FINAL REPORT

DETAILS

Project number		M106/14 (**000353**)
Project title		Evaluation of integrated weed management practices in conservation agriculture on the Highveld
Project manager		Dr E Hugo
Co-worker(s)	Internal	Mofokeng A, Phokompe MI, Tshetlhe GW, Van der Walt MM, Du Toit AEJ
	External	None
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Final abstract

The objectives of this study were to determine the species diversity and elucidate the interaction between conventional and CA systems within a monoculture system and where maize is rotated with two or three crops, respectively. The occurrence and infestation levels of weed species are known to vary greatly within CA systems since weed species will react differently to different habitats. CA systems provide a specific set of environmental conditions, which affect the occurrence of weed populations according to the dominant weed species present in fields where conservation agriculture is being practiced. The two on-farm trial sites were established during the 2008/09 season to the specifications of the FAO definition of conservation agriculture. The first trial was planted on the farm Buffelsvallei near Ventersdorp (sandy loam soil, North-West Province, South Africa; 26.4949 S, 26.602 E), whilst the second was planted near Viljoenskroon (Ditsim farm, sandy soil, Free State, South Africa; 26.9819S, 27.02729 E). Visual surveys of weed species were conducted annually at both trial sites. The current study reports on the findings regarding the weed spectrum observed as evaluated from 2012 to 2016. Several studies have indicated that a shift in weed species may occur when CA systems are being successfully implemented. CA systems may also promote the germination and emergence of newly produced weed seed due to the shift in species diversity and / or infestation levels. Both of these dynamics have been observed to a more or lesser extent at the respective trial sites. The weed spectrums differed significantly between the two localities, but the diversity of weed species stayed rather constant across seasons. A weed specie shift was recorded for the sandy loam soil where numbers of *Commelina benghalensis* increased rapidly after three years, while *Crotalaria sphaerocarpa* numbers more than doubled in treatments on the sandy soil trial. The knowledge of the biology and ecology of these species are much needed to optimize

different management systems to control these species successfully. New weed species also started to germinate at the sandy loam soil trial site and included *Helichrysum caesititium* (Rose poppy) and *Vernonia poskeana.*

1. Introduction

Conservation agriculture (CA) in cropping systems consists of a number of principles with the aim of soil conservation and sustainability of crop production. The most important of these factors are little or no disturbance of the soil, multiple cropping/crop rotation, permanent soil cover (Mallet *et al,.* 1981), integrated soil fertility and acidity management, integrated weed-, pest- and disease management as well as crop and livestock integration. A number of these principles have been implemented extensively in southern America, particularly in Brazil with substantial success. In view of these successes in Brazil and elsewhere the adoption of CA practices is seen as a key to sustainable agriculture in South Africa (Bolliger *et al.,* 2006; Christoffeleti *et al.*, 2007). Of the 106 million ha reported to be under CA worldwide, Africa currently contributes only 0.4%, with the majority of this being on commercial farms in South Africa (Kassam *et al.,* 2009).

The potential benefits of conservation tillage primarily depend on the soil characteristics and climatic conditions of the specific location where it is practised. CA, however, requires careful planning of crop rotations, novel approaches to weed control and pest management strategies. Knowledge of the long-term effect of tillage or reduced-tillage practices on weed diversity and species composition are accordingly crucial in order to provide information necessary for improving weed management in agro-ecosystems. The constant use of certain active ingredients of herbicides such as glyphosate in a monoculture-maize production system also raises a concern for development of resistant weed populations. Most research to date on weed control in reduced tillage practices have shown clearly that tillage has a profound effect on the species composition and subsequent shift in the weed spectrum (Carter and Ivany 2006; Kurstjens 2007; Norsworthy 2008).

The 2016/17 estimated production input cost for maize for the North-West province varied between R9,080 and R9,762.92 ha^{-1} (estimated yield of 3.5 t ha^{-1}) with the cost associated with weed control varying between 6.4 and 9.8% of the total input cost per ha (Anonymous, 2017). Several research results have shown that weed infestation has a negative effect on yield. When averaged across data generated over a seven-year period, weed interference in maize in the United States and Canada caused an average of 50% yield loss (Soltani *et al*., 2016). Similar results have been reported locally, with weed infestation resulting in maize yield losses of between 40 and 60% (Thobatsi, 2009). This negative effect on yield is, however, seldom converted into financial terms.

The absence of soil disturbance and presence of crop residue cover in CA systems generally lead to an increase over seasons in organic matter content of the soil, soil moisture, temperature and microbial activity. These factors may have a direct or indirect effect on weed control efficacy, including weed species present, time of weed seed germination and emergence, weed-crop interference, competition between weed species, effective herbicide application and residual efficacy of herbicides as well as waiting period of herbicides on follow-up crops (Johnson and Coble 1986; Tuesca and Puricelli 2007). Soil and residue manipulation can, however, assist weed control by interfering with weed biology and enhancing crop establishment and growth. Herbicide selection, formulation, timing and method of application will also be affected by CA practices (Norsworthy, 2008). Effective weed control, reduced tillage practices and/or crop rotation can form a crucial part of the cost effectiveness of crop production in South Africa. New products and active ingredient development in the herbicide market occur only sporadically and new approaches towards combining soil conservation with non-chemical weed management are needed.

