ANNEXURE SS

DETAILS

Project number		M106/15
Project title		Impact of conservation agricultural practices on crown and root rot of maize
Project manager		M Craven
Co-worker(s)	Internal	AA Nel, MB Kwele, MM Mahlobo, MO Motheketlela, KA Tantasi, SB Mahlatsi, TJ Baas, NY Maila, PR Mogotlwane, DB Biya, Res Technician (vacant), F Mashinini, W Deale, TM Ramusi, AEJ du Toit.
	External	None
Status		Complete
Duration		01/10/2008 to 31/03/2014
Funder(s)		ARC/Maize trust

Final abstract

Two conservation agriculture (CA) trials planted by the M106/11 project near Ventersdorp (Buffelsvallei farm - sandy loam soil, North West province) and Viljoenskroon (Erfdeel farm - sandy soil, Free State) were monitored as part of the impact study of conservation agricultural practices on crown and root rot of maize. The study was conducted over a six year period (2008/09 to 2013/14) under dryland conditions. The two trials differed to some extend with regard to the treatments tested at the various sites. The trail layout for the Viljoenskroon trial (sandy soils) was a randomised complete block design with four treatments and four replicates (TMT1 - mono-cropped maize under conventional tillage; TMT2 - mono-cropped maize under minimum soil disturbance; TMT3CP - a two-year system of maize in rotation with cowpea under minimum soil disturbance and TMT4CP - a three-year cowpea/maize/pearl millet rotation system under minimum soil disturbance). The same four treatments were planted at the Ventersdorp trial (TMT1, TMT2, TMT3CP and TMT4CP) together with two additional treatments (i.e. TMT3SF - a two-year system of maize in rotation with sunflower under minimum soil disturbance and TMT4SF - a three-year sunflower/maize/pearl millet rotation system under minimum soil disturbance). Six treatments were accordingly monitored at the Ventersdorp trial. Parameters evaluated at both sites included yield, plant mass and root and crown rot severity. Ten randomly selected plants were sampled per plot at 21, 70 and 100 days after planting (DAP) in order to generate the required data which included the plating out of root and crown material in order to establish fungal frequencies within these plant parts at the various sampling dates. Data generated over a three year period (2011/12 to 2013/14) were included in the final report, as the data generated from these seasons represented more established cropping systems.

organism of charcoal rot) as well as *S. maydis* correlated with the crown rot, plant mass as well as the eventual yield measured during 2012/13.

The impact of four established cultivation practices on specific plant parameters were lastly compared over a two year period (2012/13 and 2013/14) over the two localities (Viljoenskroon - sandy soil and Ventersdorp - sandy loam soil). TMT2 yielded significantly lower yields at Viljoenskroon as opposed to TMT1 which was the lowest yielder at Ventersdorp. Plant mass at 100 DAP demonstrated the same effect as that of yield with TMT2 and TMT1 resulting in lower plant mass at Viljoenskroon and Ventersdorp respectively. Early during the season, greater plant mass were linked to the cowpea rotations systems which could not be linked to the disease severities measured which might point to additional beneficial aspects brought about by the specific rotation systems. Prominent disease severity was only measured at 100 DAP and could mostly be attributed to the 2012/13 results which indicated higher levels of disease severity in TMT1, TMT2 and TMT3CP. Fungi that demonstrated to have significantly higher levels at this specific sampling date were *M. phaseolina* and *S. maydis* as measured within the crowns of TMT1. The higher degree of disease severity observed in TMT2 during the same season can be attributed to *F. graminearum* occurrence. The late drought conditions experienced at the Ventersdorp site during 2013/14 resulted in plants in TMT1 suffering severe water stress as opposed to the other treatments which all had cover layers to protect them. This predisposed the plants to infection by *M. phaseolina* (which is known for its prevalence to dry hot conditions) as well as *S. maydis* which is known for is prevalence to maize as its only host. The continued cultivation of maize under monoculture together with the cover layer as experienced in TMT2 resulted in conditions which was suitable for *F. graminearum* infection. This effect was however only limited to the Ventersdorp trial, most probably due to the fact that the Viljoenskroon trial were not exposed to such dry conditions during 2012/13 as the Ventersdorp trial. The increase disease severity observed for TMT3CP at Ventersdorp (2012/13) could not be attributed directly to any one fungus.

Over a period of six years of evaluation, only one season resulted in significant disease development (2012/13) at one of the localities evaluated, which emphasised the importance that climate plays in whether root and crown rot develop or not. Based on the findings of especially the 2012/13 season, it is clear that Conservation Agriculture can play a very important role in the management of charcoal rot especially in the dryland production areas of the North West province which often suffers from the disease due to the generally hotter and dryer conditions experienced.

The relevance of soil applications such as anhydrous ammonia (AA) with known fungicidal

PROJECT HISTORY

Conservation agriculture (CA) with minimum soil disturbance as one of its principles is becoming an increasingly accepted practice all over the world. South Africa lags behind other countries in the adoption of CA due to, among others a lack of knowledge and uncertainty about the chances for successful implementation of this practice under local conditions. This project started during the spring of 2008 to investigate the feasibility of CA in two typical soil types, namely a Clovelly and a Hutton on the Highveld. There is ample evidence that elements of CA can affect plant pathogens either positively or negatively and this research was initiated in order to study plant diseases in the context of the CA research programme of ARC-GCI.

