CHAPTER 2

Influence of cover crops *Secale cereale* and *Lolium multiflorum* on the growth of *Zea mays* and *Cyperus esculentus* under field conditions

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1. INTRODUCTION

In KZN, crops are produced on 5.2% of high potential soils, whilst 2.7% of production is on low potential soils. However, land degradation is increasing at an alarming rate due to, amongst other factors, soil erosion and bush encroachment (Bennet, 2008, Personal communication)[1]. The area available for crop production on high potential soil is therefore decreasing, forcing producers to incorporate more marginal areas into production. One major challenge facing crop producers in KZN is to increase food production in a sustainable manner by incorporating new production practices while at the same time dealing with higher input costs. Inadequate weed control could lead to lower crop yields impacting on sustainability and costs.

In KZN, *Cyperus esculentus* (yellow nutsedge), among other weeds, can become dominant and difficult to control in a conservation tillage system if inadequate weed control is applied. It is a herbaceous perennial weed that is characterized by prolific vegetative growth which produces a complex underground system of rhizomes and tubers (Gifford & Bayer 1995). Interference by *C. esculentus* reduces yields of maize (*Zea mays*) (Stoller *et al.*, 1979), cotton (*Gossypium hirsutum*) (Moffett & McCloskey 1998) and vegetables (Johnson III & Mullinix Jr 1999) through competition (Stoller *et al.*, 1979) and allelopathy (Drost & Doll 1980). Aqueous extracts of tubers and foliage of immature and mature *C. esculentus* plants inhibited the growth of the essential symbiotic ectomycorrhiza *Boletus maxaria* isolated from patula pine (*Pinus patula)* roots on agar medium (Reinhardt & Bezuidenhout 2001). Results suggested that the interference potential of *C. esculentus* varies with its growth stage.

[1] R.G. Bennet, DAEARD, Private Bagx9059, PMB, 3200

Short-term weed control efforts concentrate on controlling existing weed populations while long-term objectives must aim to prevent and reduce weed growth. Although previous studies have shown that inadequate weed control, especially at an early stage in crop development, can reduce crop yields (Hall *et al.*, 1992; Halford *et al.*, 2001), Ryan *et al.* (2009) and Davis *et al.* (2005) found that the yields of crops growing in organic systems, which depended more on cultural weed control methods, were not compromised by higher weed biomass levels. They concluded that the crop competitiveness and improved yield capacity were responsible for the apparent tolerance to weed competition. Cover crops can from part of a cultural management approach to limit the number of competitive weed species through influencing weed density and/or development (Liebman & Davis 2000).

According to Teasdale *et al.* (2007), cover crops improve the soil structure, increase organic material, reduce soil erosion and improve water infiltration. It also suppresses weed growth by creating a physical barrier to growth and a change in microclimatic conditions (Teasdale 1993; Teasdale & Mohler 2000). The degree of weed suppression depends on the cover crop species, the thickness of the mulch and the management system used, because different weed species react differently to the residues of cover crops (Creamer *et al.*, 1996). The most widely used cover crop species include stooling rye (*Secale cereale*), hairy vetch (*Vicia villosa*), wheat (*Triticum aestivum*) and *Trifolium* species. Dhima *et al.* (2006) found that stooling rye, triticum (x *Triticosecale*) and barley (*Hordeum vulgare*) reduced the emergence of *Echinochloa crus-galli* (barnyard grass) and *Setaria verticillata* (bristly foxtail) in the field by 27–80% and 0–67%, respectively, in comparison to cover crop mulch-free plots, without affecting maize emergence.

In South Africa, limited work has been done on the ability of cover crops to suppress weed growth in a crop situation. Fourie *et al.* (2006) evaluated different cover crops for weed control in vineyards in the Western Cape, while Little and van Staden (2003) have done work on the use of legumes to suppress weed growth in forestry. Ferreira and Reinhardt (2010) explored the possibility of using allelopathic crop residues to suppress herbicide resistant weeds in the Western Cape. No information on the ability of cover crops to suppress weed growth in a crop situation in the KZN region is available. The objectives of this study were to determine the ability of annual ryegrass and stooling rye as winter-grown cover crops to suppress *C. esculentus* growth and evaluate the subsequent influence on maize germination and growth in a field situation.

2. MATERIALS AND METHODS

2.1 Experimental site

A field experiment was carried out from 2003 to 2007 at the Cedara Research Centre of the KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development, South Africa (latitude 29°32'S; longitude 30°16'E; altitude 1051 m). The mean annual rainfall is 880 mm, of which about 130 mm falls in winter (April to August) and about 750 mm in summer (September to March). The annual A-pan evaporation is 1655 mm and 6.8 hours of sunshine per day are received during October to March (Camp 1999). The climatic data for 2003 to 2007 was received from the South African Weather Service automatic weather station at Cedara. The soil is of the Avalon form, orthic A on a yellow-brown apedal B and soft plintic B horizon. Soil analysis showed an average of 37% clay, 20% silt, 43% sand and 2.59% organic matter. The average pH (KCl) and acid saturation during the experimental period was 4.53 and 6.88% respectively. Soil analysis results for each growing season the experiment was conducted appear in Table 1. During the 2006 and 2007 growing seasons, soil analysis revealed certain plots with an average acid saturation of 25% and a pH (KCl) of 4.15. Dolomitic lime, at 2 t ha^{-1}, was applied to these plots. After application the average acid saturation of these plots fell to 11% and the pH (KCl) increased to 4.39.

TABLE 1 Nutrient content of soil for each growing season from 2003 to 2007

Season	P	K	Ca	Mg	Total cations	Acid saturation	pH
		(mg L^{-1})			(cmol L^{-1})	(%)	(KCl)
2003	9.41	113.45	808.18	198.36	6.13	2.86	4.67
2004	12.54	89.17	804.88	223.92	6.44	5.96	4.57
2005	13.36	130.27	773.23	204.92	6.23	6.15	4.52
2006	18.95	121.18	725.05	199.59	6.08	9.45	4.45
2007	20.85	145.71	760.90	186.96	6.26	9.56	4.46

2.2 Treatments

Dates on which major operations occurred are listed in Table 2. In 2006, cover crop planting was delayed due to the late harvesting of the 2005 season maize. In order to avoid a mid-summer drought during pollination, maize was planted earlier in 2006 and 2007. Two cover crop species, namely stooling rye cultivar 'Agri Blue' and annual ryegrass (*Lolium multiflorum*) cultivar 'Midmar', were planted in 150 mm spaced rows with a Connor Shea Pasture Drill, except in 2003, when it was broadcast onto the different plots. The ryegrass and stooling rye were drilled at 30 and 90 kg ha^{-1}, respectively. The broadcast rate was one and a half times the drilling rate. After seeding, fertilizer was broadcast separately on each plot and the seedbed was rolled with a Cambridge roller. Nitrogen (350 kg ha^{-1}), phosphorus (20 kg ha^{-1}) and potassium (160 kg ha^{-1}) were applied as NPK (2:3:4) (40%), with 0.5% added zinc. The balance of nitrogen (336 kg ha^{-1}) was applied as a top-dressing in the form of limestone ammonium nitrate (LAN) (28%) and potassium (133 kg ha^{-1}) as potassium chloride (KCl) six weeks after cover crop planting. Glyphosate-isopropylamine (Roundup SL, 360 g a.i. L^{-1}, Monsanto) was applied at 2160 g a.i. ha^{-1}, using a knapsack sprayer equipped with a floodjet nozzle (Lurmark Polijet 110° AN1.8) directly after planting, at a pressure of 200 kPa, to control any weeds growing at that stage. The high application rate was used as lower rates did not kill the annual ryegrass sufficiently. Supplementary irrigation, with a floppy sprinkler system, was applied according to soil moisture measurements taken with a Diviner 2000 Series moisture probe from Sentek during the cover crop growth period as the winter rainfall is too low for adequate growth. No additional pre- or post-emergence herbicides were applied to the cover crop treatments during their growth cycle. The cover crops were grown until maturity at 23 weeks, after which they were killed with glyphosate-isopropylamine applied in the same manner as described above.

Three control treatments, namely herbicide-treated (pre- and post-emergence), hand-weeded (hoeing) and non-weeded were included in the experimental design. The pre-emergence herbicide combination consisted of S-metolachlor (Dual S Gold EC, 915 g a.i. L^{-1}, Syngenta) and atrazine/terbuthylazine (Suprazine SC, 300/300 g a.i L^{-1}, Dow AgroScience) at 1189.5 and 1200 g a.i. ha $^{-1}$, respectively. Application was done at planting with a knapsack sprayer equipped with a floodjet nozzle (Lurmark Polijet 110° AN1.8) at 200 kPa. Post-emergence herbicides were applied six weeks later. These were paraquat dichloride (Gramoxone, SL, 200 g a.i. L^{-1}, Syngenta) and ametryn (Ametryn 500 SC, 500 g a.i. L^{-1}, Dow AgroScience) applied at 600 and 1000 g a.i. ha $^{-1}$, respectively, with an even flat nozzle (Teejet TP 8003E) at 200 kPA. Hand-weeding by hoeing was done as soon as 5% visual weed cover occurred. In the weeds plots no manual or chemical weeding was done and therefore weeds occurring on these plots represented the natural weed spectrum at the experimental site.

