in the soil profile where they cannot germinate successfully ✓

- Tillage leads to nitrogen losses from the soil, causing nitrogen deficiencies which reduce germination
- During tillage soil moisture is improved which increases weed seed germination
- Tillage leads to unfavourable conditions, which reduces the number of seeds that can germinate

6) How does mowing affect the weed seed bank?
   - Mowing compacts soil, which prevents seeds from reaching the weed seed bank
   - Mowing exposes seeds, which increase seed predation
   - Mowing weeds along the edges of fields and roads before they seed will prevent additions to the weed seedbank ✓
   - Mowing creates conditions which ensure seeds stay dormant and do not germinate

7) How does mulching control weeds?
   - Mulching forms a physical barrier on the soil surface which can prevent weed seeds from germinating successfully ✓
   - Mulching increases soil temperature which decreases weed seed germination
   - Mulching reduces soil water losses which decreases weed seed germination
   - Mulching increases soil fertility which can decrease weed competitiveness

8) In what types of systems is biological control suited for?
   - High input cropping systems where rapid kill is needed
   - Low input cropping systems with annual crops
   - Low input cropping systems where rapid kill is not needed ✓
   - High input cropping systems with crop rotation

9) Which of the following best describes the process of 'false seed beds'?
   - The practice of discouraging weed seeds to germinate, forcing them into a state of dormancy
   - The practice of encouraging weed seeds to germinate and emerge from the soil, before harvesting their seeds
   - The practice of discouraging weed seeds to germinate, causing higher levels of seed predation
   - The practice of encouraging weed seeds to germinate and emerge from the soil, before killing them ✓

10) How can planting density be used to control weeds?

- Increasing planting density can control weeds by ensuring the crop canopy closes quicker, preventing the weeds from accessing light ✓
- Increasing planting density can control weeds by ensuring the crop takes up all of the nutrients, causing nutrient deficiencies in the weeds
- Increasing planting density can control weeds by ensuring the crop takes up all the available water, reducing weed growth
- Increasing planting density can control weeds by ensuring the crop canopy remains open, so that the crop has access to more light

11) How can herbicide residues on crops affect consumers?
- Herbicide residues on crops affect the taste of the fresh produce, resulting in produce of a lower quality and price
- Herbicide residues on crops directly exposes the consumer to the herbicide, which can have negative impacts on their health ✓
- Herbicide residues on crops decrease the nutrients in the fresh produce
- Herbicide residues on crops decrease the shelf-life of fresh produce, resulting in increased food wastage on the consumer's home

12) What does the green band on a herbicide label indicate?
- Very toxic – Extremely/Highly hazardous. Protective equipment and clothing must be used.
- Moderately hazardous – All safety measures stated on label must be used.
- Caution – Slightly hazardous. Use carefully and use protective equipment.
- Keep Locked Away – Store away from children, food, and animals. ✓

13) What does the red band on a herbicide label indicate?
- Very toxic – Extremely/Highly hazardous. Protective equipment and clothing must be used. ✓
- Moderately hazardous – All safety measures stated on label must be used.
- Caution – Slightly hazardous. Use carefully and use protective equipment.
- Keep Locked Away – Store away from children, food, and animals.

14) What does the blue band on a herbicide label indicate?
- Very toxic – Extremely/Highly hazardous. Protective equipment and clothing must be used.
- Moderately hazardous – All safety measures stated on label must be used.
- Caution – Slightly hazardous. Use carefully and use protective equipment. ✓
- Keep Locked Away – Store away from children, food, and animals.

15) What does the yellow band on a herbicide label indicate?

- Very toxic – Extremely/Highly hazardous. Protective equipment and clothing must be used.
- Moderately hazardous – All safety measures stated on label must be used. ✓
- Caution – Slightly hazardous. Use carefully and use protective equipment.
- Keep Locked Away – Store away from children, food, and animals.

16) How can using vinegar as a herbicide damage our soils?

- Using vinegar as a herbicide can result in saline soils
- Using vinegar as a herbicide can result in nitrogen toxicity
- Using vinegar as a herbicide can result in soil compaction
- Using vinegar as a herbicide can result in soil acidification ✓

17) How can using Epsom salts as a herbicide damage our soils?

- Using Epsom salts as a herbicide can result in nitrogen toxicity
- Using Epsom salts as a herbicide can result in saline soils ✓
- Using Epsom salts a herbicide can result in soil compaction
- Using Epsom salts as a herbicide can result in soil acidification

18) How can herbicide runoff damage our environment?

- Runoff of herbicides can lead to nutrient deficiencies in our soils
- Runoff of herbicides can lead to increased adsorption of nutrients to soil particles
- Runoff of herbicides can lead to the contamination of water sources such as streams, rivers, and dams ✓
- Runoff of herbicides can lead to increased growth of invasive weed species along streams, rivers, and dams

19) Why are degradation processes important?

- Degradation processes are important for reducing the carry-over of herbicides into the next season ✓
- Degradation processes are important for increasing the efficiency of herbicides
- Degradation processes are important for ensuring the weeds absorb the herbicides
- Degradation processes are important for reducing the number of weed seeds

20) Why should we spray herbicides in the morning when temperatures are not as hot?

