Table 12. **Treatment effects on relative yield, crown and root rot severity ratings and root lodging 140 DAP, and on earthworm counts, soil temperature and moisture content 135 DAP.**

Treatment♦	% Yield	Crown Rot Severity	Root Rot Severity	Worm Count Per m²	Soil Temp °C	Soil Moist. %	Lodged Plants/ Plot
SR	100	1.54	2.58	35	24.7	21.8	9
C	98	1.79	2.92	45	24.0	24.6	7
AN+OB	97	1.67	2.79	5	25.5	14.6	43
BO	96	1.33	2.63	47	23.4	25.2	11
CAN	95	1.54	2.58	27	24.6	23.3	23
ECO	94	2.21	3.17	43	25.0	27.2	22
CR	93	1.96	2.96	20	24.2	24.9	21
MBP	93	1.42	2.42	19	23.1	17.3	78
OB	93	1.75	2.79	41	24.9	24.7	15
TP	90	1.96	2.88	12	23.9	19.7	95
ANM	89	1.58	2.71	7	26.0	14.3	67
ANP	89	1.63	2.79	14	24.0	20.7	20
GLIO	89	2.04	3.13	33	23.7	25.2	19
FP	83	2.17	3.13	43	24.0	26.0	11
FM	83	1.88	3.00	17	24.0	18.7	29
CRI	82	2.08	3.04	13	28.4	13.4	138
BF	69	2.88	3.54	0	25.0	15.0	57
MBM	64	2.30	3.13	3	25.9	12.9	176
TM	62	2.75	3.50	9	26.0	9.6	177
LSD (0.05)	10	0.51	0.29	19	2.3	4.6	29

♦ See Table 2 for description of treatments.

Soil, seedling and leaf analyses (Tables 14, 15 & 16) provided little information to suggest that the rotational effects discussed were nutrition related. However, it is interesting to note that the two lowest carbon contents recorded in the soil 28 DAP (Table 14) were those in the BF and FM treatments and that these were significantly lower than those recorded in the control (C) and stooling rye (SR) plots.

Table 13. **Treatment effects in four seasons as probably influenced by moisture availability (see Table 3).**

Treatment	2006/2007	2007/2008	2008/2009	2009/2010
Anhydrous ammonia without extra cover	14880	17390	13120	15450
Anhydrous ammonia with extra cover	-	17890	13980	15650
Anhydrous ammonia without extra cover, plus Fungimax and Organoboost	-	-	12730	15200
Bare fallow with maize residues removed	-	-	11340	12450
Black oat cover crop in winter	13210	15400	13400	14110
Control with wheat as winter crop	13820	14370	13470	14070
Canola cover crop in winter	13500	16060	13560	14320
Crambe cover crop in winter	13250	15470	13500	14800
Ripped as for anhydrous, but without gas	-	17010	12020	13230
Winter wheat with Eco-T applied to maize	13620	15490	13410	14040
Winter wheat with Extrasol applied to maize	13530	15130	-	-
Maize fallow without extra cover	12270	15150	11650	12640
Maize fallow with extra cover	-	14820	12730	14110
Methyl bromide without extra cover	12540	16110	11810	13130
Methyl bromide with extra cover	-	17180	13270	14640
Winter wheat with nematicide applied to maize	11750	15000	-	-
Winter wheat with Fungimax and Organoboost applied to maize	12860	15790	12890	14110
Winter wheat with Spin+Webstarter applied to maize	13570	14940	-	-
Soya fallow without extra cover	12390	-	-	-
Soya-wheat-maize	13430	-	-	-
Tilled as for MB fumigation, but without extra cover	12900	16190	11710	12780
Tilled as for MB fumigation with extra cover	-	16580	13190	14220
Stooling rye cover crop in winter	-	-	13340	14370
LSD (0.05)	671	928	1084	802

Table 14. **Treatment effects on soil properties 28 DAP.**

Soil Test	TREATMENT♦																		
	ANM	ANP	ANM + OB	BF	BO	C	CAN	CR	CRI	ECO	FM	FP	MBM	MBP	GLIO	OB	SR	TM	TP	LSD (0.05)
P (mg/L)	92	84	74	64	50	68	60	55	85	91	77	68	55	48	61	55	55	60	60	31
K (mg/L)	190	242	172	168	182	164	216	168	178	198	192	188	138	188	145	153	229	149	165	65
Ca (mg/L)	1171	1131	1103	967	1151	1148	1046	1020	1259	1130	1028	1056	1187	1114	1112	998	955	1138	1160	193
Mg (mg/L)	195	195	197	156	206	197	178	163	224	190	177	175	220	206	185	180	169	181	224	40
Al+H (cmol/L)	0.12	0.13	0.08	0.09	0.07	0.07	0.11	0.07	0.05	0.10	0.05	0.11	0.05	0.07	0.06	0.09	0.11	0.06	0.05	0.05
Acid Sat. (%)	1.7	1.3	1.0	1.3	1.0	1.0	1.7	1.0	0.7	1.3	0.7	2.0	0.7	1.0	1.0	1.3	1.3	1.0	0.7	0.81
pH (KCℓ)	5.0	5.0	5.0	4.7	4.8	4.8	4.6	4.7	5.2	4.7	4.8	4.6	5.0	4.7	4.9	4.7	4.7	4.8	5.0	0.3
Zn (mg/L)	9	8	7	7	7	9	7	6	8	9	9	6	7	7	7	6	9	6	7	2
Cu (mg/L)	4	4	4	4	4	4	4	3	4	4	4	3	3	4	3	3	4	4	3	1
Mn (mg/L)	34	34	29	26	34	30	32	27	29	32	31	21	34	36	27	26	34	38	36	9
C (%)	1.80	1.70	1.70	1.62	1.65	1.92	1.78	1.67	1.87	1.80	1.62	1.80	1.77	1.73	1.63	1.70	1.87	1.70	1.83	0.25

♦ **See Table 2 for description of treatments.**

Table 15 Treatment effects on whole plant composition 28 DAP.

Plant Content	TREATMENT◆																			
	ANM	ANP	ANM + OB	BF	BO	C	CAN	CR	CRI	ECO	FM	FP	MBM	MBP	GLIO	OB	SR	TM	TP	LSD (0.05)
N (%)	4.6	4.9	4.8	4.2	4.6	4.6	4.6	4.6	4.6	4.8	4.6	4.5	4.6	4.5	4.6	4.7	4.8	4.3	4.4	0.28
P (%)	0.40	0.40	0.44	0.34	0.43	0.43	0.39	0.42	0.42	0.43	0.39	0.36	0.40	0.37	0.44	0.45	0.45	0.41	0.39	0.05
K (%)	2.86	3.99	2.72	3.40	4.42	4.75	4.72	4.72	2.25	4.85	3.44	4.07	3.41	3.92	3.98	4.28	4.97	3.25	3.73	0.78
Ca (%)	0.58	0.55	0.55	0.53	0.58	0.50	0.55	0.47	0.68	0.54	0.54	0.51	0.60	0.54	0.60	0.50	0.51	0.62	0.63	0.11
Mg (%)	0.48	0.44	0.49	0.45	0.46	0.40	0.43	0.36	0.67	0.42	0.46	0.39	0.50	0.43	0.51	0.39	0.40	0.58	0.60	0.11
S (%)	0.25	0.27	0.27	0.24	0.25	0.26	0.27	0.26	0.27	0.26	0.25	0.25	0.27	0.25	0.25	0.25	0.26	0.25	0.28	NS
Na (mg/kg)	198	311	228	585	821	552	552	259	236	243	249	273	1072	379	211	561	732	110	334	681
Zn (mg/kg)	51	56	47	37	44	57	48	47	47	53	42	38	46	42	46	45	47	40	39	9
Cu (mg/kg)	10	9	11	9	10	9	10	9	12	8	9	7	12	11	10	9	10	10	9	3
Mn (mg/kg)	125	97	100	64	68	67	60	73	81	69	66	61	75	80	70	71	61	68	67	17
B (mg/kg)	10	14	10	9	9	12	13	9	10	10	11	9	10	7	12	13	11	9	8	5

◆ See Table 2 for description of treatments.