to survive at least 630 days in surface or buried maize residue. It was also indicated that the survival of the fungi was greater in superficial that in buried residues (Cotten and Munkvold, 1998). Some research studies reported that *Fusarium* spp. such as *F. verticillioides, F. proliferatum* and *F. subglutinans* as well as *Rhizoctonia solani* Kuhn occurred more frequently in unploughed soil (Herman, 1984, Skoglund and Brown, 1988; Weller *et al*,.1986), whilst others found that the average incidence of stalk rot caused by *F. moniliforme* and *Macrophomina phaseolina* was significantly lower in no-till plots compared to those in conventionally tilled plots (Osunlaja, 1990). The study of tillage practices in combination with crop rotation have proven to be challenging as the combination of tillage and crop rotation has a more complex effect than either factor alone (Smit, 1998 Lipps and Deep, 1991)

The importance of crop rotation systems was emphasized by local research as canola-maize systems yielded the highest root rot severity and lowest yield, with all other canola systems yielding less that non-canola systems (Nel and Lamprecht, 2011). The inclusion of a legume within a crop rotation system has demonstrated to alter the soil fungal species composition (relative abundance of species in wheat with soybean as opposed to wheat with corn; Wang *et al.* 2010). Similar findings with regard to bacterial communities and arbuscular mycorrhizal fungi were also reported by other researchers (Alvey *et al.*, 2003; Oehl *et al.*, 2004).Research conducted demonstrated that the effect of crop rotation on isolates of maize root fungi are complex and isolated fungi are affected differently by various rotation systems under conventional agricultural practices, implying that no single cropping system favour all fungi (Smit and Van Rensburg, 1997). The study of tillage practices in combination with crop rotation have proven to be challenging as the combination of tillage and crop rotation has a more complex effect than either factor alone (Smit, 1998; Lipps and Deep, 1991).

AMMI (Additive Main Effects and Multiplicative Interactions (Gauch,1992.) and more recently the GGE biplot (Jalata, 2011) are tools generally applied by plant breeders for Genotype x Environment studies. AMMI has, however, also been utilised to determine the effect of different tillage and residue management practices on soil bacterial communities (Ceja-Navarro *et al.,* 2010). If the research emphasis is on the evaluation of various cropping systems, a cropping system-focused GGE biplot can be constructed (Yan and Falk, 2002). In general, GGE biplot refers to genotype main effects plus GE (Kroonenberg, 1995). The differences between the AMMI and the GGE biplot analysis is that GGE biplot analysis is based on environment-centred principle component analysis (PCA), whereas AMMI analysis is based on double centred PCA. GE biplots are considered to be a more accurate presentation of GGE data as it explains more G + GE that the AMMI1 graph (Yan *et al.*, 2007).

GENERAL MATERIALS AND METHODS

Soil preparation and field trial layout

Two conservation agriculture (CA) trials planted by the M106/11 project near Ventersdorp (Buffelsvallei farm - sandy loam soil, North West Province) and Viljoenskroon (Erfdeel farm - sandy soil, Free State) were monitored as part of the impact study of conservation agricultural practices on crown and root rot of maize. The study was conducted over a six year period (2008/09 to 2013/14) under dryland conditions. Top dressing was applied six weeks after planting (LAN, 100 kg ha^{-1}). The two trials differed to some extend with regard to the treatments tested at the various sites.

The trail layout for the Viljoenskroon trial (sandy soils) was a randomised complete block design with four treatments and four replicates. Each trial plot consisted of 16 rows, 30m in length spaced 0.9 m apart. Treatments consisted of the following:

- TMT1 - Mono-cropped maize under conventional tillage.
- TMT2 - Mono-cropped maize under minimum soil disturbance.
- TMT3CP - A two-year system of maize in rotation with cowpea under minimum soil disturbance.
- TMT4CP - A three-year Cowpea/maize/pearl millet rotation system under minimum soil disturbance.

The trail layout for the the Ventersdorp trial *(loamy sand)* was a randomised complete block design with six treatments and four replicates. Each trial plot consisted of 28 rows, 20 m in length spaced 0.9 m apart. Treatments consisted of the following:

- TMT1 - Mono-cropped maize under conventional tillage.
- TMT2 - Mono-cropped maize under minimum soil disturbance.
- TMT3CP - A two-year system of maize in rotation with cowpea under minimum soil disturbance
- TMT3SF - A two-year system of maize in rotation with sunflower under minimum soil disturbance
- TMT4CP - A three-year cowpea/maize/pearl millet rotation system under minimum soil disturbance.
- TMT4SF - A three-year sunflower/maize/pearl millet rotation system under minimum soil disturbance

Trials were planted in such a manner that each treatment was accounted for each season.Fertilizer application was applied with planting based on soil analysis. Top dressing

Photo 1. General sanitation, sampling and processing procedures applied throughout the duration of the project.