Maize planting furrows were drawn with a V-shaped hoe. Fertilizers were applied to each treatment, according to the soil analysis done on samples. Soil samples were collected twice during the growing season in the different treatments; after spraying the cover crops with glyphosate-isopropylamine and after maize harvesting. Nitrogen (140 kg ha^{-1}) and phosphorus (20 kg ha^{-1}) were applied as NPK (2:3:4) (40%) with 0.5% added zinc and the balance of nitrogen (110 kg ha^{-1}) was applied as a top-dressing in the form of limestone ammonium nitrate (LAN) (28%) five weeks after maize planting. Soil analysis indicated that potassium levels were adequate and therefore no additional potassium was needed. Fertilizer was applied in the furrow at planting and covered with soil. Maize, Pioneer Seed cv. PHB 32D99, was hand-seeded at 44 444 seeds ha^{-1}, which represents the recommended plant density for dry-land conditions in the area (Mallett 1991).

2.3 Data collection

Data collection dates are given in Table 2. Maize data for the 2004 season were omitted, as adverse wet and rainy conditions prevented measurements being taken at designated times. Biomass samples of the cover crops were collected on each plot in four randomly placed 0.09 m^2 blocks and oven-dried at 70°C. Maize was considered to have emerged fully when the first leaf was completely unfolded. The date of final emergence was the last day emergence was measured and expressed as the percentage of seeds planted. Each plot was divided into four quarters to record the accruement of maize seedling dry weight after maize emergence. At about 14 days after emergence (DAE), 60 maize seedlings in the first quarter of each plot were cut above the soil surface and their dry weights recorded. It was repeated in the second and third plot quarters, at about 28 and 44 DAE. During 2003-2005 *C. esculentus* growth was only visually assessed but in 2006 and 2007 the leaf mass of *C. esculentus* was measured to obtain a more quantitative measurement (Table 2). Leaf material of *C. esculentus* was collected in six 0.09 m^2 blocks, in the same plot quarters used for the maize measurements. The leaf material was collected separately in inter- and intra-row maize planting lines at about 16, 28 and 41 DAE, and the dry weights determined and expressed on a per plant basis. Maize heights were measured from the soil surface to the ligule of last unfolded leaf. Harvesting was done by hand 176 DAE to determine the yield.

TABLE 2 Schedule for major field operations and measurements done on maize and *C. esculentus*

	Growing season				
Operation	**2003**	**2004**	**2005**	**2006**	**2007**
Planting of cover crops	9 Apr.	3 May	28 Apr.	31 May	14 May
Taking biomass samples	16 Oct.	12 Oct.	27 Oct.	19 Sept.	11 Oct.
Spraying cover crops	24 Oct.	14 Oct.	28 Oct.	11 Oct.	12 Oct.
Planting of maize	6 Nov.	10 Nov.	3 Nov.	23 Oct.	29 Oct.
Emergence of maize	13 Nov.		11 Nov.	29 Oct.	6 Nov.
Final maize emergence	7 DAE[1]		7 DAE	6 DAE	7 DAE
Maize seedling sampling					
1st	13 DAE		18 DAE	9 DAE	13 DAE
2nd	28 DAE		28 DAE	23 DAE	27 DAE
3rd	46 DAE		51 DAE	36 DAE	42 DAE
C. esculentus sampling					
1st				18 DAE	14 DAE
2nd				26 DAE	29 DAE
3rd				40 DAE	42 DAE
Maize height measurement	83 DAE		117 DAE	164DAE	128 DAE
Maize harvesting	166 DAE		173 DAE	169 DAE	197 DAE

1 DAE denotes days after emergence

2.4 Statistical analysis

Cover crop measurements were taken on 108 m^2 (18 x 6 m) plots. Maize measurements were taken on four data rows, 18 m in length and spaced 0.75 m apart. Treatments were replicated four times in a randomized block design. Data were analysed using the analysis of variance (ANOVA) procedure in the statistical package Genstat (Payne *et al.*, 2007). Treatment means were compared using Fisher's Protected Least Significant Difference procedure P=0.05. Leaf dry weight of maize seedlings, sampled at different times, was subjected to regression analysis. The non-linear relationship between dry weight and time was transformed to form a linear relationship (Gomez & Gomez 1984).

3. RESULTS

3.1. Cover crop growth

3.1.1 Climatic conditions

The mean minimum and maximum temperature data for the six-month cover crop growing period during each of the five growing seasons are shown in Figures 1 and 2.

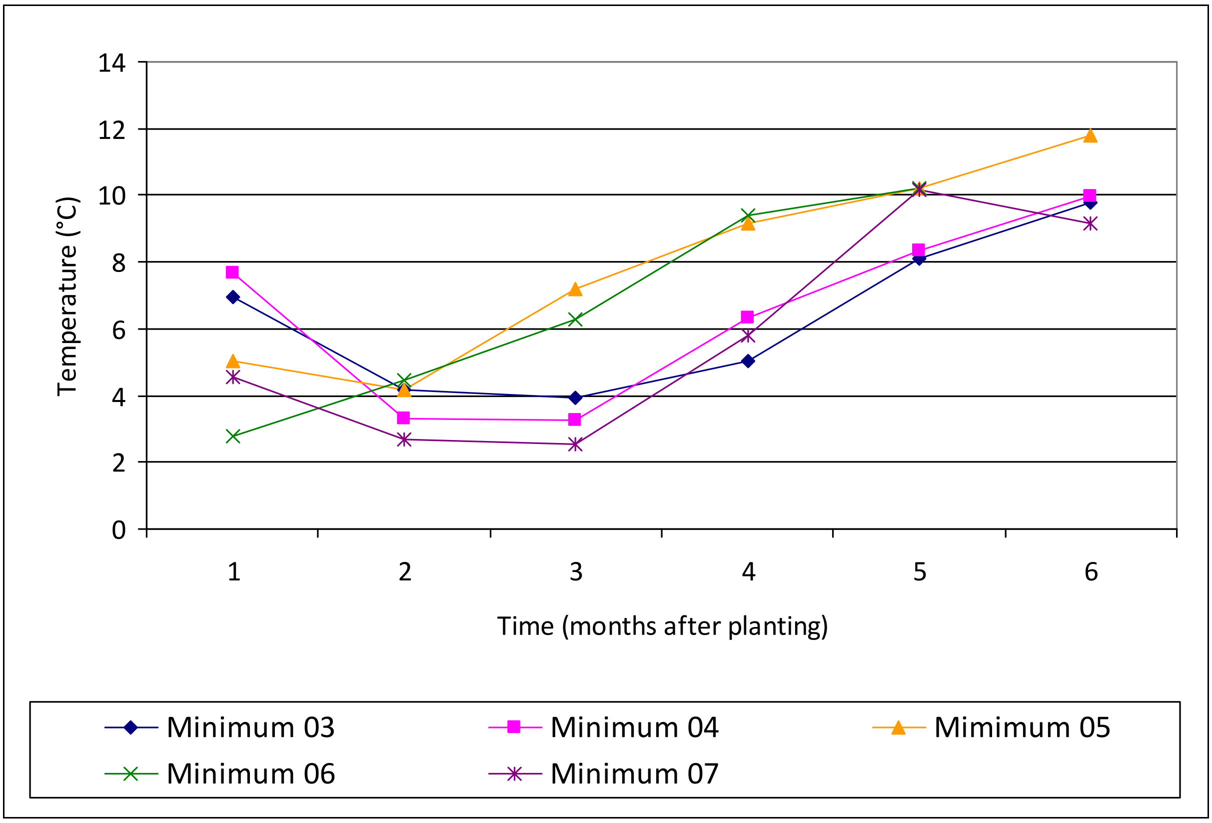

FIGURE 1 Mean minimum monthly temperatures for the six-month cover crop growth period for each of the five growing seasons

A month after planting in 2003 and 2004 the mean minimum temperatures were relatively high compared to the other seasons. Thereafter a sharp decline in temperature occurred (Figure 1). Two months after planting the mean minimum temperature in 2005 and 2006 were higher compared to the other seasons.