Table 16. Treatment effects on leaf composition 71 DAP.

Plant Content	TREATMENT♦																			
	ANM	ANP	ANM + OB	BF	BO	C	CAN	CR	CRI	ECO	FM	FP	MBM	MBP	GLIO	OB	SR	TM	TP	LSD (0.05)
N (%)	3.65	3.67	4.00	3.44	3.00	3.58	3.28	3.48	3.84	3.38	3.44	3.22	3.38	3.57	3.31	3.46	3.82	3.23	3.31	0.56
P (%)	0.32	0.34	0.35	0.32	0.30	0.32	0.31	0.36	0.39	0.32	0.32	0.29	0.31	0.35	0.30	0.32	0.32	0.32	0.32	0.05
K (%)	2.03	2.33	1.90	2.07	2.20	2.13	2.21	2.61	2.15	2.01	1.98	2.13	1.85	2.44	2.04	2.17	1.97	1.87	2.24	0.50
Ca (%)	0.54	0.56	0.60	0.62	0.54	0.57	0.54	0.63	0.73	0.62	0.63	0.54	0.63	0.64	0.54	0.57	0.64	0.57	0.61	0.12
Mg (%)	0.28	0.25	0.32	0.38	0.33	0.31	0.29	0.33	0.44	0.33	0.36	0.27	0.36	0.36	0.32	0.31	0.30	0.38	0.33	0.07
S (%)	0.23	0.21	0.22	0.22	0.21	0.25	0.21	0.23	0.20	0.22	0.22	0.21	0.24	0.26	0.22	0.25	0.26	0.22	0.20	NS
Na (mg/kg)	79	87	56	105	131	153	92	154	104	70	66	152	139	111	107	127	122	136	124	87
Zn (mg/kg)	30	28	29	15	19	20	15	21	23	23	16	18	17	20	18	20	18	18	19	7
Cu (mg/kg)	11	11	13	10	8	10	9	10	10	10	10	9	10	10	9	10	11	9	9	2
Mn (mg/kg)	169	160	172	86	70	95	80	106	95	95	86	77	100	118	81	94	91	84	88	37
B (mg/kg)	5	7	7	4	4	3	5	5	6	5	4	3	5	5	4	5	4	5	4	1.8

♦ **See Table 2 for description of treatments.**

Crown and root rots

Treatment effects on crown and root rots of maize 64 and 140 DAP are shown in Tables 11 and 12. At 64 DAP (Table 11), maize planted after canola (CAN), crambe (CR), black oat (BO), fallow (FM) and stooling rye (SR) had significantly less crown and root rot than maize planted after wheat (C) or the bare fallow (BF). The lowest crown and root rot severities were recorded in maize planted after crambe and canola, where the relative yields were 98 % and 97 %, respectively, while the highest disease incidences were recorded in maize planted after wheat (C) and bare fallow (BF), where the relative yields were 86 and 80%, respectively.

By 140 DAP, however, the situation had changed quite markedly (Table 12). Roots of maize planted after canola, stooling rye and black oat continued to be significantly less diseased than maize planted after wheat or bare fallow, but by this stage the crambe and fallow (FM) plots were no better than the control in terms of disease severity and the crowns and roots of plants grown in bare fallow (BF) plots were significantly more diseased than those grown in any other treatment (Fig. 3). The relative yield of the bare fallow treatment was 69% compared to the relative yield of the canola (95%), stooling rye (100%) and black oat (96%). This strongly suggests that root diseases were a primary yield-limiting factor.

Crop rotation can significantly impact on soilborne diseases, and has been recommended as a control measure against soilborne diseases of maize and small grains (Williams & Schmitthenner, 1963). Kruger & Speakman (1997) in Germany, found that monoculture maize led to a high level of root rot, whereas disease levels were lower in rotations, even those containing a high proportion of cereals. According to Govaerts *et al.* (2007), rotation of maize and wheat decreased the incidence of maize root rot up to 30%, but unfortunately they did not determine which pathogens were involved. Information on the effect of crop rotation on root rot of maize is unfortunately very limited in South Africa. Smit *et al.* (1997) studied the effect of monoculture maize and rotation with soyabean, sunflower and groundnut on the incidence of maize root rot. According to them the effect of crop rotation was inconsistent and they concluded that "crop rotation may have a long-term effect on soil fungus populations

(a) Roots of bare fallow (BF) maize.

(b) Crowns of bare fallow (BF) maize.

Fig 3. Roots (a) and crowns (b) of bare fallow (BF) maize 140 DAP.

Fungi associated with crowns and roots

The highest incidences of *Acremonium* spp. were recorded on maize planted after canola (CAN) and the lowest after bare fallow (BF), wheat (C), crambe (CR), stooling rye (SR) and fallow without cover (FM) (Table 17).

Incidences of *F. graminearum* in crowns of maize planted after the different rotation crops did not differ significantly (Table 18). This confirms results obtained during the previous season. However, incidences of *F. graminearum* in roots of maize planted after bare fallow, canola, crambe and fallow without cover were significantly lower than in roots of maize planted after black oat, wheat and stooling rye (Table 17). Incidences of the fungus in crowns and roots of maize planted after the different rotation crops did not increase significantly as the season progressed (Tables 6 and 17). These results are similar to results obtained during the previous season, except for the low incidence of the fungus on roots of maize planted after canola. The high incidences of the fungus on maize planted after black oat, wheat and stooling rye shows clearly that grass crops are hosts of this pathogen. As already mentioned in previous reports, the high incidences of *F. graminearum* in maize crowns and roots in our study are not unexpected, since wheat was the preceding crop for many of the treatments. Many researchers have found that *F. graminearum* increases under wheat-maize rotations (Schaafsma *et al.*, 2005). This fungus is also regarded as an aggressive pathogen of maize roots by certain researchers (Miller, 1964; Kruger & Speakman, 1997). Kruger & speakman (1997) in Germany, found in crop rotation studies which included maize and other cereals that the highest incidences of *F. graminearum* were recorded after rotation with black oat and wheat, and Fernandez & Dos Santos (1992) reported that the percentage incidence of *F. graminearum* was similar among residues of wheat, barley, oat and black oat.

There were no significant differences in the incidences of *F. oxysporum,* in crowns and roots of maize planted after the different rotation crops (Table 17). Although not significant, the incidences of *F. oxysporum* in roots of maize planted after bare fallow, canola, crambe and fallow without cover were higher than in roots of maize planted after black oat, stooling rye and wheat.

Contrary to the previous season, there were no significant differences in the incidences of *P. terrestris* in maize crowns and roots planted after the different rotation crops, and the incidences of the fungus did not significantly decrease from the first to the second sampling time (Table 6 and 17).

Phialophora spp. were not isolated from crowns of maize planted after the different rotation crops (Table 18). It is interesting to note that the highest incidences of these fungi in maize roots were recorded when maize was planted after bare fallow and fallow without cover (Tables 17 and 18).

Contrary to the previous season, incidences of *Trichoderma* spp. in crowns of maize planted after the different crops differed significantly, with the highest incidences recorded for maize planted after black oat (Table 17). There were, however, no significant differences in the incidences of *Trichoderma* spp. in roots of maize planted after the different crops (Table 17). This is also different to the previous season when significant differences were recorded and the highest incidences of *Trichoderma* spp. in roots were recorded in maize planted after black oat, stooling rye and wheat and the lowest for canola.

Similar to the previous season, there were no significant differences in the incidences of *Diplodia/Stenocarpella* spp. in crowns and roots of maize planted after the different crops (Table 17).