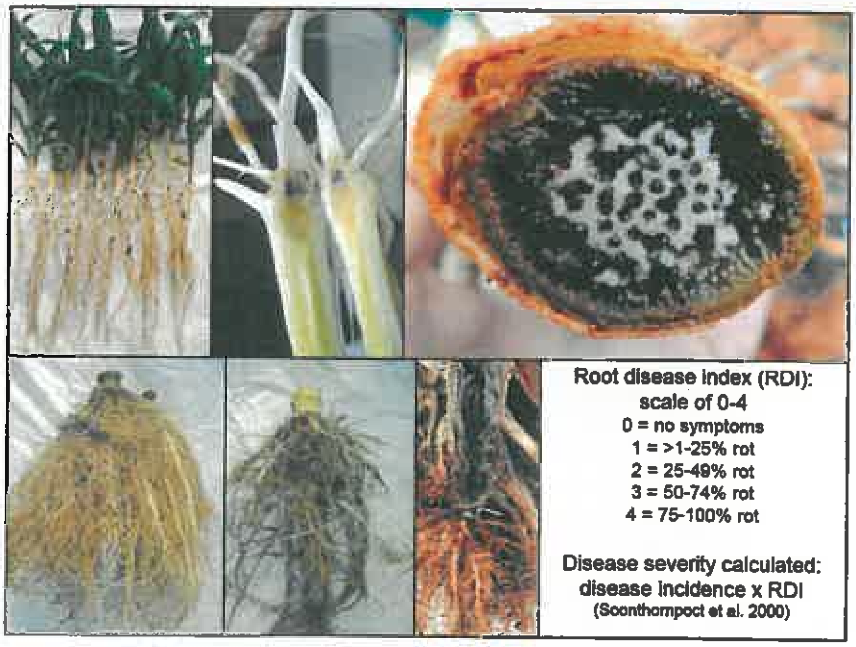


Photo 2. Root and crown rot was assessed at 21, 70 and 100 days after sampling (DAP)

Frequency assessment

Twenty pieces of roots and crows respectively were plated out on five different growth media (potato dextrose agar with chlorcol - PDA+; Pythium selective medium; selective *Fusarium*

Statistical analysis

Analysis of variance was conducted on the yield as well as plant mass at 21, 70 and 100 DAP over the three years. A Split-split plot analysis was conducted on root and crown rot disease severity obtained for the three years combined (year = main plot, treatment = sub-plot, plant part from which isolated from (i.e. roots or crowns) = sub-sub plot).

Fifteen known root and crown rot pathogens were selected for analysis. The selected fungi were *Aspergillus spp., Alternaria spp., F. clamydosporum, F. culmorum, F. graminearum, F. oxysporum, F. scirpi, F. semitectum, F. solani, F. subglutinans, F. verticillioides, Macrophomina phaseolina. Rhizoctonia* spp., *Stenocarpella maydis* and *Trichoderma* spp. Two approaches were followed in order to interpret the impact of the various treatments on the selected fungal frequencies measured within the roots and crowns. A split-split plot analysis was conducted on the frequencies within the roots and crowns obtained per sampling date over years combined (year = main plot, treatment = sub-plot, plant part from which isolated from (i.e. roots or crowns) = sub-sub plot). Student's t-LSD (Least Significant Difference) was calculated at a 5% significance level to compare means. For the purpose of this report, the focus was only on the possible effect that treatment had on the fungal frequencies, so attention was only paid to treatment as main effect or year-by-treatment, treatment-by-plant part or year-by-treatment-by-plant part interactions. All the analyses were done using SAS v9.2 statistical software (SAS, 1999) and means of significant effects presented in table and figures.

The GGE biplot model methodology was secondly used to visualise the response of fungal frequencies to various crop rotation systems and tillage practices of main effects or interactions that indicated to be significant.The various treatments were portrayed as 'Genotype' whilst the fungal frequencies were used as 'Environment'. A visual interpretation could accordingly be obtained which demonstrated which treatments had the greatest effect on the specific fungi and its frequencies measured. Biplots were generated with Genstats (Version 14, Payne *et al.*, 2011).

Interpretation of GGE biplot analysis

As previously stated, biplot analysis assists with the visual interpretation of the GE interaction patterns. In the original sense of GGE biplot, G (genotype) and GE (genotype x environment) are displayed (Yan *et al.*, 2007). The use of GGE biplot can, however, very easily be applied in the study of fungal frequencies and how they are affected by treatments by allocating the treatment (which represent the main focus of the study) to the G component of the GGE biplot analysis (Yan, 2013 - personal communication).