When first implemented, the use of herbicides in CA will, however, remain high for the first two seasons. Therefore, it is essential to determine the existing weed species diversity, initial seed bank composition and vertical weed seed distribution at various trial sites (Benvenuti, Macchia and Miele, 2001). Research has shown that shallow-germinating weed spp. may increase in importance since CA promotes germination of shallow germinators (Carter and Ivany, 2006). Although some shallow-germinating weeds could be controlled more effectively by reduced tillage, the late-season germinators may become an increasing challenge (Christoffoletti *et al.* 2007; Bolliger *et al.* 2006). CA usually causes a shift in weed spectra, where some weeds such as sedges and perennial weeds are more difficult to control. It is difficult to predict the composition of a weed population that may emerge in a crop rotation sequence that include several crops. Reduced tillage in combination with a sound crop rotation system may reduce weed densities and expenses on weed control management (Murphy, *et al.* 2006). A comparison between herbicide-resistant, e.g. glyphosate-resistant crops and the use of other registered herbicides on crops that will be grown in rotation systems will be necessary in order to determine cost effectiveness and the effect on weed species dynamics.

The objectives of this study were accordingly to determine the species diversity and elucidate the interaction between conventional and CA systems within a monoculture system and where maize is rotated with two or three crops, respectively.

2. Materials and Methods

2.1. Field trials

The two on-farm trial sites were established during the 2008/09 season to the specifications of the FAO definition of conservation agriculture. The first trial was planted on the farm Buffelsvallei near Ventersdorp (sandy loam soil, North-West Province, South Africa; 26.4949 S, 26.602 E), whilst the second was planted near Viljoenskroon (Ditsim farm, sandy soil, Free State, South Africa; 26.9819S, 27.02729 E). The current study report on the findings regarding the weed spectrum observed as evaluated from 2012 to 2016.

Conservation agriculture systems included no-tillage treatments with crop rotation of three different crops i.e. maize, forage sorghum and cowpeas or sunflower. At the Buffelsvallei site, both sunflower and cowpea were included as rotational crops. A representation of the plot layout for one replicate of the trial over seasons is given in Table 1. Treatments accordingly consisted of the following combinations of crop and tillage systems:

- A maize monoculture under conventional mouldboard plough tillage (MM-CT) which served as the control,
- A maize monoculture under no-till (MM-CA)
- A cowpea or sunflower – maize two-year rotation under no-till (2yr-CP or SF-CA)
- A pearl millet (*Pennisetum glaucum* (L.) R. Br) - cowpea or sunflower - maize three-year rotation under no-till (3yr-CP or SF-CA).

Two plots were allocated for the two-year rotation treatments whilst three plots were allocated for the three-year rotation treatments (Table 1). With the two-year rotation treatments, one plot was planted with maize, whilst the other was planted with the cowpea/sunflower split arrangement. The following season the crops planted were swopped (i.e. cowpea/sunflower split arrangement on the first plot and maize on the second plot). A similar approach was accordingly followed with the three-year rotation treatments, with each crop included in the rotation planted in one of the three plots allocated to the treatment. This allowed a maize treatment to be screened from each treatment every season. A similar approach was followed regarding the Ditsim trial with the exception that only maize, cowpea and millet were included as rotational crops. Sunflower was not included as the area was not suited for sunflower production. Plots at Ditsim consisted of 16 rows, 30 m in length spaced 0.9 m. Buffelsvallei plots consisted of 28 rows, 20 m in length spaced 0.9 m apart.

Table 1: Plot layout for one replication of the trial planted at Buffelsvallei over a period of eight years demonstrating the crop rotation sequences and the split arrangement for the cowpea and sunflower rotation treatments within the same plot

<table>
<tr><th></th><th colspan="12">Plot number</th></tr>
<tr><th></th><th>1</th><th>2</th><th colspan="2">3</th><th colspan="2">4</th><th colspan="2">5</th><th colspan="2">6</th><th colspan="2">7</th></tr>
<tr><th>Treatment</th><th>MM-CT</th><th>MM-CA</th><th colspan="2">2yr-CA-CP/SF</th><th colspan="2">2yr-CA-CP/SF</th><th colspan="2">3yr-CA-CP/SF</th><th colspan="2">3yr-CA-CP/SF</th><th colspan="2">3yr-CA-CP/SF</th></tr>
<tr><td>Season</td><td></td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>2008/09</td><td>Maize</td><td>Maize</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Millet</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td></tr>
<tr><td>2009/10</td><td>Maize</td><td>Maize</td><td>Cowpea</td><td>Sunflower[a]</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Millet</td><td colspan="2">Maize</td></tr>
<tr><td>2010/11</td><td>Maize</td><td>Maize</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Millet</td></tr>
<tr><td>2011/12</td><td>Maize</td><td>Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Maize</td><td colspan="2">Millet</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td></tr>
<tr><td>2012/13</td><td>Maize</td><td>Maize</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Millet</td><td colspan="2">Maize</td></tr>
<tr><td>2013/14</td><td>Maize</td><td>Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Maize</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Millet</td></tr>
<tr><td>2014/15</td><td>Maize</td><td>Maize</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Millet</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td></tr>
<tr><td>2015/16</td><td>Maize</td><td>Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Maize</td><td>Cowpea</td><td>Sunflower</td><td colspan="2">Millet</td><td colspan="2">Maize</td></tr>
</table>

[a] - Plots associated with the cowpea and sunflower rotation systems were split in two sections to accommodate each of the two crops

2.2. Weed spectrum assessment

Visual surveys of weed species were conducted since 2012 at both trial sites. The surveys were conducted after planting and the first herbicide application when weed species start to germinate again. The only soil residual herbicide applied at planting was s-metolachlor, thereafter glyphosate was applied post-emergence. The summer weed species were counted and identified during the middle week of January 2016, recording the second flush of weed species. The number of weed species were counted in the middle two crop rows of each treatment (32 m^{-2}). All species were identified and new species were sent to the herbarium of the North-West University for positive identification (Prof S Siebert). The surveys were repeated during the first week of July 2016 to identify and quantify the winter weed species in all treatments.