Table 17. Treatment effects on the incidence of fungal species in crowns and roots (means for 64 and 140 DAP).

Fungus[u]	PP[v]	Incidence (%)[x,y]																			LSD[z]
		ANM	ANP	ANM+OB	BF	BO	C	CAN	CR	CRI	ECO	FM	FP	MBM	MBP	GLIO	OB	SR	TM	TP	
Acrem	**C**	0.8d	0.8cd	0.0d	1.7b-d	5.0ab	0.0d	8.3a	1.7cd	0.8cd	1.7b-d	0.0d	4.2bc	0.0d	4.2bc	0.8cd	2.5b-d	1.7b-d	0.0d	4.2bc	3.99
	R	0.0a	0.0a	0.0a	0.0a	0.8a	0.8a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	0.0a	0.0a	0.0a	NS
Dipl/Steno	**C**	0.0a	0.8a	1.7a	0.8a	0.0a	0.8a	3.3a	0.0a	0.0a	0.0a	1.7a	4.2a	0.0a	0.8a	0.8a	0.0a	0.0a	0.8a	0.0a	NS
	R	0.0a	0.0a	0.8a	0.8a	0.0a	0.0a	0.0a	0.8a	0.8a	0.0a	2.5a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.8a	0.0a	NS
F.equi	**C**	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.8a	NS
	R	0.8a	3.3a	1.7a	0.0a	3.3a	0.0a	0.0a	0.0a	0.8a	1.7a	0.0a	0.8a	0.8a	0.0a	0.0a	0.8a	2.5a	0.8a	1.7a	NS
F.gram	**C**	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.
	R	10.0e-g	10.8d-g	6.7fg	5.0g	25.8ab	25.0a-c	7.5fg	7.5fg	10.0e-g	20.0b-d	11.7g-g	12.5d-g	14.2d-g	12.5d-g	30.8a	19.2b-e	19.2b-e	10.0e-g	15.8c-f	9.57
F.oxy	**C**	5.0a	4.21	2.5a	8.3a	3.3a	5.8a	9.2a	3.3a	5.0a	6.7a	8.3a	10.0a	5.8a	5.0a	4.2a	6.7a	6.7a	12.5a	8.3a	NS
	R	40.8a	43.3a	43.3a	53.3a	37.5a	35.0a	55.8a	43.3a	46.7a	42.5a	50.8a	53.3a	29.2a	35.8a	25.8a	40.0a	38.3a	45.0a	45.0a	NS
F. prol	**C**	0.8a	0.8a	1.7a	0.0a	0.8a	2.5a	0.0a	1.7a	1.7a	1.7a	3.3a	1.7a	2.5a	0.8a	1.7a	0.8a	0.8a	0.0a	3.3a	NS
	R	0.8a	0.0a	1.7a	0.8a	0.0a	1.7a	0.0a	0.0a	1.7a	0.8a	0.0a	0.8a	3.3a	0.0a	0.8a	0.8a	2.5a	0.0a	0.0a	NS
F.sol	**C**	0.0a	0.0a	1.7a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	0.0a	0.8a	4.2a	0.0a	NS
	R	4.2a	1.7a	5.0a	5.0a	2.5a	4.2a	0.8a	4.2a	2.5a	5.0a	5.8a	5.8a	10.0a	5.0a	4.2a	1.7a	5.0a	3.3a	3.3a	NS
F.subg	**C**	8.3a	9.2a	12.5a	3.3a	15.0a	5.0a	10.8a	15.0a	13.3a	12.5a	6.7a	8.3a	10.8a	5.8a	8.3a	5.8a	18.3a	7.5a	2.5a	NS
	R	1.7a	5.8a	5.0a	0.0a	5.8a	5.0a	7.5a	5.0a	2.5a	6.7a	1.7a	5.8a	7.5a	3.3a	5.8a	6.7a	5.0a	8.3a	4.2a	NS
Phia	**C**	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.	Inter.
	R	0.8a	5.0a	1.7a	1.7a	0.8a	0.8a	0.0a	0.8a	0.0a	0.0a	4.2a	1.7a	2.5a	1.7a	0.0a	1.7a	0.8a	1.7a	0.8a	NS
Pyren	**C**	3.3a	3.3a	1.7a	0.8a	0.0a	1.7a	0.0a	0.8a	0.0a	0.8a	0.0a	3.3a	2.5a	4.2a	0.8a	0.0a	0.0a	1.7a	0.0a	NS
	R	18.3a	4.2a	10.8a	10.8a	6.7a	5.0a	10.0a	9.2a	10.0a	1.7a	9.2a	4.2a	8.3a	10.0a	6.7a	2.5a	4.2a	3.3a	3.3a	NS
Pyth	**C**	0.0a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.8a	0.0a	0.0a	NS
	R	2.5ab	3.3a	0.0c	0.0c	0.0c	0.0c	1.7a-c	0.0c	0.0c	0.0c	0.0c	0.8bc	0.0c	0.0c	0.0c	0.0c	0.0c	0.8ba	2.5ab	1.77
Trich	**C**	1.7c	5.8bc	2.5c	2.5c	9.2b	2.5c	0.8c	2.5c	0.8c	5.0bc	4.2bc	1.7c	17.5a	5.8bc	3.3bc	3.3bc	2.5c	4.2bc	1.7c	5.98
	R	21.6a	27.5a	20.8a	21.7a	21.7a	27.5a	21.7a	20.0a	11.7	24.2a	20.8a	21.7a	41.7a	33.3a	31.7a	31.7a	23.3a	25.8a	19.2a	NS

[u] Acrem = *Acremonium* spp., Diplo/Steno = *Diplodia/Stenocarpella* spp., Fequi = *Fusarium equiseti*, Fgram = *Fusarium graminearum*, Foxys = *Fusarium oxysporum*, Fprol = *Fusarium proliferatum*, Fsola = *Fusarium solani*, Fsubg = *Fusarium subglutinans*, Phia = *Phialophora* spp., Pyren = *Pyrenochaeta terrestris*, Pyth = *Pythium* spp.,

Trich = *Trichoderma* spp.

[v] PP = Plant Part; C = Crown; R = Root.

[x] Means within a fungus, within a plant part followed by the same letter do not differ significantly (P = 0.05).

[y] See Table 1 for treatment descriptions.

[z] LSD = Least significant difference at P = 0.05.

Table 18. Interaction means for the effect of sampling time and treatments on the incidence of fungal species in crowns and roots

Fungus	PP[v]	ST[w]	Incidence (%)[xy]																			LSD[z]
			ANM	ANP	ANM+OB	BF	BO	C	CAN	CR	CRI	ECO	FM	FP	MBM	MBP	GLIO	OB	SR	TM	TP	
F.graminearum	C	1	1.7bc	0.0c	1.7bc	0.0c	1.7bc	3.3bc	0.0c	0.0c	0.0c	1.7bc	0.0c	1.7bc	0.0c	0.0c	0.0c	1.7bc	0.0c	0.0c	0.0c	4.51
		2	0.0c	1.7bc	3.3bc	3.3bc	1.7bc	0.0c	3.3bc	1.7bc	3.3bc	5.0b	0.0c	0.0c	1.7bc	0.0c	3.3bc	1.7bc	0.0c	15.0a	3.3bc	
Phialophora spp.	C	1	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	1.09
		2	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	1.7b	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	0.0c	3.3a	0.0c	

[v] PP = Plant Part; C = Crown; R = Root.

[w] ST = Sampling time; ST1 = 64 DAP, ST2 = 140 DAP.

[x] Means within a fungus, within a plant part followed by the same letter do not differ significantly (P = 0.05).

[y] See Table 1 for treatment descriptions.

[z] LSD = Least significant difference at P = 0.05.