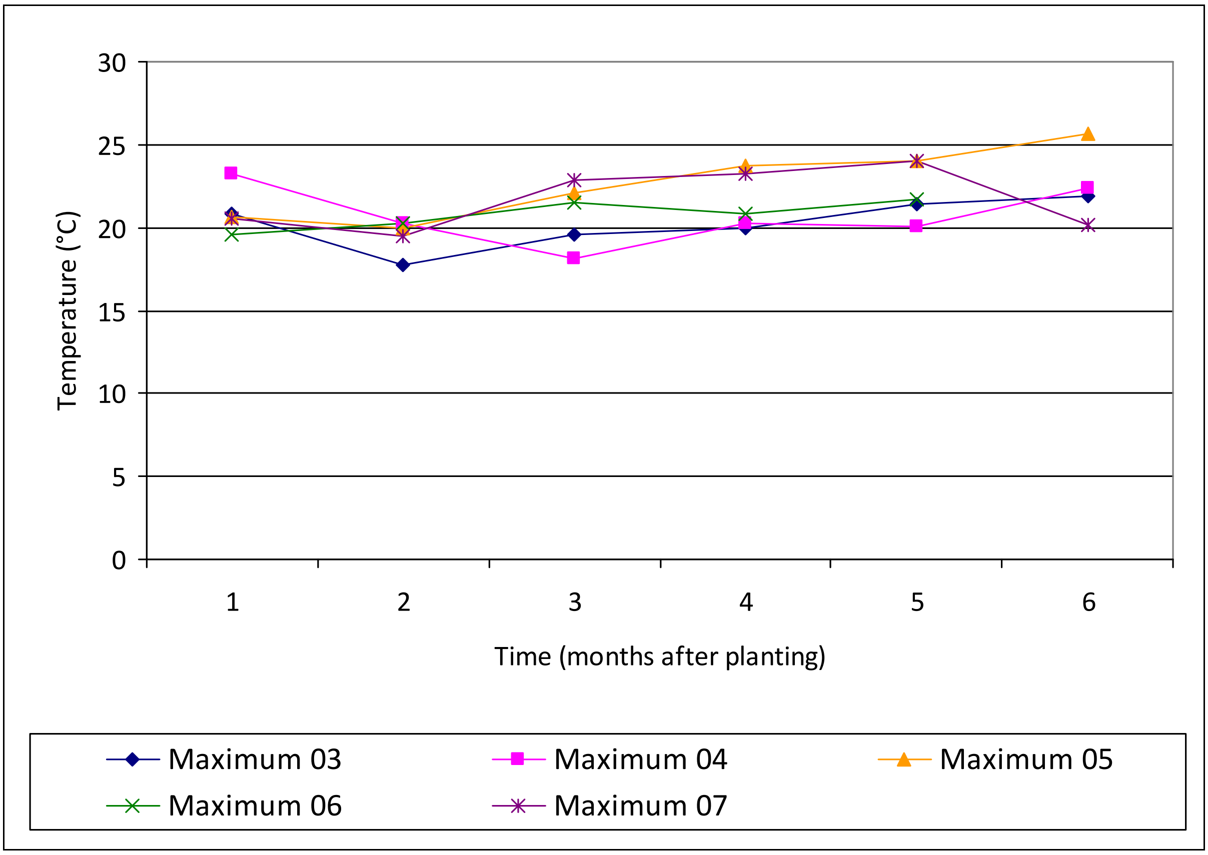

FIGURE 2 Mean maximum monthly temperatures for the six-month cover crop growth period for each of the five growing seasons

The mean maximum temperatures over the five seasons were relatively similar for the first two months after planting, except for higher temperatures in 2004, a month after planting. Two months after planting, relatively cooler conditions were experienced in 2003 and 2004 compared to the other seasons. During the last month of growth in 2007 lower temperatures were measured

The rainfall received during the six-month cover crop growth period for the five years appears in Table 3. In addition to rainfall, supplemental irrigation was supplied. Four months after the cover crop was planted, the rainfall started to increase. The highest rainfall during the growing season was received in 2003 with 229.00 mm rainfall, followed by 2007 (180.39 mm). In spite of the fact that the 2006 growing season was one month shorter, higher rainfall was received compared to the 2004 and 2005 seasons.

TABLE 3 Rainfall received during the six-month cover crop growth period for each of the five growing seasons

	Growing seasons				
	2003	**2004**	**2005**	**2006**	**2007**
Months after planting	**Rainfall received (mm)**				
1	43.00	0.40	9.00	5.20	0.20
2	6.80	20.20	1.00	0.80	33.00
3	0.20	16.00	27.39	38.39	0.00
4	33.40	12.40	16.30	32.60	12.99
5	50.60	60.59	43.40	58.99	23.20
6	95.00	6.00	16.40		111.00
Total	**229.00**	**115.59**	**110.79**	**135.98**	**180.39**

3.1.2 Cover crop yields

Growing seasons had a strong influence on the cover crop yield, as the interaction between season and treatment was highly significant (Appendix A Table 1). A decline in cover crop yields were seen from 2003 onwards, with an increase occurring in the last season (2007). In 2003, both cover crops had significantly higher yields than the weeds, while no significant yield differences between the treatments were seen in 2004–2006. In 2007, only the annual ryegrass produced significantly more biomass than the weeds. Comparison of the cover crop species with one another in each season showed no significant differences in yield.

TABLE 4 Dry matter yield of weeds and two cover crop species, annual ryegrass and stooling rye grown over five seasons (statistical analysis in Appendix A Table 1)

	Growing season					
	2003	**2004**	**2005**	**2006**	**2007**	**Mean**
Treatment	**Dry matter yield (t ha^{-1})**					
Weeds	3.45 df	8.61 b	1.98 f	2.97 ef	2.25 ef	**3.85 y**
Annual ryegrass	8.73 ab	8.69 b	3.82 df	2.08 f	5.29 cd	**5.72 x**
Stooling rye	10.82 a	6.88 bc	2.27 ef	1.73 f	4.33 de	**5.21 x**

	Treatment	**Season*Treatment**	**Means within a season**
SED	0.534	1.048	1.195
LSD	1.091	2.121	2.440
CV (%)		34.3	

[1] Means followed by the same letter are not significantly different at $P \leq 0.05$

3.2. Early maize growth

3.2.1 Climatic conditions

Different climatic conditions during the growing seasons occurred between spraying the cover crops, planting maize and 44 days after planting (DAE). Overall, 2005 and 2006 experienced warm, wet conditions, while 2003 was warmer but drier. Cool, wet conditions marked 2007. In 2003, the climatic conditions from planting to 14 DAE were characterized by hot dry conditions with most of the rain received towards the end of this period (Table 5). In contrast, in 2005, the same period was marked by warm, wet conditions with the rainfall evenly distributed during this period. In 2006 and 2007, conditions during planting to 14 DAE were marked by lower temperatures, accompanied by low rainfall in 2006 and higher rainfall in 2007. On both occasions rainfall was received towards the end of this period. During 14–44 DAE, hot dry conditions occurred in 2003 and 2006, with the rainfall evenly distributed throughout the period. In comparison, 2005 was warm but wetter, with the rainfall received throughout the period. The 2007 season was marked by cool, wet conditions, with most of the rainfall received at the beginning.

TABLE 5 Average heat units per day and total amount of rainfall received from cover crop spraying to 44 days after maize emergence

	Spraying to planting		Planting to 14 DAE[1]		14 to 44 DAE	
Season	Heat units[2] (per day)	Rainfall (mm)	Heat units (per day)	Rainfall (mm)	Heat units (per day)	Rainfall (mm)
2003	8.94	21.20	10.21	43.80	9.19	113.80
2005	10.08	58.80	8.64	59.00	8.69	166.53
2006	8.86	67.59	7.55	27.79	9.10	127.80
2007	6.53	52.80	6.93	45.40	7.50	150.80

[1] DAE denotes days after emergence

[2] Heat units are calculated using a base temperature of 10°C

Soil water measurements taken by the Sentek Diviner 2000 probe from planting to 44 DAE are shown in Table 6. Unfortunately, due to equipment failure the data for 2007 could not be recorded. Generally, the soil moisture content in the two non-residue treatments was lower compared to the residue treatments. With regards to the residue treatments, higher soil moisture levels were measured in the stooling rye treatment, followed by the weeds treatment. In spite of the low rainfall received during the planting to 14 DAE in 2006, the soil moisture content was higher than 2003, which received more rain, probably due to the lower temperature in 2006.

TABLE 6 Average volumetric soil water content in the upper 100 mm of soil measured from planting maize seedling to 44 days after emergence

	Planting to 14 DAE[1]			14 to 44 DAE		
	2003	**2005**	**2006**	**2003**	**2005**	**2006**
Treatments	**Volumetric soil content (mm)**					
Weeds	16.95	18.57	21.94	20.66	15.79	25.25
Annual ryegrass	15.42	16.95	21.08	18.75	14.94	24.67
Stooling rye	18.23	21.43	25.22	21.88	18.57	28.47
Hand-weeded	14.30	17.26	17.67	16.66	17.81	19.60
Herbicide	14.52	16.89	19.02	16.89	18.73	22.57

[1] DAE denotes days after emergence

3.2.2 Final maize emergence

The interaction between seasons and the final maize emergence percentages counted 7 DAE was not significant (Appendix A Table 2), but the main effects were (Table 7). Both cover crop species and the weed residues inhibited maize emergence more, as significantly fewer seedlings emerged in the latter than in the two non-residue treatments. No significant differences occurred between the two cover crop residue treatments. Significantly lower cover crop plant populations were measured in 2005 and 2007 compared to 2003 and 2006, with the lowest population in 2005.