Ten soil cores to a depth of 15 cm were taken at both localities between the middle two rows of each plot, just before planting in November 2015. Each sample was transferred to a plastic container where it was kept in a glasshouse and watered regularly to stimulate germination and emergence of seed in the seedbank. Weed species were counted as soon as they could be identified. The containers were watered for three months before termination to ensure total germination of all summer annual species.

2.3. Statistical analyses

Data (counts) from 2012 to 2016 of the most dominant weed species in all treatments of each trial site were subjected to an ANOVA using GenStat for Windows 15th edition (Payne, 2011). The means of significant interaction effects between seasons and treatments were compared using Fisher's Protected t-LSD at a 5% significant level to determine weed specie shifts between conventional and no-till treatments.

3. Results

3.1. Weed species spectrum

Weeds observed at both sites over the various seasons were in general predominantly annual species. In Tables 2 and 3 the most common summer and winter weed species are listed as recorded during the final year of the study (2016). After the implementation of different rotation systems on the two different soil types over an eight-year period, greater seed species diversity was present on the sandy loam compared to the sandy soil for summer weeds. *Commelina benghalensis* (Wandering Jew) occurred in the highest numbers on the sandy loam soil, whereas *Crotalaria sphaerocarpa* (Mealie Crotalaria) was the most dominant species on sandy soil. An increase in the number of grass species such as *Urochloa mosambicensis* and *Eleusine coracana* were recorded during 2016. The winter weed spectrums were, however, more similar on both soil types. The most dominant winter weed species on both soil types was *Senecio consanguineus* (Starvation Senecio), with exceptionally high numbers on the sandy soil trial site. High numbers of *Arcthoteca calendula* (Cape marigold) were recorded for the first time during July 2016 at the sandy soil trial site. The numbers of *Argemone ochroleuca* (White-flowered Mexican poppy) increased significantly in the conventional monoculture maize treatments when compared to monoculture under CA on the sandy loam soil. *Conyza* spp. occurred in very low numbers at both localities during the past winter period.

Photo 1. Annual summer weed species occurring in high numbers at the trial sites

Photo 2. Annual winter weed species occurring in high numbers at the trial sites.

Table 2: Dominant summer weed species spectrum on a sandy loam and sandy soil, respectively during 2015/16 season

Broadleaf weeds	**Grass weeds**	**Other**
Sandy loam soil		
Common pigweed (*Amarathus hybridus*)	Goosegrass (*Eleusine coracana*)	Wandering Jew (*Commelina benghalensis*)
Khakiweed (*Tagetes minuta*)	Herringbone grass (*Uorchloa mosambicensis*)	Purple nutsedge (*Cyperus purpurea*)
Dwarf marigold (*Schkuhria pinnata*)	Large crabgrass (*Digitaria sanguinalis*)	
Green goosefoot (*Chenopodium carinatum*)		
White goosefoot (*Chenopodium album*)		
Devil's thorn (*Tribulus terestris*)		
Purslain (*Portulaca oleracea*)		
Khaki bur weed (*Alternathera pungens*)		
Sandy soil		
Mealie Crotalaria (*Crotalaria sphaerocarpa*)	Naked crabgrass (*Digitaria nuda*)	Wandering Jew (*Commelina benghalensis*)
Khakiweed (*Tagetes minuta*)		Slender sedge (*Bulbostylis hispidula*)
Green goosefoot (*Chenopodium carinatum*)		

Table 3: Dominant winter weed species (broadleaves) spectrum on two soil types

Sandy loam soil	**Sandy soil**
Starvation Senecio (*Senecio consanquineus*)	Starvation Senecio (*Senecio consanquineus*)
Rose poppy (*Helichrysum caesititium*)	Rose poppy (*Helichrysum caesititium*)
Cape marigold (*Arctotheca calendula*)	
White-flowered Mexican poppy (*Argemone ochroleuca*)	

3.2. Effect of no-till and crop rotation on weed density from 2012 to 2016

The effect of the different production systems on the number of broadleaf and grass spp. is shown in Figure 1 (sandy loam soil) and Figure 2 (Sandy soil) across five and four consecutive seasons, respectively.

3.2.1. Summer weeds (Sandy loam soil)

Although the total number of weeds were high, data were pooled into the two categories of broadleaf and grass species due to inconsistent numbers recorded for most of the species during the 2015/16 season on the sandy loam soil. Both seasons and treatments (conventional and CA treatments) affected the number of broadleaf species equally (F-values) on the sandy loam soil significantly ($F = 7.46$, $P<0.001$; $F = 7.26$, $P<0.001$), resulting also in a significant interaction between the two factors ($F = 7.14$, $P<0.001$) (Figure 1A). The highest number of broadleaf species occurred in the CA plots in rotation with three different crops, especially during the 2015/16 season. There was however, no significant difference in the number of broadleaf species between the conventional monoculture and CA plots in rotation with two crops or monoculture maize.