Nematodes

At 64 DAP the total number of herbivores in the bare fallow (BF), black oat (BO), canola (CAN), crambe (CR), fallow (FM), and stooling rye (SR) treatments were more than in the maize after wheat (C) treatment (Table 8). In both the black oat and canola treatments, the population numbers of the bacterivores were significantly higher than that of the fungivores. These two treatments benefited bacterivores over fungivores. This increase in bacterivores is directly related to the rate of decomposition of different organic substrates or amendments (Pattison *et al.,* 2006). The incidence of the herbivores was higher than that of the beneficial nematodes in all the rotational treatments (Fig 2). This trend was also observed in the maize after wheat treatment (C). The structure of the beneficial nematodes was also influenced by the rotational treatments, as incidence of the bacterivores was higher in the maize after wheat treatment (Fig. 2). Since nematodes are aquatic animals, they do require free water for movement and survival. Low soil moisture usually restricts their movement. The theory is that in areas with fallow (low soil moisture and lack of a host plant) nematode populations will decline, except for species that can enter some kind of dormancy as a survival strategy (Shurtleaff & Averre, 2000). The lesion nematodes (*Pratylenchus* spp.) and also those belonging to the Hoplolaimidae found in the different treatments will be able to go in anhydrobiosis, either in the soil or within the dried roots of the previous season. These nematodes will thus be able to survive till the next crop is planted.

Microbial diversity and activity in soil

Results obtained reflect mainly the response of the fast-growing copiotrophic fraction of the soil microbial population as the Biolog EcoPlates reacted within 40-72 hours after inoculation. Copiotrophic organisms are inclined to be found in nutrient-rich environments, particularly with respect to carbon. Oligotrophic organisms, on the other hand, survive in much lower carbon concentrations.

Root exudate composition changes as maize seedlings mature, based on different nutritional requirements through different growth stages (Garland, 1996). Soil microbial populations in the rhizosphere also change accordingly, depending on their ability to utilise specific carbon sources (Garbeva *et al.*, 2004). No significant differences could be observed in either the number of different bacterial species, or the abundance of species within soil microbial communities within treatments over time (Table 19).

Table 19. Diversity Indices of soil microbial populations in rotational treatments 64 and 140 DAP.

Rotational Treatment	Shannon (H') 64 DAP ^{z}	Shannon (H') 140 DAP ^{z}	Evenness (E) 64 DAP ^{z}	Evenness (E) 140 DAP ^{z}
C	2.604^{abc}	2.756^{bc}	0.838^{a}	0.835^{a}
CAN	2.685^{abc}	2.742^{abc}	0.808^{a}	0.839^{a}
CR	2.480^{ab}	2.509^{abc}	0.824^{a}	0.817^{a}
BO	2.687^{abc}	2.629^{abc}	0.851^{a}	0.847^{a}
SR	2.789^{bc}	2.581^{abc}	0.840^{a}	0.840^{a}
BF	2.687^{abc}	2.360^{a}	0.852^{a}	0.794^{a}
FM	2.875^{c}	2.492^{abc}	0.845^{a}	0.848^{a}

^{z}Means within a column followed by the same letter do not differ significantly ($P = 0.05$).

According to the Shannon-Weaver diversity index, canola (CAN), crambe (CR) and control (C) treatments demonstrated a slight increase in the number of soil microbial species within the soil microbial community 140 DAP. Black oat (BO), stooling rye (SR), bare fallow (BF) and fallow (FM) treatments, on the other hand, demonstrated a decrease in number of soil microbial species (Table 19). Bare fallow (BF) treatments indicated a significantly lower number of microbial species, compared to the control (C) treatment 140 DAP.

Although no significant differences could be observed regarding species abundance within the soil microbial community, the general diversity of soil microbial communities is clearly inconsistent throughout the different rotational treatments, due to the effect of different root exudates present in soil from rotational crops (Garbeva *et al.*, 2004). A superior positive alteration, i.e. increased diversity, in soil microbial species variation could be observed in CAN treatments, whereas the contrary applied to BF treatments . The SR, FM, BO, and C treatments illustrated a more equally abundant variation in species variation, i.e. less variation in microbial populations between species, thus less dominance, suggesting a higher diversity 64 and 140 DAP (Magurran, 1988; Zak *et al.*, 1994). The "stability" in species variation in SR treatments, and FM, BO, and C treatments to a lesser extent, could also indicate a soil microbial population with the ability to cope with external soil disturbances.

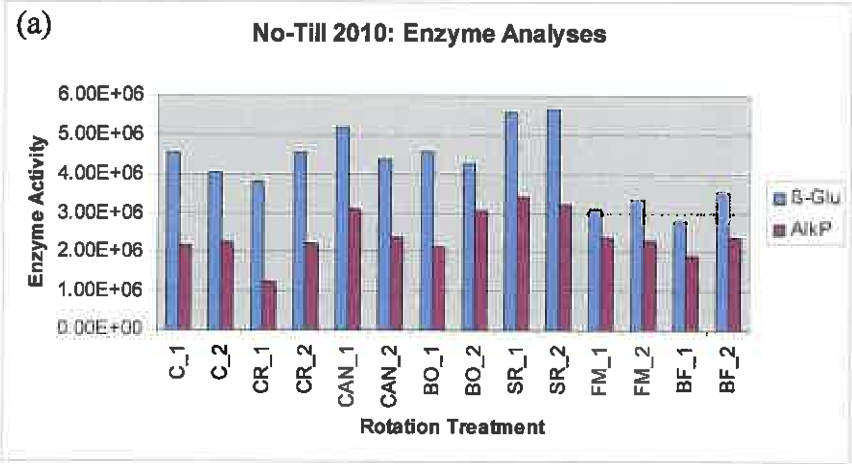
ß-glucosidase is one of the most widespread and prevalent soil enzymes (Tabatabai, 1994). Bandick & Dick (1999) found ß-glucosidase useful as an indicator of soil quality and the management effect of soils. Acid and alkaline phosphatases are a broad group of enzymes that are believed to fulfill critical roles in P cycles in soil ecosystems. The activity of these two phosphatase enzymes has been found to correlate with organic matter in various studies. Soil pH is one of the most important factors found to influence the rate of synthesis, release and stability of phosphatase (Tabatabai, 1994). Soil urease originates mainly from plants and microorganisms found as both intra- and extra-cellular enzymes. Urease stability and activity is affected by several factors, including cropping history, organic matter content, soil depth, soil amendments, heavy metals, and environmental factors.

Table 20. Average microbial enzyme activities in biocontrol plots 64 and 140 DAP.

Rotational Treatment	ß-Glucosidase^{z}	Alkaline Phosphatase^{z}	Urease^{z}
C	4.28E+06^{a}	2.20E+06^{a}	2.01E+01^{a}
CR	4.17E+06^{a}	1.72E+06^{a}	1.97E+01^{a}
CAN	4.79E+06^{ac}	2.74E+06^{ab}	2.40E+01^{a}
BO	4.41E+06^{a}	2.59E+06^{ab}	2.55E+01^{a}
SR	5.62E+06^{c}	3.32E+06^{b}	2.33E+01^{a}
BF	3.16E+06^{b}	2.12E+06^{a}	1.98E+01^{a}
FM	3.21E+06^{b}	2.31E+06^{ab}	2.21E+01^{a}

^{z}Means within a column followed by the same letter do not differ significantly (P = 0.05).