TABLE 7 Influence of weeds and residues of annual ryegrass and stooling rye on the final number of maize seedlings that emerged seven days after planting (statistical analysis in Appendix A Table 2)

	Growing season				
	2003	**2005**	**2006**	**2007**	**Mean**
Treatment	**Final emergence (%)**				
Weeds	92.1	63.9	86.4	69.7	**78.0 b**
Annual ryegrass	77.5	37.2	78.4	49.4	**60.6 c**
Stooling rye	84.7	49.7	80.0	51.8	**66.5 c**
Hand-weeded	93.3	73.6	93.1	83.5	**85.9 a**
Herbicide	95.5	72.7	94.7	86.4	**87.3 a**
Mean	**88.6 a**	**59.4 c**	**86.5 a**	**68.1 b**	

	Season	**Treatment**
SED	3.81	3.66
LSD	8.30	7.35
CV (%)	13.7	

[1] Means followed by the same letter are not significantly different at $P \leq 0.05$

3.2.3 Maize seedling growth over time

The relationship between accumulated seedling dry weight and time, as influenced by the different treatments over four seasons, is shown in Figure 3. Despite different climatic conditions and significant differences in maize emergence between residue and non-residue treatments, it had little effect on the dry weight of maize seedlings 14 DAE. Thereafter, climatic conditions and the applied treatments influence growth as the seedling growth increase was higher in non-residue treatments compared to the residue treatments. Comparison of the residue treatments indicated that maize growth was more suppressed in the annual ryegrass residues than in either the stooling rye or weeds residues. The least reduction in maize growth occurred in the weeds treatment.

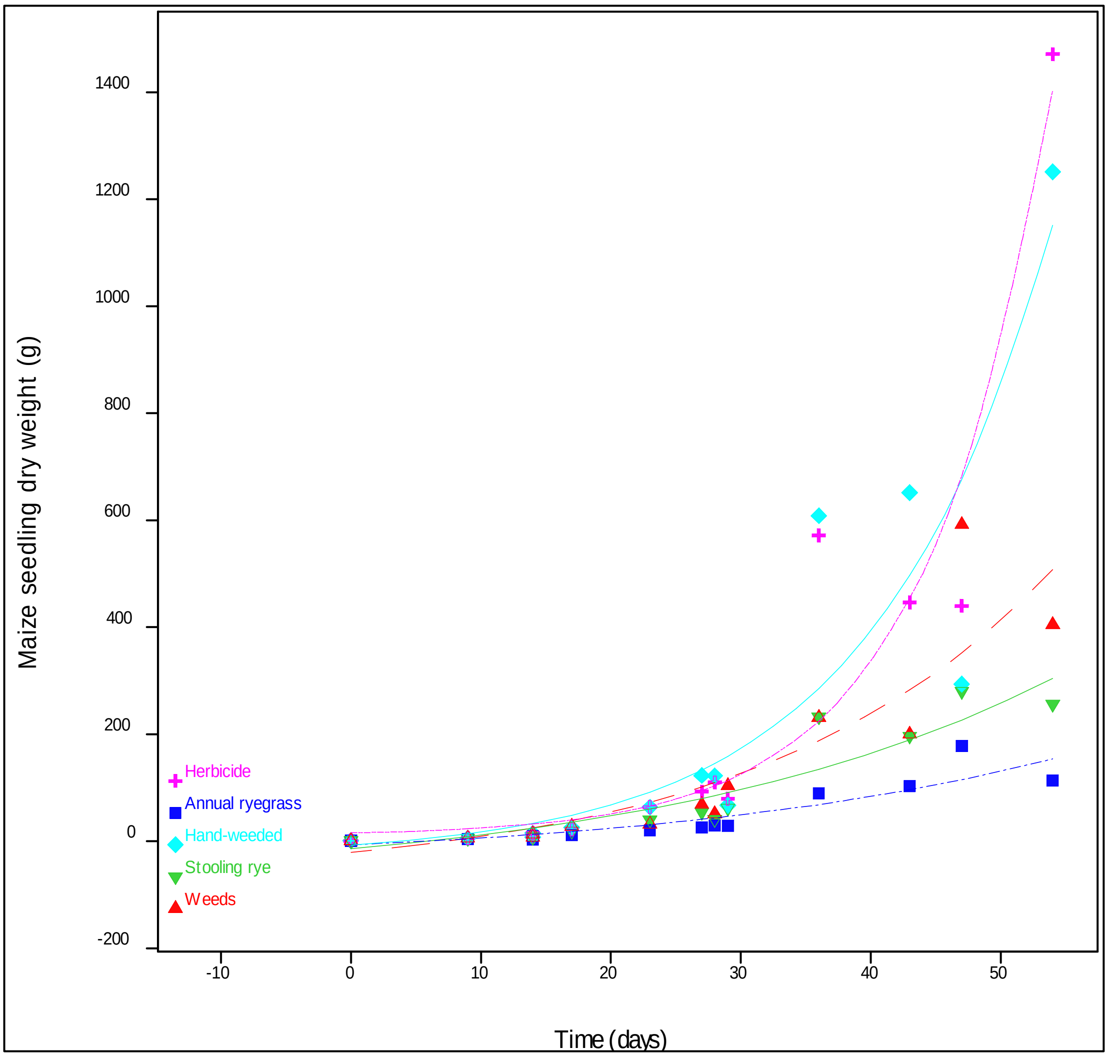

FIGURE 3 Relationship between maize seedling dry weight and time (days after emergence) as influenced by different treatments over four seasons.

Adjusted R^2=84.90.The equation for the curves are: $Y^{Weeds}=6.25+8.42e^{(0.077x)}$, $Y^{Rye}=13.73+5.06e^{(0.077x)}$, $Y^{Ryegrass}=7.83+2.54e^{(0.077x)}$, $Y^{Hand\text{-}weeded}=-18.25+18.12e^{(0.077x)}$, $Y^{Herbicide}=-44.79+20.74e^{(0.077x)}$ where Y is the dry weight of the maize seedlings (g per m^2) and X is the time after sowing. (statistical analysis in Appendix A Table 3)

The non-linear transformation of the growth curves to a linear function showed that maize seedling growth, expressed in dry weight, was positively correlated (y=0.10174x+0.292) with time (Figure 4). Maize seedlings growing in non-residue treatments had higher dry weights while maize growth was significantly inhibited by the annual ryegrass residues compared with the rest of the treatments, except the stooling rye treatment. Differences between the weed residues and the stooling rye treatments were not significant, this despite the fact that stooling rye and annual ryegrass had relatively similar amounts of residue on the soil surface.

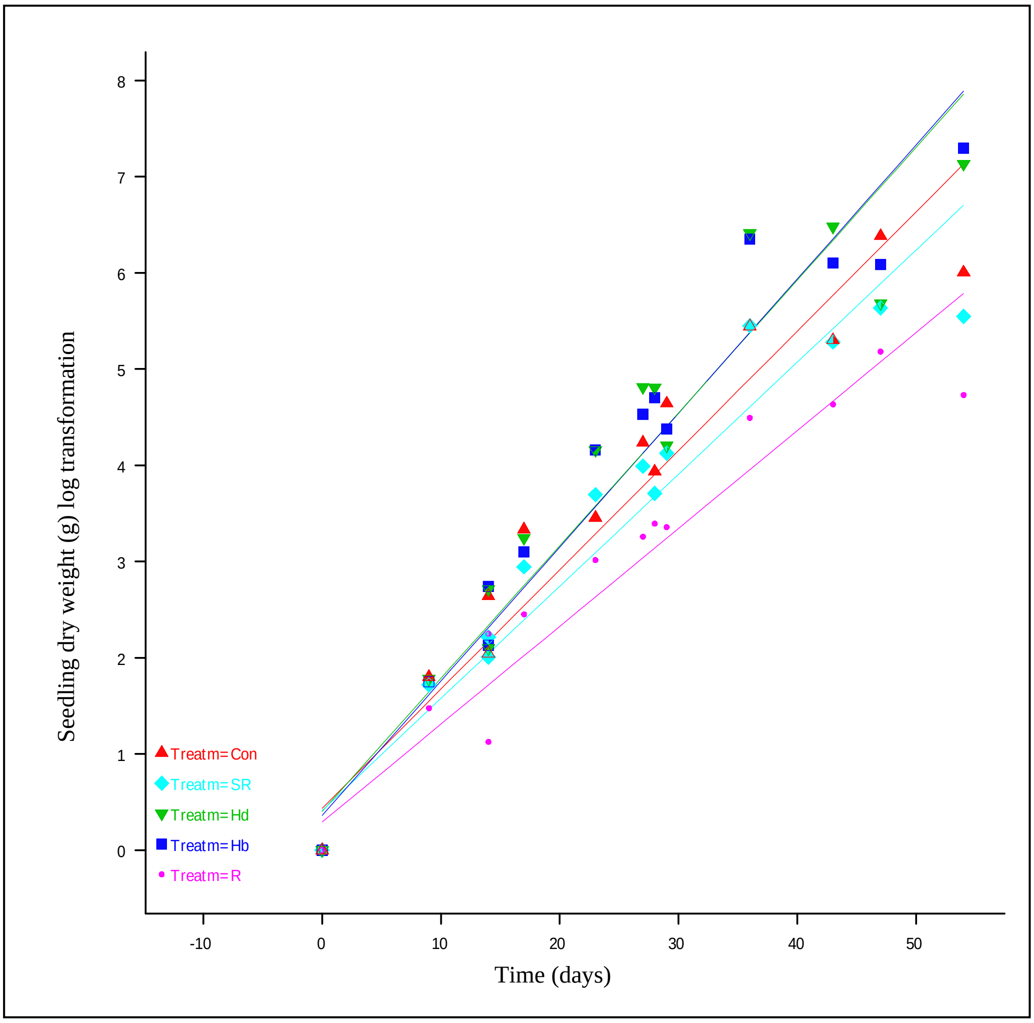

FIGURE 4 Relationship between maize seedling dry weight and time as influenced by different treatments: Con (weeds), SR (stooling rye), Hd (hand-weeded), Hb (herbicide) and R (annual ryegrass).