The same tendencies were observed for grass species on the sandy loam soil. The different treatments (conventional and CA systems) did, however, had the greater effect on the number of grass species. (Seasons: $F = 7.30$, $P<0.001$; Treatments: $F = 29.01$, $P<0.001$; Interaction: $F = 6.91$, $P<0.001$). It seems that the infestation levels of grass species increased over time in the CA system in rotation with three crops, with the highest number of grass species occurring in these plots during 2015/16 season (Figure 1B).

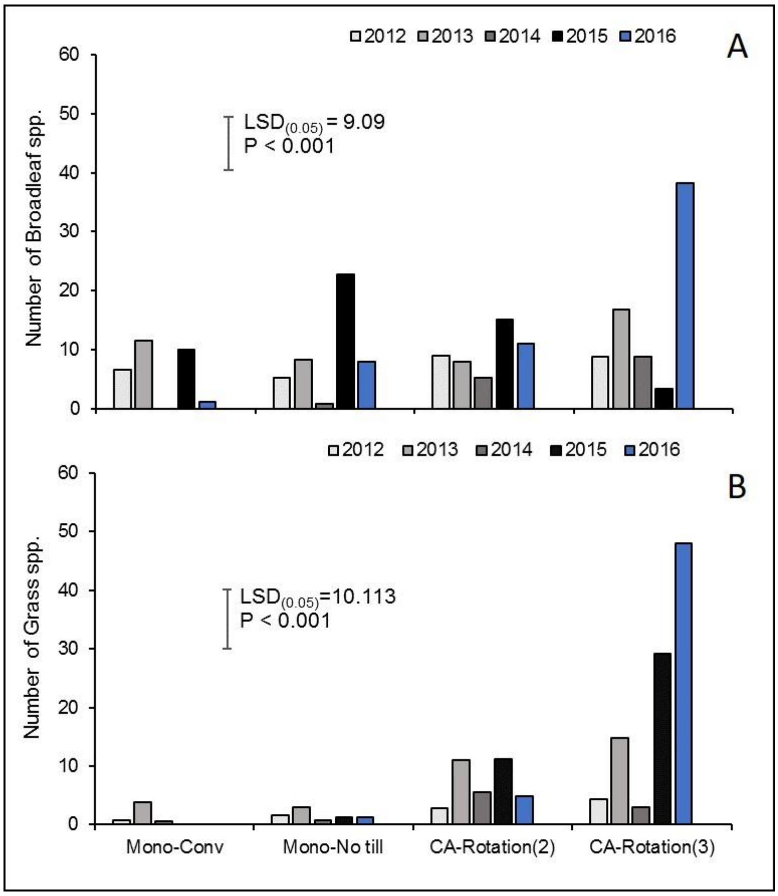

Figure 1: Effect of conventional monoculture maize and conservation agricultural systems on the number of broadleaf (A) and grass (B) weed species recorded over five consecutive seasons on a sandy loam soil. (Conv = conventional tillage with mouldboard plough; CA-rotation = maize rotated with either cowpeas or sunflower; CA-Rotation (3) = maize rotated with either cowpeas or sunflower and forage sorghum) (Significance determined at P=0.05 according to Fisher's LSD).

3.2.2. Summer weeds (Sandy soil)

The number of broadleaf species present on the sandy soil was only significantly affected by seasons (Figure 2A). Although the interaction between seasons and treatments was not significant for the number of broadleaf and grass species, it is included for comparison between the two soil types across seasons. The number of broadleaf species more than doubled during the 2015/16 season, consisting mostly of *Crotalaria sphaerocarpa* (Mealie-Crotalaria), followed by *Tagetes minuta* (Khakiweed).

There are, however, no significant differences in broadleaf and grass weed species numbers between conventional monoculture and CA treatments (monoculture and crop rotation) on the sandy soil. Grass numbers are still very low, but tended to increase constantly each season, with the highest infestation levels during 2015/16 season (Figure 2B). Contradictory to weed species numbers on the sandy loam soil, weed numbers tend to be lower in the CA systems when compared to the conventional monoculture system on the sandy soil.