While no conclusive trend could be shown with data from only two samplings during the season, it is unmistakable that bare fallow (BF), fallow (FM) and crambe (CR) treatments illustrated overall reduced enzyme activity, whereas the stooling rye (SR), canola (CAN) and black oat (BO) illustrated overall higher enzyme activity compared to the other treatments (Table 20). ß-Glucosidase activity for BF, FM, and SR treatments differed significantly from all the other rotational treatments. ß-Glucosidase and alkaline phosphatase activity for SR differed statistically significantly from the control treatment. Despite fluctuations in ß-glucosidase and alkaline phosphatase activity during the season (Fig. 4a), urease activity increased insignificantly for all rotational treatments (Fig. 4b), with SR and BO demonstrating the highest urease activity. The current higher trend in enzyme activities for the SR treatment could indicate this rotational crop to have the potential to enhance soil quality and fertility. On the other hand, the low microbial enzyme activities recorded for the bare fallow (BF) and fallow (FM) treatments could probably be ascribed to the absence of winter crops which resulted in lesser amounts of carbon sources. The low enzymatic activity found in BF treatments could eventually result in low mineralisation rates and slower nutrient recycling which, in the long term, could result in decreased soil quality and fertility.



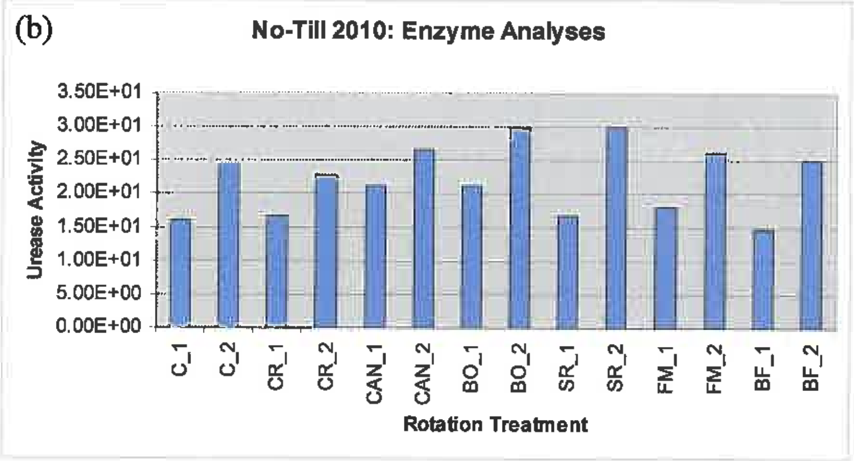


Fig. 4. **ß-glucosidase and alkaline phosphatase (a), and urease (b) activity for rotation treatments 64 ("_1") and 140 ("_2") DAP.**

For more reliable answers, any effect of a management system on soil quality and productive capacity is best evaluated using long-term trials (Subbian *et al.*, 2000).

BIOCONTROL AGENT EFFECTS

Growth, plant and soil analysis

The effects of the biocontrol agents, Fungimax plus Organoboost (OB), Eco-T (ECO) and Gliogrow (GLIO), on biomass and grain yield were non-significant (Table 9). Similarly, there were no effects on earthworm counts or soil moisture readings (Tables 10, 11 & 12), or on soil and plant analyses (Tables 14, 15 & 16).

Crown and root rots

Sixty four days after planting, Eco-T (ECO), Fungimax plus Organoboost (OB) and Gliogrow (GLIO) significantly reduced the severity of crown rot in maize. Except for GLIO these treatments did not reduce the severity of root rot when compared with the control The combined application of OB and anhydrous ammonia (ANM+OB), however, did not reduce crown and root rot significantly compared to the ANM treatment alone (Table 11).

At the final sampling (140 DAP), none of the biological treatments differed significantly from the control (C) (Table 12). As was the case 64 DAP, there was no extra benefit to be obtained from combining OB with ANM.

Fungi associated with crowns and roots

The application of the GLIO treatment significantly increased the incidences of *F.graminearum* in maize roots compared to the application of EcoT and OB (Table 17). High incidences were also recorded for the OB and ECO treatments compared to the ANM and ANM+OB treatment (Table 17). Mao *et al.* (1997), in a study on the effect of seed treatment with a fungal or bacterial antagonist for reducing maize damping-off caused by species of *Pythium* and *Fusarium*, found that seed treatment with *Gliocladium virens* was most effective against *F. graminearum, P. arrhenomanes* and *P. ultimum* compared to *Trichoderma viride* and *Burkholderia cepacia*. The Gliogrow treatment used in our study contained only the compound Epipolythiodioxperazine and not spores of the fungus. During the previous season, incidences of *F. graminearum* in maize roots were significantly increased by the application of OB treatment at the first sampling. At the second sampling during the previous season, high incidences of the fungus were recorded for the ECO and OB treatment, but the incidences did not differ significantly from those recorded for the C (wheat) treatment. This corresponds to the results obtained this season. The low incidences of the fungus recorded in maize roots subjected to the ANM and ANM+OB treatments also correspond to results obtained during the previous season (Table 17). In crowns, significantly higher incidences of the fungus were recorded in maize subjected to the ECO treatment than the ANM and the control (wheat) treatment. It therefore seems at this stage that the biological control products do not reduce the incidences of *F. graminearum* in this trial.

The different biocontrol products did not significantly affect the incidences of *F. oxysporum* in maize crowns and roots (Table 17). This confirms results obtained during the previous season. The lowest incidence of this fungus was recorded for the GLIO treatment (Table 17).

Contrary to the previous season, incidences of *P. terrestris* in maize crowns and roots were not significantly affected by the biocontrol/growth promoting products. However, *Pythium* spp. were significantly more frequently isolated from maize roots from the ANM treatment than the other treatments (Table 17). Since this has not been reported previously it needs to be confirmed in future studies.

Phialophora spp. were not isolated from maize crowns at the first sampling time. At the second sampling time these fungi were significantly more frequently isolated from the ECO treatment that the other treatments. This differs from the previous season when the different treatments did not affect the incidence of these fungi in crowns and roots. Similar to the previous season the biological products did not significantly affect the incidences of these fungi in roots.

Contrary to the previous season, significant differences in the incidences of *Trichoderma* spp. in crowns and roots of plants treated with the different compounds were not recorded. Similar to the previous season the highest incidences of *Trichoderma* spp. in crowns were recorded for the ECO treatment, but incidences of these fungi did not differ from those recorded for the C (wheat) treatment (Table 17). The active ingredient of Eco-T is *T. harzianum*, and Fernandez & Dos Santos (1992) in Brazil reported that the inoculation with this fungus of wheat and oat straw collected in Brazil, resulted in a reduction of *F. graminearum* and other *Fusarium* spp. Bjorkman *et al.* (1998) also showed that *T. harzianum* strain 1295-22 reduced root rot and increased root growth of sweet corn in the USA. It was suggested by these researchers that increased root growth caused by colonization with *T. harzianum* can restore some stress-induced growth reduction. In our studies we have found that the incidences of *Trichoderma* spp. on maize roots are high in the beginning of the season, but decline as the season progresses. Our results over the past seasons showed that where Eco-T was applied only once in the beginning of the season there were no beneficial effects with regard to growth and yield, whereas an application twice during the season can improve yield.

Similar to the previous season, there were no significant differences in the incidences of *Diplodia/Stenocarpella* spp. in crowns and roots of maize after treatment with the different biocontrol and growth promoting products (Table 17). These fungi were isolated from the ANM+OB and GLIO treatments, but not the ECO and OB treatments.

Nematodes

The biocontrol agents anhydrous plus Organoboost (ANM+OB), Fungimax plus Organoboost (OB), Eco-T (ECO) and Gliogrow (GLIO) benefited the herbivores 64 DAP (Table 8), as the population numbers of the herbivores were higher than that of the beneficial nematodes. As during the 2008-2009 growing season lower population numbers of herbivores were observed in the maize after wheat treatment (Table 8). The population number of the total number of herbivores and in particular that of the *Helicotylenchus/Scutellonema* group, *Paratrichodorus minor*, *Pratylenchus* species and *Rotylenchulus parvus* was higher in the GLIO treatments than in the maize after wheat treatment (C) (Table 8).