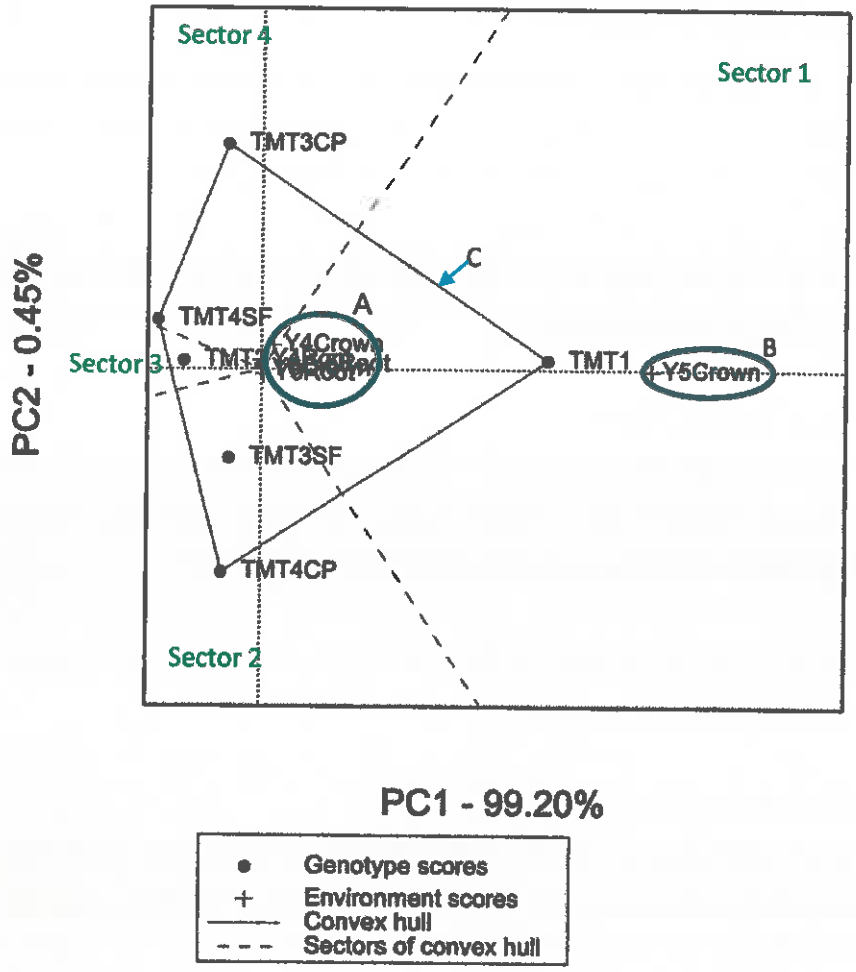


Figure 1. Example of a biplot generated for *M. phaseolina* to demonstrate the impact that the various treatments had on the frequency of the fungus as measured over seasons and the plant part from which isolated from. (Y4 - 2011/12; Y5 - 2012/13; Y6 - 2013/14).

For the purpose of our studies, GGE biplots are accordingly applied as supplementary to statistical analysis as ANOVA results are often very difficult to interpret. GGE biplots accordingly allow for a visual interpretation of which treatments affected the fungal frequencies the most.

Due to the magnitude of data generated the findings of the M106/15 project are presented in five sections:

Section 1 provides a general over view of yield, plant mass, disease severity as well as fungal frequencies measured over the whole duration of the study. No statistical analysis or interpretation on data generated is given within this section.

SECTION 1

A general overview of yield, plant mass and root and crown rot severity measured at two localities (Viljoenskroon - 2011/12 to 2013/14; Ventersdorp - 2009/10 to 2013/14)

SUMMARY

Two conservation agriculture (CA) trials planted by the M106/11 project near Ventersdorp (Buffelsvallei farm - sandy loam soil, North West Province) and Viljoenskroon (Erfdeel farm - sandy soil, Free State) were monitored as part of the impact study of conservation agricultural practices on crown and root rot of maize. The study was conducted over a six year period (2008/09 to 2013/14) under dryland conditions. The two trials differed to some extend with regard to the treatments tested at the various sites. The trail layout for the Viljoenskroon trial (sandy soils) was a randomised complete block design with four treatments and four replicates (TMT1 - mono-cropped maize under conventional tillage; TMT2 - mono-cropped maize under minimum soil disturbance; TMT3CP - a two-year system of maize in rotation with cowpea under minimum soil disturbance;TMT4CP - a three-year Cowpea/maize/pearl millet rotation system under minimum soil disturbance) Two additional treatment to the four planted at the Viljoenskroon trial were planted at Ventersdorp (i.e. TMT3SF - a two-year system of maize in rotation with sunflower under minimum soil disturbance and TMT4SF - a three-year sunflower/maize/pearl millet rotation system under minimum soil disturbance resulting in six treatment accordingly evaluated at Ventersdorp. Within this section actual yield, plant mass as well as disease severities obtained for the duration of the study is provided.

At Viljoenskroon, consistently lower yields were obtained for TMT2 compared to TMT1, TMT3CP and TMT4CP over the three seasons (2011/12 to 2013/14). This effect was also evident in the plant mass measured at 21, 70 and 100 DAP. Low levels of root rot disease severity was observed at 21 DAP for all three seasons of evaluation. Crown rot was low for all sampling dates and seasons with the disease severity index being lower than 8. General root rot severity at 100 DAP was similar for 2011/12 and 2012/13 with slightly higher levels of root rot being measured for 2013/14. *F. oxysporum* followed by *Trichoderma* spp., *F. verticillioides*, *F. semitectum* as well as *Aspergillus* spp. were the most prominent fungi isolated at Viljoenskroon during 2011/12 to 2013/14.

At Ventersdorp, the highest yields was obtained during 2013/14 with the lowest recorded during 2011/12. A general pattern is observed in the yields obtained by the various treatments for especially the 2009/10, 2010/11 and 2013/14 seasons, with yield peaking at the two cowpea rotation systems. The impact of the various treatments on plant mass measured at 21, 70 and 100 DAP varied over seasons. Similar to the Viljoenskroon trial, root and crown rot

1.1.2. Plant mass

Plant mass of ten randomly selected plants for each plot, as measured over four cropping systems in the Viljoenskroon area 21, 70 and 100 days after planting (DAP) over a three season period (2011/12 - 2013/14) is provided in Figure 2.