Adjusted R^2 = 94.2 Y = 0.10174x + 0.292 (statistical analysis in Appendix A Table 4)

3.3 C. esculentus *growth*

Due to the dominance of *C. esculentus,* leaf growth was measured separately in the intra- and inter-row maize planting lines in 2006 and 2007. High coefficient of variance (CV) characterized the statistical analysis of the dry weight data of *C.*

esculentus. Transformation of the data did not stabilize the CV or change the significance. The interaction between growing season and treatment was not significant for sampling in intra- and inter-row planting lines at 16, 28 and 41 DAE but the treatment effect was (Appendix A Tables 5–10).

Dry weight of *C. esculentus* top growth sampled in 2006 and 2007 were not significantly different, except for leaf material collected in the intra-row planting lines 16 DAE (Table 8). Although differences were not significant, more *C. esculentus* leaf material was collected in the intra-row planting lines in 2006 compared to 2007. It was only during 16 DAE that higher amounts of leaf material were collected in 2006 in the inter-row planting lines. Thereafter, more *C. esculentus* material was collected in 2007.

TABLE 8 Dry weight accruement of *C. esculentus* top growth sampled over two seasons in intra- and inter-row maize planting lines at 16, 28 and 41 days after maize emergence (statistical analysis appears in Appendix A Tables 5–10)

	Intra-row planting lines			**Inter-row planting lines**		
	Sampling period			**Sampling period**		
	16 DAE[1]	**28 DAE**	**41 DAE**	**16 DAE**	**28 DAE**	**41 DAE**
Season	**Dry weight (t ha^{-1})**			**Dry weight (t ha^{-1})**		
2006	0.99 a	1.76 a	2.87 a	0.50 a	0.83 a	1.39 a
2007	0.45 b	1.41 a	2.40 a	0.30 a	0.91 a	1.89 a

	Intra-row planting lines			**Inter-row planting lines**		
	Sampling period			**Sampling period**		
	16 DAE	**28 DAE**	**41 DAE**	**16 DAE**	**28 DAE**	**41 DAE**
SED	0.218	0.337	0.215	0.159	0.163	0.219
LSD	0.534	0.826	0.526	0.389	0.399	0.536
CV (%)	52.6	42.5	39.0	69.5	35.9	45.9

[1] DAE denotes days after emergence

[2] Means followed by the same letter within a sampling period are not significantly different at $P \leq 0.05$

Comparisons of *C. esculentus* dry weight collected in the intra-row maize planting lines, at the three sampling periods, indicated that it was only at 16 DAE, that significantly different amounts of *C. esculentus* leaf material were collected amongst the treatments (Table 9). Stooling rye residues suppressed *C. esculentus* growth significantly more than the weed residues, but the effect of the former was not significantly different from the annual ryegrass treatment. *C. esculentus* growth suppression by annual ryegrass residues was similar to that achieved by the weed residues. After 16 DAE, no significant differences were observed amongst the treatments, even though the suppression by stooling rye residues was longer lasting.

TABLE 9 Dry weight accruement of *C. esculentus* top growth sampled in the intra-row maize planting lines at 16, 28 and 41 days after maize emergence (statistical analysis appears in Appendix A Tables 5–7)

Treatment	Sampling period 16 DAE[1]	28 DAE	41 DAE
	Dry weight ($t\ ha^{-1}$)		
Weeds	1.02 a	1.87 a	2.94 a
Annual ryegrass	0.62 ab	1.67 a	2.82 a
Stooling rye	0.53 b	1.23 a	2.14 a

	Collection period 16 DAE	28 DAE	41 DAE
SED	0.190	0.338	0.514
LSD	0.415	0.735	1.120
CV (%)	52.6	42.5	39.0

[1] DAE denotes days after emergence
[2] Means followed by the same letter within a sampling period are not significantly different at $P \leq 0.05$

Evaluation of the influence of the different residue types on *C. esculentus* growth that occurred in the inter-row maize planting lines showed that, during 16 and 28 DAE, the residues of both cover crop species significantly reduced *C. esculentus* growth compared to the weed residues (Table 10 and Figures 5 and 6).

At 41 DAE, only stooling rye residues significantly reduced *C. esculentus* growth, compared to the weed residues.

TABLE 10 Dry weight accruement of *C. esculentus* top growth sampled in the inter-row maize planting lines at 16, 28 and 41 days after maize emergence (statistical analysis appears in Appendix A Tables 8–10)

Treatment	**Sampling period**		
	16 DAE[1]	**28 DAE**	**41 DAE**
	Dry weight (t ha^{-1})		
Weeds	0.74 a	1.23 a	2.18 a
Annual ryegrass	0.17 b	0.65 b	1.54 ab
Stooling rye	0.30 b	0.74 b	1.19 b

	Collection period		
	16 DAE	**28 DAE**	**41 DAE**
SED	0.140	0.156	0.376
LSD	0.304	0.341	0.820
CV (%)	69.5	35.9	45.9

[1] DAE denotes days after emergence

[2] Means followed by the same letter within a sampling period are not significantly different at $P \leq 0.05$

FIGURE 1 ***C. esculentus*** **growth in the (A) weed residues, (B) annual ryegrass and (C) stooling rye residues 16 days after maize emergence**

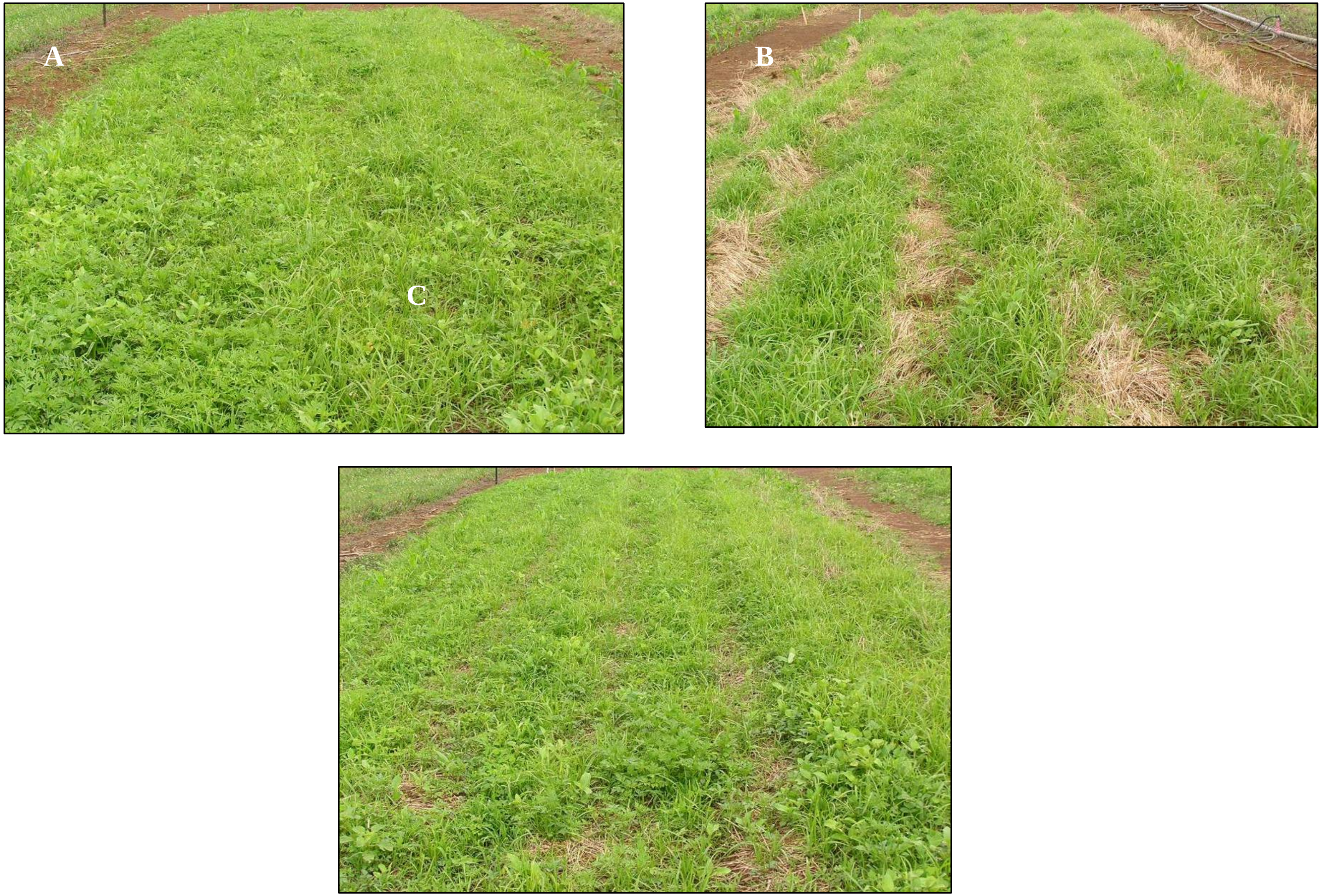

FIGURE 2 *C. esculentus* growth in the (A) weed residues, (B) annual ryegrass and (C) stooling rye residues 28 days after maize emergence

3.4 Maize height growth and yields

3.4.1 Climatic conditions

The climatic conditions over the four growing seasons from 44 days after maize emergence up to harvesting (176 DAE) are presented in Table 11. Hot conditions characterized the 2003 and 2006 seasons, main difference being that 2006 was generally drier. The 2005 and 2007 seasons were both cooler, but with more total rainfall received in 2005. The 2003 and 2005 seasons were therefore relatively more favourable for maize and *C. esculentus* growth compared to 2006 and 2007. During pollination of maize plants in January of each season, hot conditions were recorded, with the lowest rainfall received in 2006 and 2007.