Microbial diversity and activity in soil

No statistically significant difference could be observed in soil microbial diversity between the number of different bacterial species or the abundance of species within soil microbial communities within biocontrol treatments at 64 and 140 DAP, except for the significant decrease in microbial diversity within soil microbial communities in anhydrous ammonia minus extra wheat straw + Fungimax and Organoboost (ANM+OB) and gliogro (GLIO) treatments (Table 21).

Table 21. Diversity Indices of soil microbial populations in biocontrol treatments 64 and 140 DAP.

Biocontrol Treatment	Shannon (H') 64 DAP ^{z}	Shannon (H') 140 DAP ^{z}	Evenness (E) 64 DAP ^{z}	Evenness (E) 140 DAP ^{z}
C	2.604^a	2.756^a	0.838^{ab}	0.835^{abc}
ECO	2.642^a	2.560^a	0.839^{ab}	0.808^{bc}
OB	2.864^a	2.782^a	0.857^a	0.860^a
ANM+OB	2.645^a	2.522^a	0.851^{ab}	0.794^c
GLIO	2.829^a	2.504^a	0.875^a	0.812^{bc}

^{z}Means within a column followed by the same letter do not differ significantly (P = 0.05).

With the exception of the control (C) treatment, all the other biocontrol treatments demonstrated an insignificant reduction in the number of soil microbial species (Shannon diversity index) from 64 to 140 DAP (Table 21). Biocontrol agents have a striking influence on the variation between species within soil microbial populations (Evenness Index) (Table 21). A sharp negative alteration in species diversity / variation within soil microbial populations could be observed in Eco-T (ECO), GLIO, and ANM+OB treatments, resulting in more variation within microbial populations. As a result, the more variation exists with in a microbial population, the higher the dominance of a specific species within the community, suggesting a decrease in microbial diversity (Zak *et al.*, 1994). The increase in species dominance in especially GLIO and ANM+OB treatments could be attributed to the fact that Gliogro and Fungimax + Organoboost are marketed to enhance fungal and bacterial populations in soil. Since there is a decline in the number of species within the soil microbial population, but an increase in dominance, it could be speculated that ECO and GLIO enhance / favour certain species within the microbial population. Soil bacterial species diversity / variation within microbial populations in OB treatments, on the other hand, would seem to have stabilised, similar to the C treatment at 64 and 140 DAP (Table 21).

Table 22. Average microbial enzyme activities in biocontrol plots 64 and 140 DAP.

Biocontrol Treatment	**ß-Glucosidase** ^{z}	**Alkaline Phosphatase** ^{z}	**Urease** ^{z}
C	4.28E+06^{ab}	2.20E+06^{a}	2.01E+01^{a}
ECO	5.49E+06^{c}	2.73E+06^{a}	1.96E+01^{a}
OB	4.61E+06^{bc}	2.17E+06^{a}	2.14E+01^{a}
ANM+OB	3.48E+06^{a}	2.16E+06^{a}	2.10E+01^{a}
GLIO	4.17E+06^{ab}	1.91E+06^{a}	2.06E+01^{a}

^{z}Means within a column followed by the same letter do not differ significantly (P = 0.05).

Although no statistically significantly differences could be observed in alkaline phosphatase and urease activity between treatments, it is evident that the ECO treatment demonstrated significantly higher ß-glucosidase activity compared to treatments other than OB (Table 22). Regardless of fluctuations in ß-lucosidase and alkaline phosphatase activity during the season (Fig. 5a), urease activity increased insignificantly for all biocontrol treatments (Fig. 5b). ß-Glucosidase and alkaline phosphatase activity in the OB and C treatments at 64 and 140 DAP, seem to have stabilized (Fig. 5a), while enzyme activity in GLIO and ANM+OB increased insignificantly. Slightly higher overall enzyme activity could be observed in ECO treatments, compared to the other biocontrol treatments (Fig. 5).

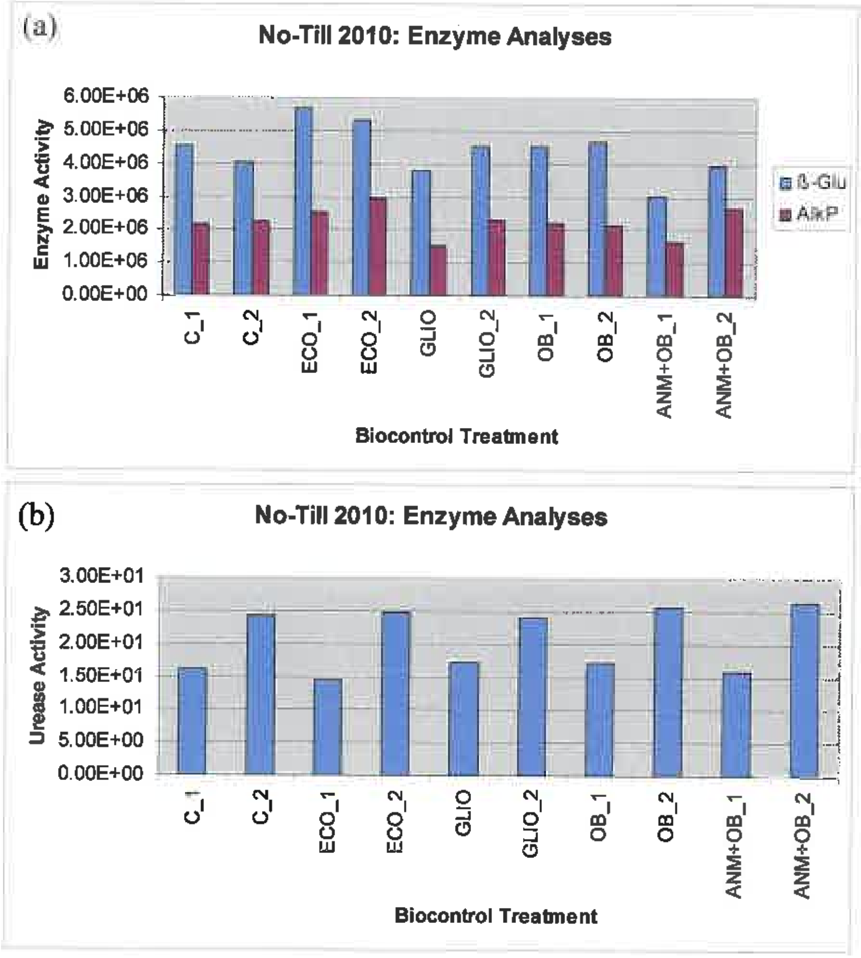


Fig. 5. **ß-glucosidase and alkaline phosphatase (a), and urease (b) activity for biocontrol treatments at 64 ("_1") and 140 ("_2") DAP.**

Correlating the diversity indices with enzyme activity from only two sampling times (64 and 140 DAP), it could be speculated that dominant soil bacterial species are responsible for the majority of enzyme activities. For more reliable answers, any effect of a management system on soil quality and productive capacity is best evaluated using long-term trials (Subbian *et al.*, 2000).

CHEMICAL BIOCIDE EFFECTS

Growth, plant and soil analysis

Methyl bromide fumigation in the absence of extra wheat straw cover (MBM) again proved very disappointing in terms of plant growth and yield (Table 9). An initial very marked benefit 28 DAP (Tables 9, 10, 11, & 12) was followed by a decline in performance, which proved equally marked 140 DAP and at harvest. Other important aspects which should be noted, include the negative effects of the MBM treatment on soil moisture content at all sampling times, the highly significant negative effect on earthworm populations and the alarming effect on plant standability (Tables 10, 11 & 12). It seems likely, that an explanation for these effects is soilborne disease related (see section to follow). It also seems probable that any benefits which may have resulted from fumigation have been overwhelmed by the beneficial effects of cover.