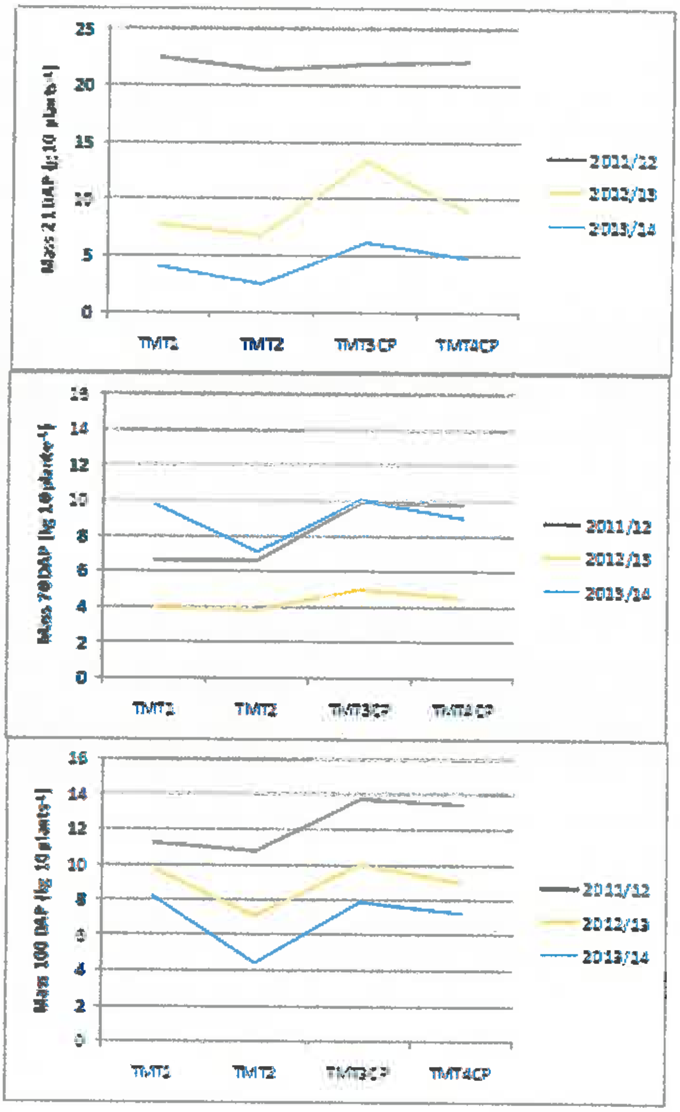
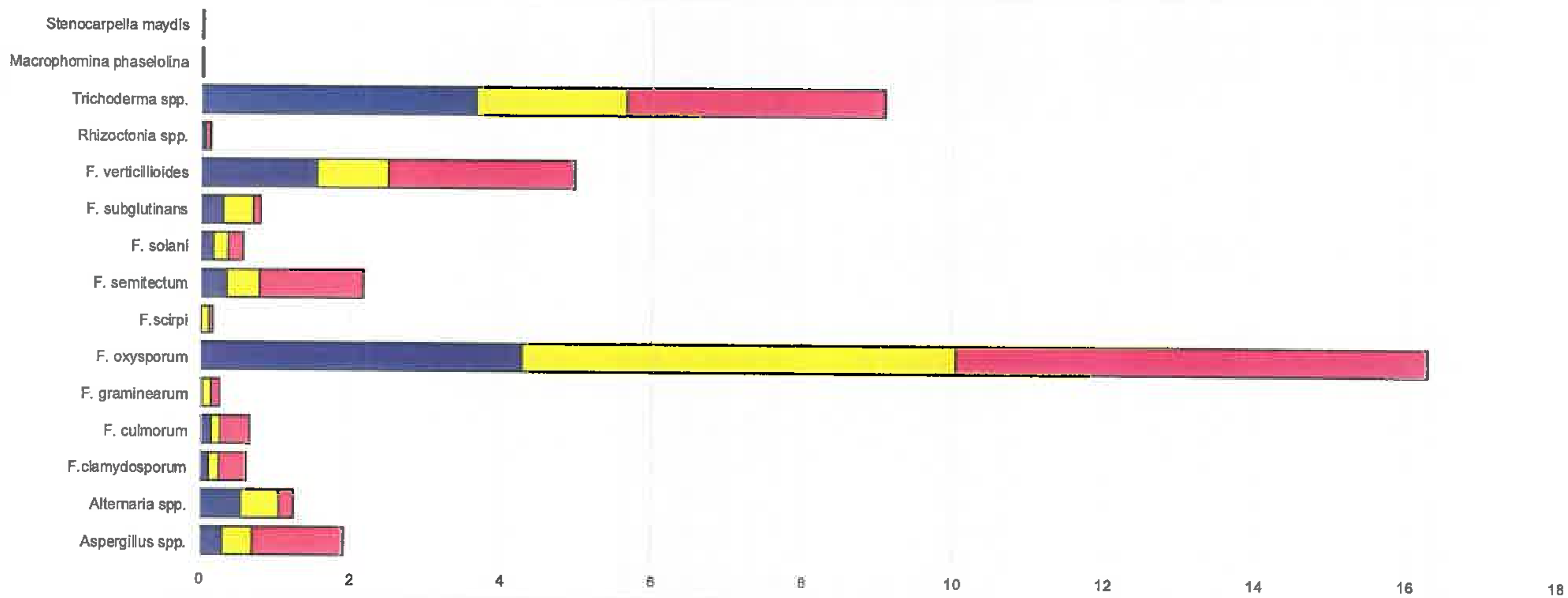


Figure 2. Plant mass of ten randomly selected plants for each plot, as measured over four cropping systems in the Viljoenskroon area 21, 70 and 100 days after planting (DAP) over a three season period (2011/12 - 2013/14). (TMT1 - maize monoculture under conventional tillage practices; TMT2 - maize monoculture under conservational practices (CA); TMT3CP - maize-cowpea two year rotational system under CA; TMT4CP - maize-cowpea-pearl millet three year rotational system under CA).

1.1.4. *Fungal frequencies*

Figure 4. Frequencies of twelve known root and crown rot pathogens as measured at the Viljoenskroon trail over three seasons (2011/12, 2012/13 and 2013/14).