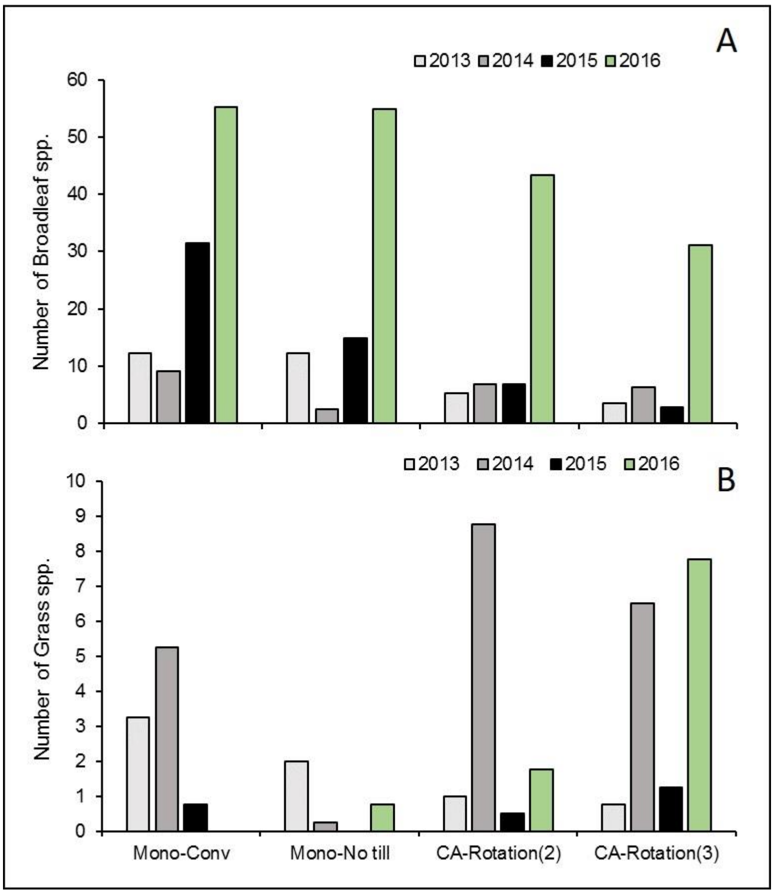

Figure 2: Effect of conventional monoculture maize and conservation agricultural systems on the number of broadleaf (A) and grass (B) weed species recorded over four consecutive seasons on a sandy soil. (Conv = conventional tillage with mouldboard plough; CA-rotation = maize rotated with either cowpeas or sunflower; CA-Rotation (3) = maize rotated with either cowpeas or sunflower and forage sorghum) (The interaction between seasons and treatments was not significant).

3.2.3. Dominant annual species

As mentioned above, *Commelina benghalensis* was the dominant broadleaf weed species on the sandy loam soil trial site. The effect of seasons, treatments and the interaction thereof had a significant effect on the infestation levels of this species. The numbers of *C. benghalensis* did not differ between the monoculture maize plots, regardless of tillage or no-tillage, but increased almost 10 fold in the CA systems rotated with three different crops.

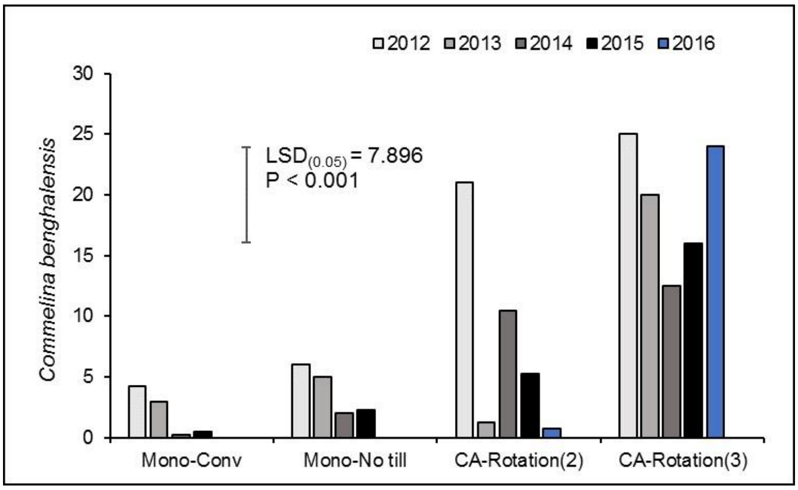

Figure 3: Effect of conventional monoculture maize and conservation agricultural systems on the number of *Commelina benghalensis* recorded over five consecutive seasons on sandy loam soil. (Conv = conventional tillage with mouldboard plough; CA-rotation = maize rotated with either cowpeas or sunflower; CA-Rotation (3) = maize rotated with either cowpeas or sunflower and forage sorghum) (Significance determined at P=0.05 according to Fisher's LSD).

During the 2015/16 growing season *Crotalaria sphearocarpa* infestation levels were extremely high on the sandy soil trial site, but no significant treatment effects were observed across seasons. Contradictory to infestation levels of *Commelina benghalensis*, numbers of *Crotalaria sphaerocarpa* tend to decrease in CA systems with crop rotation of two or three different crops.

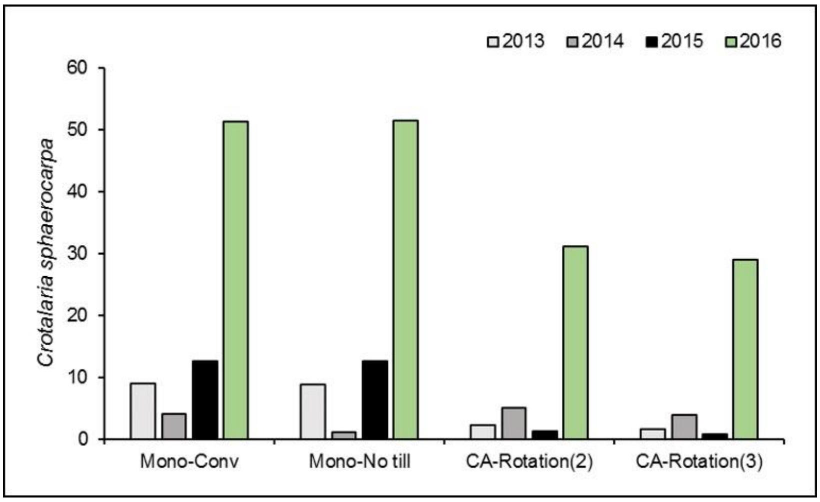

Figure 4: Effect of conventional monoculture maize and conservation agricultural systems on the number of *Crotalaria sphaerocarpa* recorded over four consecutive seasons on sandy soil. (Conv = conventional tillage with mouldboard plough; CA-rotation = maize rotated with either cowpeas or sunflower; CA-Rotation (3) = maize rotated with either cowpeas

or sunflower and forage sorghum) (The interaction between seasons and treatments was not significant).