This season, anhydrous ammonia again proved to result in improved yields 28 and 64 DAP (Table 9). Although not statistically significant 28 DAP, the effects were so 64 DAP. By the third sampling, however, they were no different to the control plots. The effects on soilborne disease severity 64 DAP were encouraging and will be discussed in more detail below. Also encouraging was the fact that earthworm counts in plots which received anhydrous ammonia were not significantly different from those where plots had been similarly ripped (CRI), but without gas (Tables 11 & 12). This suggests that concerns frequently expressed about the negative effects of gas on soil life are questionable.

Interestingly, although the effects of ANM were almost statistically negative relative to C 140 DAP, in terms of final grain yield, the benefit of ANM was substantial and highly significant. This is difficult to explain unambiguously, but possibly resulted from the fact that the ANM plots were the last to be sampled and weighed. There would have been appreciable moisture loss from these plots during the course of the day, but facilities to determine oven dry mass were not available. In this regard, it should be noted that topsoil moisture contents in these plots were significantly lower than those in control plots at 42, 73 and 135 DAP (Tables 10, 11 & 12).

There were no meaningful effects of anhydrous ammonia on soil properties 28 DAP (Table 14). However, there were highly significant effects on plant composition both 28 and 71 DAP. At both times the Mn content of plants in anhydrous ammonia plots was very markedly increased (Tables 15 & 16). At 71 DAP, the Zn content was also significantly greater than that in most other treatments. This is almost certainly a consequence of rhizosphere acidification having resulted from NH_4^+ uptake, an effect previously noted in the case of leaf Mn content and considered to probably result in the depression of soilborne disease severity. It is of interest to note that the probable role of NH_4^+ is also reflected in significantly reduced K uptake 28 DAP (Table 15). Antagonism between K^+ and NH_4^+ is a well-known phenomenon.

Crown and root rots

The effects of MBM and ANM were both highly significant 64 DAP, when these treatments resulted in an appreciable decrease in the incidence of both crown and root rot. This beneficial effect was unfortunately not statistically significant 140 DAP (Tables 11 & 12).

Fungi associated with crowns and roots

Similar to the previous season, application of anhydrous ammonia (ANM) and methyl bromide (MBM) significantly reduced the incidences of *F. graminearum* in maize roots, but not crowns, compared to the C treatment (Table 17 and 18). Incidences of the fungus were reduced from 25% for the C treatment to 10% for the ANM and 14.2% for the MBM treatment. The highest incidence recorded in the crowns was 3.3% for the C treatment (Table 18).

Incidences of *F. oxysporum* in maize crowns and roots did not differ significantly for the ANM, MBM and C treatments (Table 17). This confirms results obtained during the previous season.

Although incidences of *P. terrestris* in roots did not differ significantly in maize roots subjected to the ANM, MBM and C treatments, as was the case during the previous season, the highest incidence of *P. terrestris* was similar to the previous season and again recorded in roots of the ANM treatment (Table 17). *Pythium* spp. were also significantly more frequently isolated from roots of maize from the ANM than the MBM and C treatments (Table 17).

Although not significant, *Trichoderma* spp. were, like the previous season, frequently isolated from maize roots from the C and MBM treatments and less frequently from the ANM treatment (Table 17). In the crowns, significantly more *Trichoderma* spp. were recorded for the MBM compared to the ANM and C treatments (Table 17).

Nematodes

The chemical biocide treatments affected the incidences of herbivores (Table 8, Fig 1). Relative to the control, anhydrous ammonia (ANM), or methyl bromide (MBM) had no statistically significant effect on the population number of the herbivores. The lowest number of herbivores was, as during the past seasons, observed in the methyl bromide treatments (Lamprecht *et al.,* 2007; 2008; 2009). In contrast with the 2007-2008 and 2008-2009 seasons, the incidence of *P. minor* was not the highest in the methyl bromide treatments. The methyl bromide treatment (MBM) was one of two treatments where the incidence of the beneficial nematodes was lower than that of the previous season (Fig. 6). During the past two seasons the highest population numbers of herbivores were observed in the anhydrous treatments. During the current season this was not the case, but the anhydrous treatment (ANM) still significantly benefited the herbivores, as the population number of the herbivores was still appreciably higher than that of the beneficial nematodes (Table. 8, Fig 1).

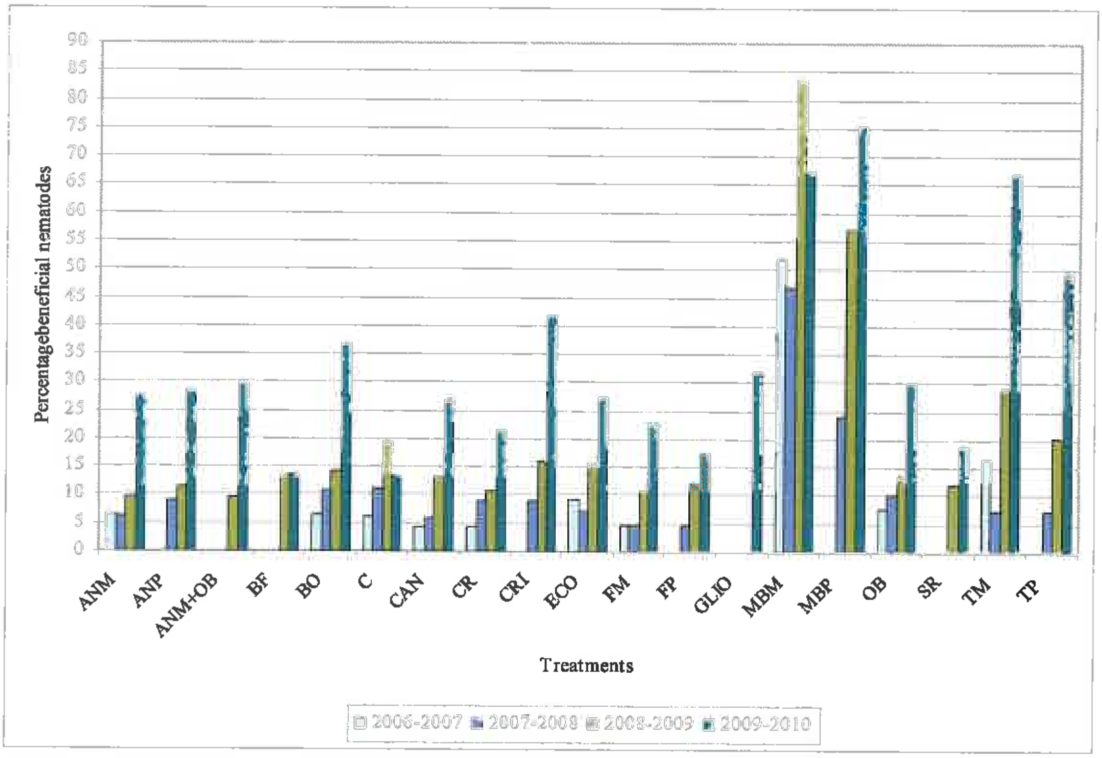


Fig 6. Incidence of beneficial nematodes in the soil and roots 64 DAP.

Microbial diversity and activity in soil

As is evident in Table 23, no statistically significant difference could be observed between the number of different bacterial species, nor the abundance of species within soil microbial communities within treatments over time.

Table 23. **Diversity Indices of soil microbial populations in chemical biocide treatments 64 and 140 DAP.**

Chemical Biocide Treatment	Shannon (H') 64 DAP [z]	Shannon (H') 140 DAP [z]	Evenness (E) 64 DAP [z]	Evenness (E) 140 DAP [z]
C	2.604[a]	2.756[a]	0.838[a]	0.835[a]
ANM	2.680[a]	2.525[a]	0.836[a]	0.839[a]
MBM	2.580[a]	2.250[a]	0.855[a]	0.831[a]

[z]Means within a column followed by the same letter do not differ significantly (P = 0.05).