	Aspergillus spp.	Alternaria spp.	F.clamydosporum	F. culmorum	F. graminearum	F. oxysporum	F.scirpi	F. semitectum	F. solani	F. subglutinans	F. verticillioides	Rhizoctonia spp.	Trichoderma spp.	Macrophomina phaselolina	Stenocarpella maydis
11/12	0.3	0.54	0.12	0.15	0.03	4.28	0.02	0.34	0.16	0.29	1.55	0.04	3.67	0	0.02
12/13	0.39	0.51	0 13	0.11	0.11	5.77	0.09	0.44	0.21	0.4	0.95	0 03	2	0.02	0
13/14	1.22	0.2	0.37	0.4	0.12	6.26	0.05	1.38	0.19	0.11	2.48	0.06	3.42	0.01	0.01

1.2.2. Plant mass

The average plant mass obtained at the Ventersdorp trial 21, 70 and 100 DAP over the five seasons are indicated in figure 6.

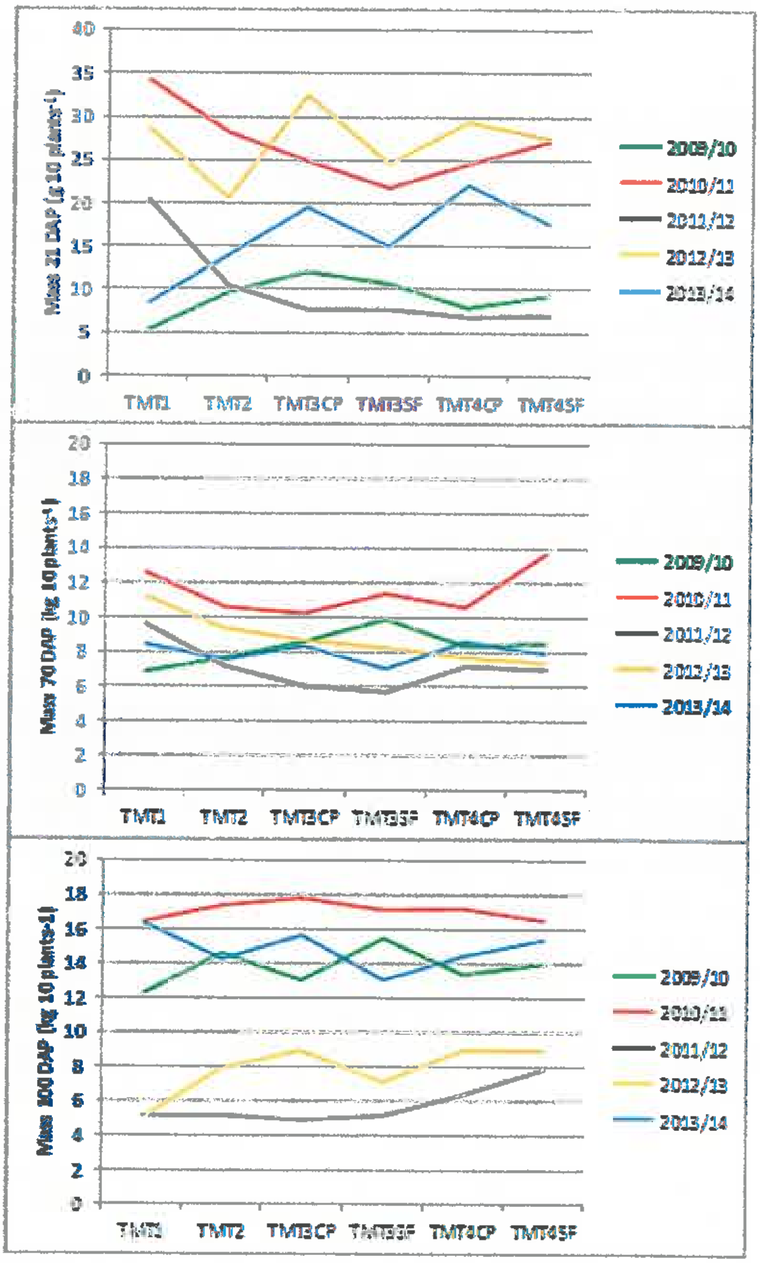
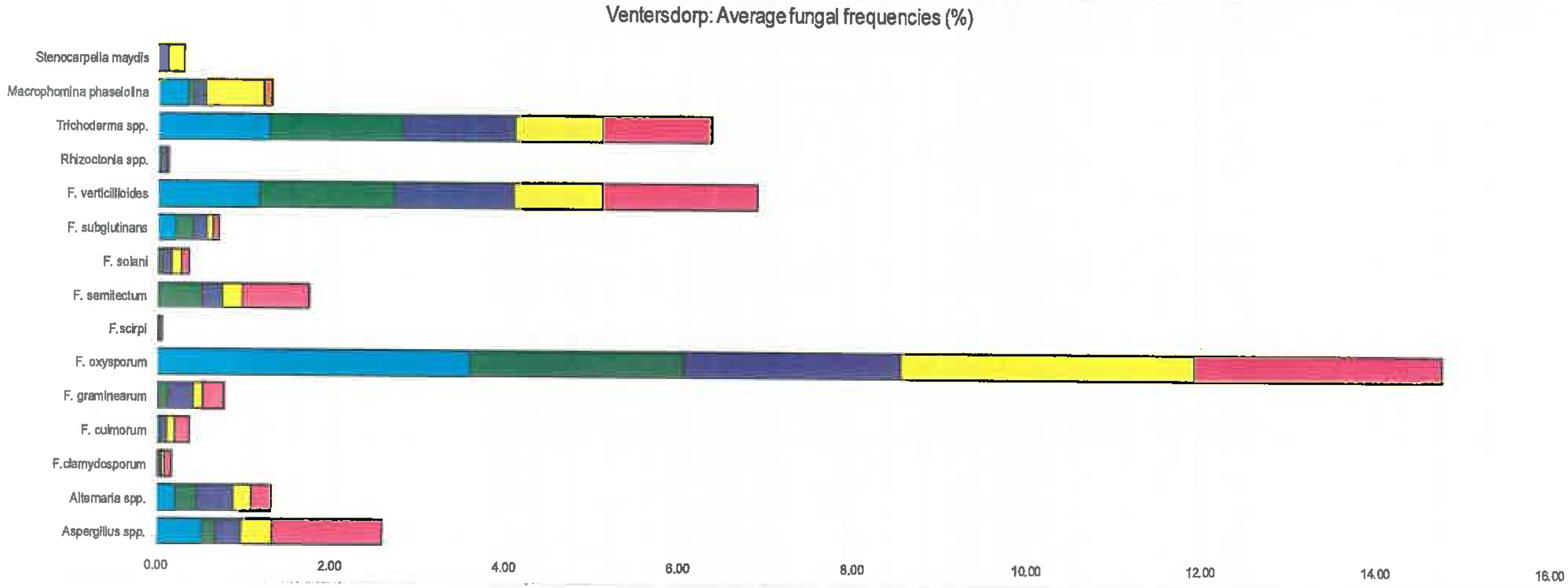