- To reduce adsorption

- To reduce volatilisation ✓
- To reduce runoff
- To reduce leaching

21) How can over-irrigating our fields reduce the effectiveness of herbicides for weed control?
    - Over-irrigation increases herbicide adsorption to soil particles, reducing effectiveness of weed control
    - Over-irrigation increases herbicide volatilisation, reducing effectiveness of weed control
    - Over-irrigation decreases absorption of herbicides, reducing effectiveness of weed control
    - Over-irrigation increases herbicide leaching, reducing the effectiveness of weed control ✓

22) Why should we not apply herbicide on days where it is forecast to rain?
    - Rain will lead to increased volatilisation of freshly-applied herbicides
    - Rain could lead to increased adsorption to soil particles of freshly-applied herbicides
    - Rain could lead to increased growth of weeds
    - Rain will lead to increased herbicide runoff of freshly-applied herbicides ✓

23) Why is it important to use herbicides with different modes of action?
    - To reduce herbicide adsorption to soil particles
    - To reduce the chance of herbicide resistance developing ✓
    - To increase the number of crops that will be protected
    - To increase the number of weed seeds that are predated on

24) What is the most important reason for removing any surviving weeds from the field after a herbicide has been applied?
    - To ensure that our crops are not facing competition for water
    - To remove potential homes for pests
    - To ensure herbicide resistant individuals are killed before they produce seed ✓
    - To keep our fields looking neat

25) Why is it important for us to control weeds as soon as possible in the season?
    - To reduce the negative effects of weeds on our crops and control them while they are still young and vulnerable

- To ensure our fields look neat throughout the season, so that our neighbours are impressed with our fields ✓
- To reduce the time it will take us to harvest our crops
- To ensure that we increase to organic matter content of our soils at the beginning of the season

26) What does this pictogram mean?

- When applying… ✓
- Wear protection over nose and mouth
- Wear gloves
- Wear eye protection
- Wear boots
- Wash after use
- Keep locked away and out of reach of children
- Dangerous/harmful to fish and water bodies
- Dangerous/harmful to animals
- When handling liquid concentrate

27) What does this pictogram mean?

- When applying…
- Wear protection over nose and mouth
- Wear gloves
- Wear eye protection
- Wear boots
- Wash after use ✓
- Keep locked away and out of reach of children
- Dangerous/harmful to fish and water bodies
- Dangerous/harmful to animals
- When handling liquid concentrate

28) What does this pictogram mean?

- When applying…
- Wear protection over nose and mouth
- Wear gloves
- Wear eye protection
- Wear boots
- Wash after use
- Keep locked away and out of reach of children
- Dangerous/harmful to fish and water bodies
- Dangerous/harmful to animals ✓
- When handling liquid concentrate

29) What does this pictogram mean?

- When applying…
- Wear protection over nose and mouth
- Wear gloves
- Wear eye protection
- Wear boots
- Wash after use
- Keep locked away and out of reach of children ✓
- Dangerous/harmful to fish and water bodies
- Dangerous/harmful to animals
- When handling liquid concentrate

30) What does this pictogram mean?

- When applying…
- Wear protection over nose and mouth
- Wear gloves ✓
- Wear eye protection
- Wear boots
- Wash after use
- Keep locked away and out of reach of children
- Dangerous/harmful to fish and water bodies
- Dangerous/harmful to animals
- When handling liquid concentrate

How did you access the learning programme?

- Mostly on a laptop or computer, but sometimes on a mobile phone or tablet
- On a mobile phone or tablet
- On a laptop or computer
- Equally on a mobile phone or tablet and a laptop or computer
- Mostly on a mobile phone or tablet, but sometimes on a laptop or computer

Was the course material easy to understand?

- Difficult to understand
- Easy to understand
- Not easy to understand
- Very difficult to understand
- Very easy to understand

How did you find the length of the chapters?

- Just long enough
- Not long enough
- Too long

Was it easy to view the pictures? Please explain.

Was it easy to read the information in the picture captions? Please explain.

What would you like the topic of the next learning programme to be?

If we develop more learning programmes, how long should they be and how often should we publish the chapters?

	5 chapters or less	Between 5 and 10 chapters	Between 10 and 15 chapters	More than 15 chapters
A chapter every day	☐	☐	☐	☐
A chapter every second day	☐	☐	☐	☐
Two chapters per week	☐	☐	☐	☐
One chapter per week	☐	☐	☐	☐

Did you have any difficulties accessing the Posts? Please describe.

Did you have any difficulties accessing the tests? Please describe.

Do you feel you have learnt information to better help you manage weeds in your fields?

What are the main obstacles to managing weeds in your field?

How can we improve the learning programme?

Appendix 4.5 Example of the learning programme certificate of completion


Ingesta
Farming for the Future

Certificate of Completion

This acknowledges that

has successfully completed the Weed Science learning programme

Michael van der Laan
Associate Professor
University of Pretoria

DEPARTMENT OF PLANT AND SOIL SCIENCES

Richard Hay
Research assistant
University of Pretoria