3.2.4. Winter weed species

The winter weed spectrum at both localities consisted only of broadleaf weed species with the dominant species being *Senecio consanquineus* (Starvation Senecio). Treatments (conventional and CA systems) had no effect on the number of broadleaf species on a sandy loam soil. Except for 2014, winter weed species increased across seasons with the highest number recorded for 2015/16 season. Both seasons and treatments had a significant effect on broadleaf weed species on sandy soil where the highest number was recorded in the monoculture maize plots, with no difference between conventional or no-till plots. Winter weed species also increased constantly across seasons on sandy soil.

The effect of seasons and treatments on the dominant number of *S. consanquineus* levels are shown in Figure 3 for both soil types and reflected the tendencies of broadleaf weed species. Infestation levels of *S. consanquineus* were considerably higher on sandy soil compared to levels on sandy loam soil. *Senecio consanquineus* infestation levels increased with 80% from 2012 until 2016 on a sandy soil and only with 34% on the sandy loam soil trial site.

Arctotheca calendula (Cape marigold) numbers were notably higher in the CA system rotated with three crops, while *Helichrysum caesititium* (Rose poppy) occurred in large patches across the sandy loam soil trial site. *Helichrysum caesititium* emerged for the first time during July 2016 at the sandy soil trial site.

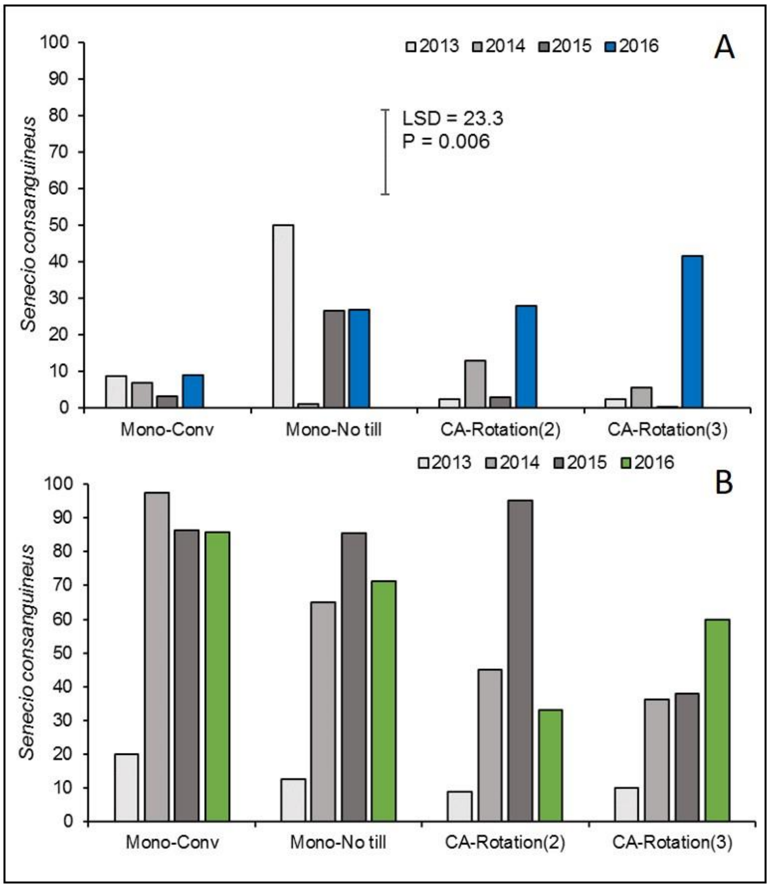

Figure 5: Effect of conventional monoculture maize and conservation agricultural systems on the number of *Senecio consanquineus* recorded over four consecutive seasons on a sandy loam (A) and sandy (B) soil type. (Conv = conventional tillage with mouldboard plough; CA-rotation = maize rotated with either cowpeas or sunflower; CA-Rotation (3) = maize rotated with either cowpeas or sunflower and forage sorghum) (Significance determined at P=0.05 according to Fisher's LSD).

3.2.5. Diversity of weed species

Seasons (F=17.75, P<0.001) and treatments (F = 11.36, P<0.001), and the interaction thereof (F = 4.38, P<0.001) significantly affected the number of different weed species on a sandy loam soil. The highest number of weed species (10 weed species m^{-2}) was recorded during the 2015/16 season, while the lowest number still occurred in the conventional monoculture maize treatments (Table 4).

Different seasons and treatments had no significant effect on the number of summer weed species on a sandy soil. A mean number of three different species were recorded across seasons and treatments.