TABLE 11 Climatic conditions during the growing period from 44 to 176 days after maize emergence with the rainfall and heat units for the month of January specified for each season

	Temperature		Rainfall		Heat units[1]	
	Maximum	Minimum	44–176 DAE[2]	Month of January	44–176 DAE	Month of January
Season	(°C)		(mm)		(per day)	
2003	24.91	14.13	411.00	161.20	9.52	10.27
2005	24.30	13.60	464.13	199.74	8.95	10.68
2006	26.20	14.31	336.75	74.59	10.26	11.37
2007	24.99	12.37	340.90	108.00	8.68	10.14

[1] Heat units are calculated using a base temperature of 10°C
[2] DAE denotes days after emergence

3.4.2 Maize height growth and yields

Growing seasons had a significant effect on the height and yield of maize amongst treatments (Appendix A Tables 11 and 12). During 2006 and 2007 the maize plants were taller than in 2003 and 2005, with plants being the tallest in 2006 (Table 12). Maize plants growing in the non-residue treatments were significantly taller compared to the residue treatments. Height differences amongst maize plants in the three residue treatments were not significantly different in 2005 and 2007, but in 2003 and 2006 significantly shorter plants occurred in the annual ryegrass treatment compared to the weeds and stooling rye treatments. Over the four seasons, maize growing in the annual ryegrass residues was shorter compared to those in the other treatments. Maize growing in the weed residues was taller than those in the stooling rye residues.

TABLE 12 Height of maize measured 123 days after emergence in three residue treatments, weeds, annual ryegrass and stooling rye and two non-residue treatments (statistical analysis appears in Appendix A Table 11)

	Growing season				
	2003	**2005**	**2006**	**2007**	**Mean**
Treatment	Height (mm)				
Weeds	1690 a	1545 b	1768 b	1668 b	**1668 y**
Annual ryegrass	1342 b	1462 b	1404 c	1610 b	**1454 z**
Stooling rye	1545 a	1483 b	1766 b	1707 b	**1625 y**
Hand-weeded	1601 a	2036 a	2059 a	2060 a	**1939 x**
Herbicide	1721 a	2038 a	2123 a	1965 a	**1962 x**

	Treatment	**Season * Treatment**	**Means within season**
SED	53.3	138.6	106.7
LSD	107.2	281.0	214.4
CV (%)		8.7	

[1] Means followed by the same letter within a season are not significantly different at $P \leq 0.05$

Yields were significantly higher in the hand-weeded and herbicide treatments compared to the residue treatments (Table 13). Variations in yield trends occurred over the four seasons. The yields obtained in the first season, 2003, showed an anomalous trend compared to the other seasons, in that significantly different yields were measured between the annual ryegrass treatment compared to the other two treatments. Yield differences obtained in the residue treatments were not significantly different in the following three seasons. During the four growing seasons maize in the annual ryegrass residues had the lowest yields, except in 2005.

TABLE 13 Yield of maize growing in three residue treatments, weeds, annual ryegrass and stooling rye and two non-residue treatments (statistical analysis appears in Appendix A Table 12)

	Growing season				
	2003	**2005**	**2006**	**2007**	**Mean**
Treatment	**Yield (t ha^{-1})**				
Weeds	6.31 a	2.56 b	3.11 b	2.18 b	**3.54 y**
Annual ryegrass	2.18 c	2.30 b	3.01 b	1.98 b	**2.30 z**
Stooling rye	4.20 b	2.02 b	4.76 ab	3.10 b	**3.52 y**
Hand-weeded	8.22 a	8.50 a	6.52 a	7.31 a	**7.64 x**
Herbicide	7.36 a	9.01 a	5.93 a	6.90 a	**7.30 x**

	Treatment	Season * Treatment	Means within season
SED	0.484	1.218	0.968
LSD	0.973	2.464	1.946
CV (%)		28.2	

[1] Means followed by the same letter within a season are not significantly different at $P \leq 0.05$

4. DISCUSSION

4.1 Cover crop growth

The relatively low cover crop yields in 2006 could be attributed to the shorter growing period due to a delay in planting. The highest cover crop yields were recorded in 2003. Contributing factors to the high yields likely included the early planting date, broadcasting the seed into the treatments as opposed to drilling them and the higher rainfall received, accompanied by lower temperatures thus creating favourable planting and growing conditions for cover crop growth. A decline in cover crop yields were seen from 2003 onwards, with an increase occurring in the last season (2007). The weed residues (weeds treatment) had generally lower yields than the cover crops due to the weed species present in the plots at the time of sampling. Overall, the most dominant weed species were

Fumaria muralis (fumitory), *Coronopus didymus* (carrot weed), *Oxalis* spp. (sorrel) and *Sonchus oleraceus* (sowthistle). Although these weeds covered the entire plot, they obtained lower yields compared to the two pasture species due to their unique growth characteristics. The relatively high weed yield obtained in the weeds in 2004 could have been due to more *S. oleraceus* and *Circium vulgare* (Scotch thistle) collected, while in 2005 herbicide drift from adjacent plots reduced weed growth.

4.2 Maize emergence

Despite previous reports that plant residues on the soil surface reduce crop emergence through mechanical resistance, reduced light reaching the soil surface, and interference with heat and water transfer between the soil and atmosphere (Teasdale & Mohler 2000; Teasdale *et al.,* 2007), contrasting results were obtained from the present study. As maize planting furrows were effectively devoid of residues because of the furrows being drawn with a v-shaped hoe, growth inhibition of maize could not have been due to a physical constraint contributed by the residues.

If, hypothetically, residues were present in the planting furrows, light should not have been a limitation to maize seedling emergence. Crops with big seeds seem to be less affected by the presence of residues than small seeds, because of the relatively large amount of resources available in the former (Putnam *et al.,* 1983; Teasdale 1993). Due to the relative large size of maize seeds enough resources should exist within the seed in order for coleoptiles to have emerged unimpeded through the cover crop residues in the present study. The reduction in emergence percentages in the residue treatments could not have been the result of nutrient imbalances, as the emerging seedling is totally dependent on seed reserves and thus not yet influenced by the nutrient status of the soil (Purvis 1990).

The optimum mean daily temperature for maize to germinate is between 18 and 20°C with growth being inhibited at temperatures below 10°C or above 30°C (Smith 1991). Although soil temperature was not measured in the experiment, it is possible that fluctuations in soil temperature over the four seasons could have contributed to some of the reductions recorded for crop emergence as soil temperature could have been lower under the residue, especially with the lower air temperatures in 2005 and 2007 accompanied by higher rainfall. Kravchenko and Thelen (2007) found that the lower soil temperatures under wheat shoot and root residues decreased maize emergence more compared to plots with no wheat residues. Teasdale and Mohler (1993) suggested that a delay in germination could be expected with lower soil temperatures under cover crop residues. Differences in soil moisture were not responsible for the differential emergence, as lower soil moisture values were measured in the non-residue treatments, yet emergence was not suppressed in these treatments.

In this study it was the type of residue, rather than the amount thereof, that impaired maize seedling emergence. Burgos and Talbert (1996b) reported similar results when the number of southern pea (*Vigna unguiculata*) plants were reduced in annual ryegrass residues, despite the latter crop's residues having had a similar amount of biomass to oats and a lower amount of biomass compared to sorghum-sudangrass (*Sorghum bicolor* x *Sorghum vulgare* var. *sudanense*). Woodland species emergence was significantly reduced under grass residues compared to woodland residues (Donath & Eckstein 2008), while pasture species proved to be more restrictive to crop establishment than cereal grains (Weston 1990).

Investigating the effect of cover crop residues on crop and weed emergence revealed the involvement of putative allelochemicals with benzoxazinones and various phenolic compounds previously identified in stooling rye (Wójcik-Wojtkowiak *et al.,* 1990; Sicker *et al.,* 2004; Belz 2004). Allelochemicals are released from plants through leaching, decomposition, volatilization and root exudation (Belz 2004) and the effect is concentration dependant. The decomposition rate, leaching of water-soluble allelochemicals and the available concentration under field conditions and the prevailing temperatures, which can vary from year to year, as well as on the soil microbial activity (Purvis 1990; Facelli & Pickett 1991).

Significantly more cover crop biomass was produced in 2003 compared to 2006, yet there were no significant differences in emergence between the two seasons. After spraying the cover crops in 2003, warm and dry conditions prevailed, rendering decomposition of residues possible, but limiting the leaching of putative allelochemicals. Leaching of allelochemicals into the root zone conceivably was further reduced by the low rainfall received (29.00 mm) during the maize germination and emergence period. Similar temperatures but more rainfall occurred in 2006 during the period between killing the cover crops and maize planting making the leaching of potential allelochemicals possible. However, only 13.20 mm of rainfall fell during the emergence period, limiting the absorption of allelochemicals which could explain the similarity in emergence percentages.