Figure 6. Plant mass obtained with six cultivation practices in the Ventersdorp area 21, 70 and 100 days after planting (DAP) over five seasons (2009/10 - 2013/14). (TMT1 - maize monoculture under conventional tillage practices; TMT2 - maize monoculture under conservational practices (CA); TMT3CP - maize-cowpea two year rotational system under CA; TMT3SF - maize-sunflower two year rotational system under CA; TMT4CP - Maize-cowpea-pearl millet rotational systems under CA; TMT4SF – maize-cowpea-pearl millet three year rotational systems under CA).

1.2.4. *Fungal frequencies*

Figure 8. Average fungal frequencies of twelve known root and crown rot pathogens as measured at the Ventersdorp locality over five seasons (2009/10 to 2013/14).



	Aspergillus spp.	Alternaria spp.	F.clamydosporum	F. culmorum	F. graminearum	F. oxysporum	F.scirpi	F. semitectum
09/10	0.52	0.22	0.01	0.03	0.01	3.60	0.01	0.01
10/12	0.16	0.23	0.02	0.02	0.12	2.46	0.01	0.50
11/12	0.30	0.43	0.03	0.07	0.29	2.49	0.01	0.24
12/13	0.35	0.21	0.03	0.09	0.11	3.38	0.01	0.23
13/14	1.27	0.23	0.08	0.16	0.24	2.83	0.02	0.77

	F. solani	F. subglutinans	F. verticillioides	Rhizoctonia spp.	Trichoderma spp.	Macrophomina phaseolina	Stenocarpella maydis
09/10	0.01	0.21	1.17	0.02	1.28	0.34	0.00
10/12	0.05	0.20	1.55	0.02	1.53	0.07	0.00
11/12	0.10	0.16	1.38	0.05	1.30	0.14	0.11
12/13	0.11	0.07	1.02	0.01	1.01	0.67	0.19
13/14	0.09	0.06	1.77	0.03	1.24	0.08	0.00

2.1. Aim

The aim of the current study is to investigate the impact that four selected CA cropping systems had on the plant mass and root and crown rot disease severity of maize over a three year period (2011/12 to 2013/14) on a sandy soil in the Viljoenskroon area. A second aspect investigated is the impact of such systems on the fungal frequencies of known root and crown rot pathogens.

2.2. Material and methods

2.2.1. Field trial

The trial was planted at Erfdeel (Viljoenskroon district, Free State, South Africa: sandy soil) over a five year period (2008/09 to 2012/13) under dryland conditions as indicated under "GENERAL MATERIAL AND METHODS". As previously stated, for the purpose of this final report, data from 2011/12 to 2013/14 will be discussed.

2.2.2. Parameters evaluated

Parameters evaluated included yield, plant mass at 21, 70 and 100 DAP, and disease severity for roots and crowns at 21, 70 and 100 DAP as well as fungal frequencies of fifteen known root and crown rot pathogens as listed under "GENERAL MATERIAL AND METHODS".

2.2.3. Statistical analysis

Yield, mass and disease severity

Data generated during 2011/12, 2012/13 and 2013/14 were used in statistical analysis. Analysis of variance was conducted on the yield as well as plant mass at 21, 70 and 100 DAP over the three years. A Split-split plot analysis was conducted on root and crown rot disease severity obtained for the three years combined (year = main plot, treatment = sub-plot, plant part from which isolated from (i.e. roots or crowns) = sub-sub plot).

2.3.4. Fungal frequency

Fungal frequencies were analysed as stated under "GENERAL MATERIALS AND METHODS'

2.4. Results

2.4.1. Yield

Analysis of variance indicated that the yield obtained as a result of the various treatments varied over seasons (Table 1). During 2011/12, the two maize mono-cropping treatments (TMT1 and TMT2; Figure1) yielded significantly lower yields compared to the two remaining cowpea treatments, as the data points allocated for the 2012/13 and 2013/14 seasons are grouped in to the sectors dominated by TMT4CP and TMT3CP.