Table 4: Effect of crop production systems and seasons on summer weed species diversity on a sandy loam and sandy soil (NT = no-till, 2 crops = maize in rotation with either cowpeas or sunflower, 3 crops = maize / forage sorghum in rotation with either cowpeas or sunflower)

Season	Mono-maize Conventional	Mono-maize NT	NT with Rotation (2 crops)	NT with Rotation (3 crops)	Mean*
			Sandy loam soil		
2012	4.8	6.0	7.0	7.3	6.3c
2013	4.8	6.3	6.5	5.5	5.8bc
2014	0.5	2.0	2.5	3.0	2.0a
2015	4.3	6.5	4.8	3.5	4.8b
2016	1.5	3.8	7.0	10.0	5.6bc
Mean	3.15a	4.90b	5.55b	5.85b	
			Sandy soil		
2013	3.3	2.5	3.0	2.8	2.8
2014	3.5	1.5	2.5	2.0	2.4
2015	1.5	1.3	2.3	2.0	1.8
2016	1.8	2.5	3.5	4.0	2.9
Mean*	2.50	1.94	2.81	2.69	

*Means within columns or rows followed by the same letter(s) do not differ significantly at P=0.05

The number of different winter weed species were significantly affected by seasons (Sandy loam soil: F=6.19, P<0.001; Sandy soil F= 16.81, P<0.001) on both trial sites. CA systems only had a significant effect on the diversity of winter weeds on sandy soil (Sandy loam soil: F=7.16, P<0.001). The diversity of weed species numbers is rather low, but constant across seasons (2 weed species m^{-2}) (Table 5)

Table 5: Effect of crop production systems and seasons on winter weed species diversity on a sandy loam and sandy soil (NT = no-till, 2 crops = maize in rotation with either cowpeas or sunflower, 3 crops = maize / forage sorghum in rotation with either cowpeas or sunflower)

Season	Mono-maize Conventional	Mono-maize NT	NT with Rotation (2 crops)	NT with Rotation (3 crops)	Mean*
			Sandy loam soil		
2013	2.3	2.3	2.8	1.8	2.3a
2014	4.0	3.5	2.8	3.3	3.4b
2015	2.0	2.3	1.8	1.0	1.8a
2016	1.5	1.8	2.3	1.8	1.8a
Mean	2.44	2.44	2.38	1.94	
			Sandy soil		
2013	2.0	1.5	2.5	0.8	1.7b
2014	1.0	1.0	1.0	1.0	1.0a
2015	2.5	2.8	2.8	1.8	2.4c
2016	1.3	1.5	2.5	1.5	1.7b
Mean*	1.69b	1.69b	2.19c	1.25a	

* Means within columns or rows followed by the same letter(s) do not differ significantly at P=0.05

3.3. Seedbank study

Soil cores were taken on both soil types before planting in November 2015 and the seedbank of the sandy loam soil type has been identified and quantified. The study for the sandy soil still needs to be completed. The dominant broadleaf and grass weed species are listed in Table 6. Most of these species have very small seeds and results corresponded with studies done on the effect of tillage and no-tillage where small seeded weed species dominate the first 5 to 10 cm within the seedbank.

Table 6: Dominant weed species from soil cores taken from treatments on the sandy loam soil trial site.

Broadleaf spp.	Grass spp.
Amaranthus hybridus	*Digitaria sanguinalis*
Chenopodium album	*Eleusine coracana*
Chenopodium carinatum	
Commelina benghalensis	
Portulaca oleracea	

The highest number of broadleaf and grass weed species germinated and emerged from the CA treatments with crop rotation of three different crops (Figure 6). These results concur with data recorded for the field survey done on a sandy loam soil.

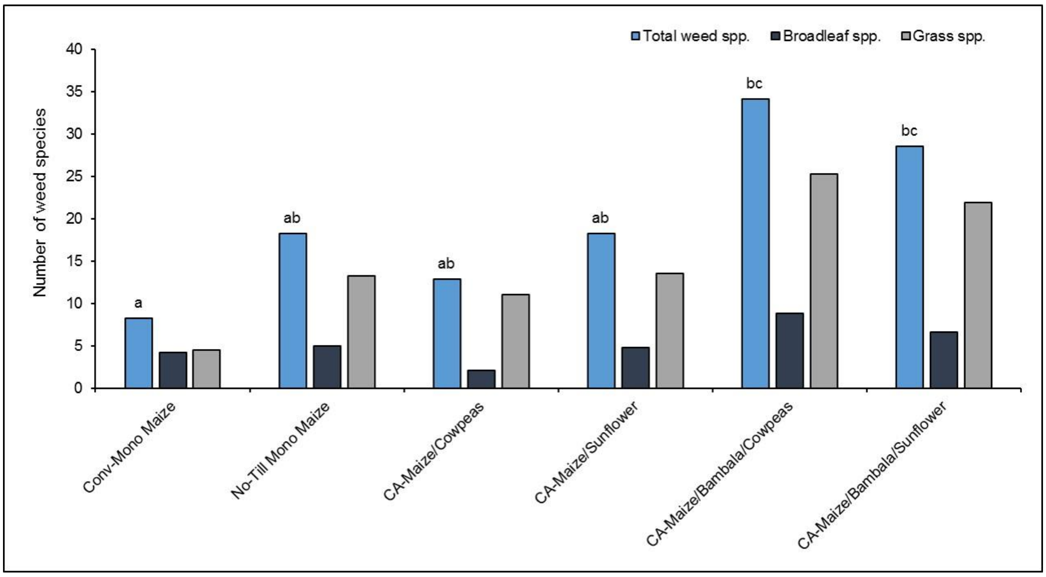

Figure 6: Seedbank composition for each across conventional and conservation agriculture systems on the loam soil trial. (Means within columns or rows followed by the same letter(s) do not differ significantly at P=0.05)