Relatively similar amounts of cover crop residues were left on the soil in 2005 and 2006, but significantly more maize seedlings emerged in 2006, compared to 2005. Warm, moist climatic conditions prevailed during the decomposition period in 2005 and 2006, probably increasing the decomposition of residues and the availability of allelochemicals. Warm and dry conditions occurred during germination and emergence in 2006, which might have reduced the availability of allelochemicals and thereby reducing the possibility of a reduction in maize emergence. In contrast, conditions in 2005 were cool and moist, which could have exposed the emerging seedlings to stressful conditions and putative allelochemicals, resulting in a significant reduction in the number of seedlings that emerged.

4.3 Maize growth

In the present study, the possibility that differences in soil water content were responsible for growth differences is small, as seedlings growing in the non-residue treatments had higher dry weights compared to the residue treatments in spite of the former having generally lower soil moisture levels. The soil water moisture levels between the weeds and annual ryegrass treatments were similar, but maize seedlings were less suppressed by the weed residues than by residues of annual ryegrass. Maize seedling growth could have been reduced by possible lower soil temperatures due to the presence of residues on the soil surface. The soil temperature under the weed residues could have possibly been higher than the cover crop residues due to the lower amount of biomass present. Both cover crop species had higher amounts of biomass present and, due to their slow decomposition residues would have been present for a longer period (Reddy 2001; Fourie *et al.,* 2001) reducing the maize growth for longer.

The residues in the current study were not incorporated and additional N was applied at planting, thereby reducing the probability that N immobilization could have suppressed growth. According to Kuo and Jellum (2002), the growth of the main crop is mainly dependant on the available N and subsequent uptake and less on the cover crop species. N mineralization is dependent on soil moisture, temperature, soil pH, the amount of available N in the soil and the C:N ratio of the residues (Kuo & Jellum 2002). The C:N ratio of cereals is mostly dependant on the time of desiccation. If killing the cover crops occurs at a late growth stage, the material would contain more carbon and the ratio could exceed 30:1, which is higher than 25:1, at which stage N immobilization would occur (Reeves 1994). In addition, N immobilization is generally greater if the residues are incorporated (Smith & Sharpley 1990). Applying N at the beginning of the growth of the main crop can reduce the initial N deficiency (Hairston *et al*., 1987; Reeves *et al*., 1990).

Another contributing factor to the difference in maize growth amongst the treatments could have been the interference from *C. esculentus* in the intra- and inter-row maize planting lines. Results from the present study, however, indicated that interference from *C. esculentus* did not have the expected impact on maize growth from planting to 14 DAE. Higher numbers of *C. esculentus* plants were sampled in the weed residue treatment compared to the cover crop treatments, yet maize seedlings had higher seedling weights in the former treatment. This is in contrast to Stoller *et al*. (1979) who found that if *C. esculentus* is not controlled from the beginning in maize production, the yield reduction can be as high as 41%, with an initial infestation of 1200 shoots m^{-2}.

Hall *et al.* (1992) stated that weed competition from the three-leaf maize growth stage reduces leaf area and expansion, thereby reducing the photosynthetic area, with a subsequent impact on growth. Reinhardt and Bezuidenhout (2001) found that maize emergence was retarded in soil where *C. esculentus* tubers were planted 28 days before planting of the crop, irrespective of whether the weeds were removed at planting. Maize emergence was not affected when the maize seeds and *C. esculentus* tubers were planted at the same time (Reinhardt & Bezuidenhout 2001).

It is possible that from 14 DAE, competition from *C. esculentus* and the presence of putative allelochemicals, both from the two cover crops and *C. esculentus,* could have been responsible for the differences in maize growth. No weed control measures were applied to the residue treatments giving rise to unlimited *C. esculentus* growth. Without adequate control, *Cyperus rotundus* (purple nutsedge) tubers increased from 0.66 tubers m^2 to 1260 tubers m^2 over two seasons increasing the competitive ability of the weed (Wang *et al*., 2008). Morales-Payan *et al.* (2003) reported a 34% reduction in tomato shoot dry weight through interference of *C. esculentus* while soyabean yields were reduced by up to 34% from *C. esculentus* interference (Nelson & Smoot 2010). Aqueous foliage extracts of immature *C. esculentus* plants (5% m/v) and tuber extracts (2% m/v) significantly inhibited germination of lettuce (*Lactuca sativa*) seeds (Reinhardt & Bezuidenhout 2001).

4.3 **C. esculentus** ***growth***

Over the three sampling stages employed in the present study, significantly higher numbers of *C. esculentus* material was sampled in the intra-row maize planting rows than in the inter-row lines. Reasons for this could be the sprouting of *C. esculentus* tubers after soil disturbance during maize planting and the absence of residues in the intra-row lines not presenting a physical barrier to *C. esculentus* growth. The weed residue treatment had the lowest quantity of residues on the soil surface compared to the two cover crop species. This could explain the higher *C. esculentus* dry weight measured in this treatment, both in the intra- and inter-row planting lines, thus supporting the conclusion of Liebl *et al.* (1992) that, compared with cover crops, annual weed residues do not suppress weed growth adequately. Various authors pointed out that residues which are left on the soil surface suppress weed growth due to the physical constraint (Teasdale & Mohler 2000; Dhima *et al.,* 2006), this despite the fact that *C. esculentus* leaves have sharp tips that could penetrate hard surfaces (Stoller & Woolley 1983; Stoller & Sweet 1987). Due to its C4 photosynthesis pathway, *C. esculentus* growth could have been restricted in the inter-row maize planting lines by the limitation of light reaching the soil surface under the residues. Li *et al.* (2001) found that the number of tubers, rhizome branching and total leaf area of *C. esculentus* were reduced by shading.

Although both cover crop species had relatively similar quantities of dry matter yield, annual ryegrass residues had a profound suppression on *C. esculentus* growth 14 DAE whereafter the effect declined. It is possible that annual ryegrass residues could have prevented light from reaching the soil surface, creating a period of low light regime. Maize, hemp (*Cannabis sativa*) and barley reduced secondary shoot density, leaf biomass and tuber production of *C. esculentus* with the biggest reduction by hemp which also created a low light regime (Lotz *et al.*, 1991). Burgos and Talbert (1996b) found that residues of annual ryegrass suppressed total weed biomass by 71% compared to no cover crop and ascribe the effect to a physical interference and allelopathy. Results from work done by Breland (1996) suggest that reduced radish (*Raphanus sativus*) germination was mainly caused by phytotoxic compounds in fresh annual ryegrass residues.

In contrast, the suppression of *C. esculentus* growth by stooling rye residues was more gradual and lasted for a longer period. Comparing the cover crop residues with one another, annual ryegrass residues were denser, with a fine structure, while stooling rye was less dense and coarser. The longer suppression effect of stooling rye on *C. esculentus* growth could possibly be due to the longer decomposition period of the coarser stooling rye compared to the annual ryegrass. This is similar to results from Masiunas *et al.* (1995) and Reddy (2001) who reported that the decomposition of stooling rye residues were slow as residues were still remaining 6–8 weeks after desiccation which could have explained why stooling rye residues suppressed *C. esculentus* growth more than annual ryegrass at 3, 6 and 9 weeks after planting soyabean. An autumn-sown rye cover crop reduced *C. esculentus* growth by 81% compared to conventional methods and Ormeño-Núñez *et al.* (2008) concluded that it was due to either the shading from the rye mulch or the possible allelochemicals released. However, both Koger *et al.* (2002) and Burgos and Talbert (1996a) reported that stooling rye residues had no suppressive effect on *C. esculentus* growth.

5. CONCLUSIONS

This study showed that both stooling rye and annual ryegrass residues suppressed *C. esculentus* establishment and density during the early growth stages of maize, possibly due to the release of putative allelochemicals from the cover crop residues. However, the influence of the cover crop residues was non-selective as it also reduced maize plant populations and fitness. This, together with competition for growth resources by *C. esculentus* later in the growing season, reduced maize height and yield. Manipulation of the cover crop killing date could influence the release of allelochemicals from the residues and alter their concentration in the root zone, thereby, either minimizing the effect on crop growth but compromise weed suppression or increase the suppression of crop and weed growth. Cover crops would have to be used in combination with chemical control methods for adequate weed suppression during the entire crop growing season due to their limited residual period. However, weed density could influence herbicide application time and method by minimizing application to planting rows only or the possibility of using only post-emergence instead of pre- and post-emergence herbicides.

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APPENDIX A Statistical analysis

TABLE 1 ANOVA for the cover crop dry matter yields over five seasons

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	4	364.27	91.07	31.90	<0.001
Residual (a)	15	13.18	0.88	0.31	
Season.Block.Treatment Stratum					
Treatment	2	27.37	18.68	1.28	NS
Control vs Cover crops	1	34.68	34.68	1.43	NS
Season.Treatment	8	116.69	14.59	5.11	<0.001
Season.Control vs Cover crops	4	97.25	24.31	8.52	<0.001
Residual (b)	30	85.64	2.86		
TOTAL	**59**	**617.15**			

*Residual (b) is greater than residual (a) resulting in a change in the VR values.