70 Days after planting

Alternaria spp. and *Rhizoctonia* spp. were both significantly affected by the year-by-treatment-by-plant part interaction (Table 5). Biplots generated for these two fungi both indicate that no clear treatment were prominent in having an effect on their frequencies (Figure 4A and B)

100 Days after planting

Analysis of variance indicated that *F. verticillioides* was significantly affected by the treatments applied at 100 days after planting (Table 6) whilst *Alternaria* spp. as well as *F. subglutinans* were the only fungi for which the effect of the treatments were dependant on the year and plant part from which isolations were made from. Biplots generated indicate that *F. verticillioides* was most significantly affected by the maize monoculture treatments (TMT1 and TMT2) during 2011/12 and 2012/13. For 2013/14, TMT3CP, however, had the greatest effect on the frequencies of this fungus (Figure 5).

2.5. Discussion and conclusion.

In actual fact, the Viljoenskroon trial has only been a true CA trial for four seasons, which implies that for example only one set of data that represents a three year rotation systems could be evaluated (maize-pearl millet-cowpea-maize). It is a known fact that cropping systems can take years to establish (Hugo and Van Rensburg 1997), and it is accordingly not surprising to find very little interaction effects with regard to the impact that the various treatments had on especially the fungal frequencies measured at the various treatments. Significantly lower yields were, however, obtained for TMT2 for two of the three seasons. evaluated (2012/13 and 2013/14) which might be an indication that maize monoculture under CA is not a viable option for sandy soils. A similar effect was also consistently observed for the plant mass measured at 21, 70 and 100 DAP, with TMT2 giving consistently lower plant mass. This observed reduction in yield and plant mass for TMT2 could, however, not be linked to either disease severity measured or specific fungi that might have contributed to the observed effect. In general the trial did not really suffer much root and crown rot with the exception of the 2013/14 season for which a general increase in root rot for all treatments were observed. This is accordingly indicative that the rotations systems that is currently in place might either not be established, or not efficient in order to combat whatever pathogen has caused the increased root rot. In general very low disease severity was measured during the whole of the evaluation period. As a result, none of the treatments had a significant effect on disease severity. Certain fungal frequencies, however, appeared to be more prominent in

Table 1. Analysis of variance on the impact of various cropping systems on the yield and plant mass at 21, 70 and 100 days after planting (DAP) at the Viljoenskroon trial as evaluated over three seasons (2011/12 to 2013/14).

	Yield	Mass 1[a]	Mass 2[b]	Mass 3[c]
Year	0.1031	<0.0001	0.001	0.0007
TMT	<0.0001	0.0185	<0.0001	0.0002
Year*TMT	0.0490	0.2964	0.0776	0.3149

[a] - Plant mass of ten plants 21 days after planting (DAP)

[b] - Plant mass of ten plants 70 DAP

[c] - Plant mass of ten plants 100 DAP

Table 2. Analysis of variance for plant mass 21, 70 and 100 days after planting obtained with four cropping systems at the Viljoenskroon trial over three seasons (2011/12, 2012/13 and 2013/14) (P=0.05).

	Mass1[a]	Mass 2[b]	Mass3[c]
TMT1	11.44b	5.09a	9.74a
TMT2	10.22b	4.64a	7.45b
TMT3CP	13.77a	6.85b	10.55a
TMT4CP	11.96ab	6.63b	9.89a

[a] - Plant mass of ten plants 21 days after planting (DAP)

[b] - Plant mass of ten plants 70 DAP

[c] - Plant mass of ten plants 100 DAP

(TMT 1 = mono-cropped maize under conventional tillage treatment, TMT2 = mono-cropped maize under minimum soil disturbance (CA), TMT3CP = two two-year maize rotation system treatments with cowpea under CA, TMT4CP = three year rotation system with millet and cowpea under CA).

Table 4. Analysis of variance on the effect of different cropping systems on the frequency (%) of fifteen soilborne pathogens as measured over four selected treatments at the Viljoenskroon trial over three years (2011/12, 2012/13 and 2013/14) in both the root and crowns of maize plants 21 days after planting.

	Alternaria spp.	*Aspergillus spp.*	*Fusarium clamydosporum*	*Fusarium culmorum*	*Fusarium graminearum*	*Fusarium oxysporum*	*Fusarium scirpi*	*Fusarium semitectum*	*Fusarium solani*	*Fusarium subglutinans*	*Fusarium verticillioides*	*Rhizoctonia spp.*	*Trichoderma spp.*	*Macrophomina phaseolina*	*Stenocarpella maydis*
Year	0.0058	0.0003	0.1246	0.4221	0.2248	0.0025	0.0262	0.0004	0.979	0.036	0.0001	0.5513	0.0106	0.2640	0.6223
Tmt	0.4970	0.7834	0.6982	0.3886	0.4175	0.2366	0.063	0.1318	0.4991	0.0419	0.0823	0.5840	0.4691	0.1677	0.5797
Year*Tmt	0.8530	0.7412	0.5134	0.0091	0.5303	0.0016	0.0505	0.4042	0.5435	0.1088	0.3951	0.4450	0.1024	0.0391	0.3529
PlantPart	0.7007	0.0001	0.7866	0.5511	0.4047	0.0001	0.0204	0.0242	0.4890	0.0563	0.0257	0.0116	0.0089	0.7084	0.9822
Year*Plantpart	0.3129	<.0001	0.2956	0.4845	0.6548	0.0309	0.0026	0.0117	0.0452	0.3621	0.2889	0.5192	0.0168	0.8053	0.2368
Tmt*Plant part	0.9265	0.0807	0.3841	0.1900	0.3491	0.3208	0.2979	0.3137	0.8591	0.7590	0.1560	0.5887	0.0231	0.8892	0.2788
Year*Tmt*Plantpart	0.9070	0.0438	0.6754	0.9411	0.6375	0.9452	0.2520	0.1151	0.8449	0.9259	0.1572	0.4499	0.0321	0.9794	0.5522