4. Discussion

The successful implementation of CA systems depends to a large extent on careful decision-making processes and the management thereof. Effective and timely management of weed control are essential to reduce yield losses when high infestation levels of weeds are experienced. It is, however, difficult to predict infestation levels of different weed species, since different species will react differently to habitats created by CA systems. Most of weed seeds in established CA systems occur in the upper 5 to 10 cm of the soil surface and only the depth of the planter will influence the vertical distribution of weed seeds in the soil profile. It is therefore essential for producers practicing CA to have adequate knowledge of the weed spectrums on each field and which species are dominant. Numerous studies have been done to determine weed species spectrums under CA systems and if any shifts in certain weed species do occur. Due to the fact that CA systems are unique to each producer and the area / environment where CA is practiced, results are inconsistent. Small seeded weed species proliferate and spread more easily under CA systems, and results found in this study confirmed these tendencies. Most of the dominant broadleaved and grass species occurring on the trial sites have very small seeds and persist across seasons in the CA treatments. Some studies found that the number of broadleaved weeds increased under no-tillage conditions, while others concluded that there was no difference in numbers between conventional and no-tillage treatments. Similar results were found for broadleaved weeds on the sandy loam soil where no difference in numbers occurred between monoculture maize under conventional and no-tillage treatments, respectively. Weed species numbers increased where crop rotation forms part of a CA system on the sandy loam soil, while the opposite was found on the sandy soil. This tendency can be ascribed to the different dominant weed species occurring at each trial site. Tillage systems or the lack thereof, can also influence emergence patterns of annual weeds differentially, which also depends on the vigour of the different species present. This could describe the predominance of *Crotalaria sphaerocarpa*, being the first species to germinate and emerge, showing more vigour compared to the rest of the broadleaved species. This same tendency has been observed for *Commelina benghalensis* on the sandy loam soil. Conventional tillage plots showed very low, if any, infestation levels of *C. benghalensis*, which could be ascribed to the deep mouldboard plough tillage. In the no-tillage treatments seed of *C. benghalensis* are not disturbed and can be dormant in the soil for years. This species has the ability to produce aerial as well as subterraneal seed, making it more difficult to control. However, numbers did start to decrease in the CA systems due to timely and continuous control of this species. Both these species also have the ability to germinate throughout the season, and with high seed numbers in the soil, can be difficult to control later in the season, causing severe yield losses.

Most grass species consist of small seeds as is the case with the dominant grass species found on both trial sites. Higher numbers of grass species have been reported on the sandy loam soil compared to the sandy soil. The infestation levels, however, increased steadily across seasons in the CA systems incorporating crop rotation of three different crops. This is a typical example of the different reaction of weed species under different habitats. Herbicide selection can also play a major role in crop rotation systems where the soil residual effect needs to be taken into account with follow-up crops. This complicates chemical weed control and might be a contributing factor in poor control of certain grass species under CA systems.

It is essential to control weeds as soon as possible after emergence to prevent flowering and seed shedding in CA systems. On the long-term, CA systems can reduce weed species numbers when effective weed control persists across seasons. Weed species numbers started to decrease over seasons on both localities, but some species increased significantly during the past season (2015/16), emphasizing the effect of environmental conditions on the germination and emergence on the respective weed species spectrums. Extreme drought conditions prevailed during the past growing season, reducing the efficacy of herbicides to an extent. Pre-emergence herbicides need soil moisture for effective control and when weeds are wilting or stressed, post-emergence herbicides are poorly absorbed and translocated.

Although results are inconsistent with regard to most of the weed species surveyed across treatments and seasons, it is not unexpected. The objectives of these studies are being achieved to determine the weed spectrums between two soil types and compare the spectrum between conventional and no-tillage systems. Each soil type has a unique weed spectrum, with distinctive dominant weed species.

Although the presence of crop residue (stubble) can influence weed seed germination and emergence, stubble levels were relatively low at both localities. It is therefore, concluded that the amount of stubble does not yet have a significant effect on weed species numbers. The percentage soil cover during pre-emergence herbicide application was also very low and did not affect the efficacy of soil applied herbicide at this stage. The first occurrence of *Helichrysum caesititium* (Rose poppy) on the sandy soil trial site might be due to the rotation of implements between the two localities. It is important to keep implements clean when used at more than one locality, since weed seeds can effectively be transported by humans and implements.

5. Outstanding

Due to the resignation of Dr Hugo during February 2017, certain aspects of this study were not finalised. Dr Craven has been appointed in Dr Hugo's position as weed scientist during June 2017. As the data of the outstanding research areas has been generated, Dr Craven will finalise the analyses and interpretation of the following aspects for publication purposes:

- Calculation of weed species richness and the Shannon-Weiner diversity (*H*) and evenness indices (*E*) for both soil types. This will give an indication if a significant shift in the weed spectrums occurred for both localities. Weed species were grouped into broadleaved and grass weeds to complete this report on time, but the effect of tillage, no-tillage and crop rotation will be determined for most of the dominant weed species present across season for each locality.

- The seedbank study for the sandy soil still needs to be finalised.

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