TABLE 2 ANOVA for the final emergence percentages of maize in the weeds and the residues of annual ryegrass and stooling rye

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	3	12125.90	4042.00	27.82	<0.001
Residual	12	1743.40	145.30	1.36	
Season.Block.Cover Stratum					
Cover	4	8897.50	2224.40	20.81	<0.001
Cover: Yes vs No	1	6375.40	6375.40	59.63	<0.001
Control vs Cover crops	1	2227.90	2227.90	20.84	<0.001
Stooling rye vs Ryegrass	1	277.80	277.80	2.60	0.114
Hand vs Herbicide	1	16.40	16.40	0.15	0.697
Season.Cover	12	1579.40	131.60	1.23	0.290
Season. Cover: Yes vs No	3	1084.60	361.50	3.38	0.026
Season. Control vs Cover crops	3	325.90	108.60	1.02	0.394
Season. Stooling rye vs Ryegrass	3	153.50	51.20	0.48	0.699
Season. Hand vs Herbicide	3	15.50	5.20	0.05	0.986
Residual	48	5131.70	106.90		
TOTAL	**79**	**29478.00**			

TABLE 3 Non-linear regression analysis for the of maize dry weight gain over time during four growing seasons

Source of variation	DF	SS	MS	VR	F pr
Regression	10	4392205	4392205	45.50	<0.001
Residual	69	666109	9654		
TOTAL	**79**	**5058314**	**64029**		
Estimates of parameter					
Parameter				**Estimate**	**SE**
Annual ryegrass				1.08	0.00724
B Treatment Weeds				8.42	
A Treatment Weeds				6.25	
B Treatment Hand				18.12	
A Treatment Hand				-18.52	
B Treatment Herbicide				20.74	
A Treatment Herbicide				-44.79	
B Treatment Stooling rye				5.06	
A Treatment Stooling rye				13.73	
B Treatment Annual ryegrass				2.54	
A Treatment Annual ryegrass				7.83	

Standard error of observations 98.3

Adjusted $R^2 = 84.9$

TABLE 4 Linear regression analyses for the maize dry weight gain over time during four growing seasons

Source of variation	DF	SS	MS	VR	F pr
Regression	9	370.02	41.11	145.04	<0.001
Residual	70	19.84	0.28		
TOTAL	**79**	**389.86**	**4.94**		
Estimates of parameter					
Parameter		**Estimate**	**SE**	**T(70)**	**F pr**
Constant		0.29	0.21	1.37	0.176
Days		0.10	0.01	13.03	<0.001
Treatment Stooling rye		0.12	0.30	0.40	0.691
Treatment Herbicide		0.07	0.30	0.23	0.816
Treatment Hand		0.11	0.30	0.37	0.713
Treatment Weeds		0.14	0.30	0.47	0.639
Days.Treatment Stooling rye		0.01	0.01	1.33	0.186
Days.Treatment Herbicide		0.04	0.01	3.41	0.001
Days.Treatment Hand		0.04	0.01	3.29	0.002
Days.Treatment Weeds		0.02	0.01	2.02	0.048

Standard error of observations 0.532

Adjusted $R^2 = 94.3$

TABLE 5 ANOVA for the *C. esculentus* dry weight gain in the intra-row maize planting lines at 16 days after maize emergence in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	1	1.74	1.74	6.07	0.049
Residual	6	1.72	0.29	1.98	
Season.Block.Treatment Stratum					
Treatment	2	1.10	0.55	3.81	0.052
Control vs Cover crops	1	1.07	1.07	7.42	0.018
Season.Treatment	2	0.23	0.12	0.81	0.469
Season.Control vs Cover crops	1	0.23	0.23	1.61	0.228
Residual	12	1.74	0.15		
TOTAL	**23**	**6.53**			

TABLE 6 ANOVA for the *C. esculentus* dry weight gain in the intra-row maize planting lines at 28 days after maize emergence in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	1	0.75	0.75	1.09	0.336
Residual	6	4.10	0.68	1.50	
Season.Block.Treatment Stratum					
Treatment	2	1.69	0.84	1.85	0.199
Control vs Cover crops	1	0.93	0.93	2.04	0.178
Season.Treatment	2	0.19	0.10	0.21	0.814
Season.Control vs Cover crops	1	0.04	0.04	0.08	0.786
Residual	12	5.47	0.46		
TOTAL	**23**	**12.19**			

TABLE 7 ANOVA for the *C. esculentus* dry weight gain in the intra-row maize planting lines at 41 days after maize emergence in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	1	1.31	1.31	1.23	NS*
Residual (a)	6	1.67	0.28	0.26	
Season.Block.Treatment Stratum					
Treatment	2	3.00	1.50	1.42	0.280
Control vs Cover crops	1	1.15	1.15	1.08	0.318
Season.Treatment	2	0.04	0.02	0.02	0.981
Season.Control vs Cover crops	1	0.01	0.01	0.01	0.939
Residual (b)	12	12.69	1.06		
TOTAL	**23**	**18.71**			

*Residual (b) is greater than residual a resulting in (a) change in the VR value. Therefore it is not significant.

TABLE 8 ANOVA for the *C. esculentus* dry weight gain in the inter-row maize planting lines at 16 days after maize emergence in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	1	0.24	0.24	1.60	0.253
Residual	6	0.91	0.15	1.95	
Season.Block.Treatment Stratum					
Treatment	2	1.45	0.72	9.28	0.004
Control vs Cover crops	1	1.38	1.38	17.72	0.001
Season.Treatment	2	0.37	0.19	2.39	0.134
Season.Control vs Cover crops	1	0.35	0.35	4.47	0.056
Residual	12	0.94	0.08		
TOTAL	**23**	**3.91**			

TABLE 9 ANOVA for the *C. esculentus* dry weight gain in the inter-row maize planting lines at 28 days after maize emergence in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	1	0.05	0.05	0.29	0.610
Residual	6	0.96	0.16	1.63	
Season.Block.Treatment Stratum					
Treatment	2	1.57	0.79	8.05	0.006
Control vs Cover crops	1	0.55	1.55	15.88	0.002
Season.Treatment	2	0.16	0.08	0.80	0.470
Season.Control vs Cover crops	1	0.03	0.03	0.34	0.569
Residual	12	1.17	0.10		
TOTAL	**23**	**3.91**			

TABLE 10 ANOVA for the *C. esculentus* dry weight gain in the inter-row maize planting lines at 41 days after maize emergence in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	1	1.51	1.51	2.67	NS*
Residual (a)	6	1.73	0.29	0.51	
Season.Block.Treatment Stratum					
Treatment	2	4.04	2.02	3.57	0.061
Control vs Cover crops	1	3.55	3.55	6.26	0.028
Season.Treatment	2	0.94	0.47	0.83	0.459
Season.Control vs Cover crops	1	0.81	0.81	1.44	0.254
Residual (b)	12	6.80	0.57		
TOTAL	**23**	**15.03**			

*Residual (b) is greater than residual a resulting in (a) change in the VR values. Therefore it is not significant.

TABLE 11 ANOVA for maize plant heights in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	3	738071.00	246024.00	2.44	0.115
Residual	12	1211538.00	100961.00	4.44	
Season.Block.Cover Stratum					
Cover	4	3010147.00	752537.00	33.08	<0.001
Cover: Yes vs No	1	2598326.00	2598326.00	114.21	<0.001
Control vs Cover crops	1	174555.00	174555.00	7.67	0.008
Stooling rye vs Annual ryegrass	1	233149.00	233149.00	10.25	0.002
Hand vs Herbicide	1	4118.00	4118.00	0.18	0.672
Season.Cover	12	704655.00	58721.00	2.58	0.010
Season. Cover: Yes vs No	3	432047.00	144016.00	6.33	0.001
Season. Control vs Cover crops	3	91266.00	30422.00	1.34	0.273
Season. Stooling rye vs Ryegrass	3	130739.00	43580.00	1.92	0.140
Season. Hand vs Herbicide	3	50604.00	16868.00	0.74	0.533
Residual	48	1092049.00	22751.00		
TOTAL	**79**	**6756461.00**			

TABLE 12 ANOVA for maize yields in the weeds, annual ryegrass and stooling rye residues

Source of variation	DF	SS	MS	VR	F pr
Season. Block Stratum					
Season	3	19.75	6.58	0.90	0.471
Residual	12	88.12	7.34	3.92	
Season.Block.Cover Stratum					
Cover	4	380.12	95.03	50.73	<0.001
Cover: Yes vs No	1	363.06	363.06	193.80	<0.001
Control vs Cover crops	1	4.24	4.24	2.262	0.139
Stooling rye vs Annual ryegrass	1	11.91	11.91	6.36	0.015
Hand vs Herbicide	1	0.91	0.91	0.49	0.489
Season.Cover	12	73.10	6.09	3.25	0.002
Season. Cover: Yes vs No	3	41.59	13.86	7.40	<0.001
Season. Control vs Cover crops	3	24.49	8.16	4.36	0.009
Season. Stooling rye vs Ryegrass	3	4.91	1.64	0.87	0.461
Season. Hand vs Herbicide	3	2.12	0.71	0.38	0.770
Residual	48	89.92	1.87		
TOTAL	**79**	**651.01**			