It is apparent that the chemical biocide treatments insignificantly influenced the number of soil microbial species within the soil microbial population between 64 and 140 DAP. As illustrated by the Shannon-Weaver diversity index, both anhydrous ammonia minus extra wheat straw (ANM) and methyl bromide minus extra wheat straw (MBM) resulted in a decrease in the number of soil microbial species, whereas the control treatment (C) demonstrated the contrary (Table 23). Variations between species within soil microbial populations (Evenness Index) are also noticeably influenced by chemical biocide treatments (Table 23). A visibly negative variation in species diversity within soil microbial populations could be observed in the MBM treatment, resulting in more variation within microbial populations. As a result, the more variation that exists with in a microbial population, the higher the dominance of a specific species within the community, suggesting a decrease in microbial diversity.

Table 24. **Average microbial enzyme activities in biocontrol plots 64 and 140 DAP.**

Chemical Biocide Treatment	ß-Glucosidase [z]	Alkaline Phosphatase [z]	Urease [z]
C	4.28E+06[b]	2.20E+06[a]	2.01E+01[a]
ANM	4.02E+06[ab]	2.09E+06[a]	2.27E+01[a]
MBM	3.31E+06[a]	2.11E+06[a]	1.46E+01[a]

[z]Means within a column followed by the same letter do not differ significantly (P = 0.05).

As shown in Table 24, no statistically significant differences could be observed in alkaline phosphatase and urease activity between treatments, but ß-glucosidase activity in control (C) treatments differed significantly from the methyl bromide minus extra wheat straw (MBM) treatments. MBM treatments indicated the lowest ß-glucosidase and urease activity, while control treatments had the highest ß-glucosidase and alkaline phosphatase activity. The highest urease activity was evident in the ANM treatment. Plots treated with chemical biocides demonstrated insignificant increases in urease activities from 64 to 140 DAP, which could indicate changes in soil quality associated with the nitrogen cycle (Fig. 7b). Fluctuations in ß-glucosidase and alkaline phosphatase activities (Fig. 7a) indicate that these enzymes are sensitive to disturbances (Balota *et al.*, 2004).

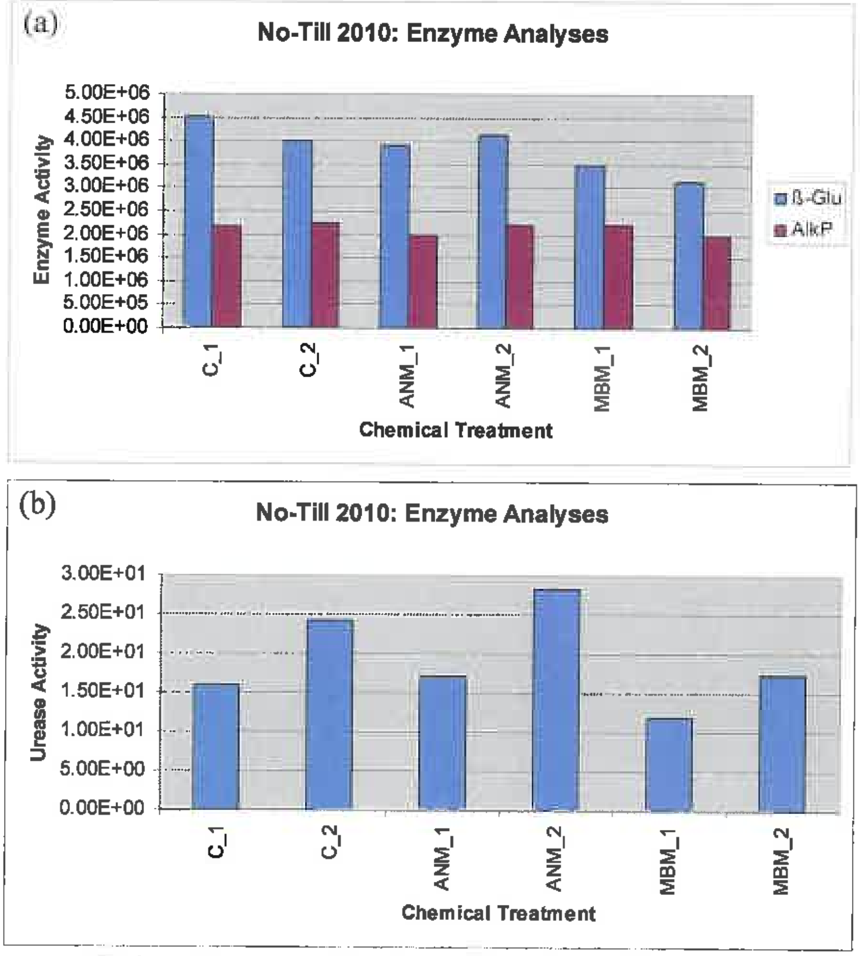


Fig. 7. **ß-glucosidase and alkaline phosphatase (a), and urease (b) activity for chemical biocide treatments at 64 ("_1") and 140 ("_2") DAP.**

For more reliable answers, any effect of a management system on soil quality and productive capacity is best evaluated using long-term trials (Subbian *et al.*, 2000).

TILLAGE EFFECTS

Growth, plant and soil analysis

The relevant treatments to be compared here are methyl bromide without extra cover (MBM) versus tilled as for MBM, but without extra cover (TM), the equivalent treatments with extra cover (MBP & TP), TP versus the control (C), and controlled rip (CRI) versus anhydrous ammonia without extra cover (ANM).

Generally, the effects of tillage *per se* were small. At 28 DAP yields in the MBM and TM plots were equally good, due in all probability to higher soil temperatures during early growth (Tables 9 & 10), but their performance dropped off markedly as the season progressed. In fact, 140 DAP and at harvest they were among the worst performing treatments in the trial. Since there was evidence that the methyl bromide had reduced disease severity 64 DAP (see discussion to follow), it is possible that fumigation of plots without cover had negatively affected the earthworm population (Tables 11 & 12) and that this had countered any beneficial effect on disease severity. Both these treatments resulted in exceptionally low soil moisture contents at all three samplings (Tables 10, 11 & 12). Another feature of these two treatments is the fact that they resulted in root lodging 140 DAP that was significantly greater than that of any other treatment (Table 12).

Yields in MBP and TP plots did not differ significantly at any sampling stage. Moreover, these two treatments, although markedly superior to their minus-cover analogues, did not differ meaningfully from one another in terms of soil moisture content, soil temperature or number of root-lodged plants (Tables 10, 11 & 12). This is somewhat surprising and suggests that soil fumigation was not providing a meaningful benefit.

When comparing TP with the control (C), it is clear that the period (18 days) that TP was without cover provided similar early season benefits to those already discussed (Table 9). At 42 DAP, the moisture content of TP plots was significantly lower than that of control plots (Table 10) and the soil temperature was higher (not significantly so). Since the experiment was irrigated 30 DAP, the moisture content difference is surprising and suggests that temperature differences may have previously been appreciably greater. The moisture content difference tended to persist up to 140 DAP and was significantly so 64 DAP. Here again, earthworm activity may have been implicated (see section to follow which deals with cover effects on infiltration), as at 140 DAP there were significantly more earthworms in control plots (Table 12) and while not statistically significant, the number 64 DAP was also appreciably greater (Table 11). Since tillage would have resulted in the incorporation of previous crop residues, surface cover in the control (C) plots would have been appreciably greater than in plots where wheat straw had been added after tillage and such effects on earthworm populations are, perhaps, to be expected. The effects of these two treatments on lodging 140 DAP are particularly interesting. The degree of lodging in control (C) plots was very markedly less than that evident in TP plots (Table 12) and so, too, was the soil moisture content significantly higher. This suggests that the very bad root lodging evident in all plots that had been tilled was related to moisture availability and corroborates the possible involvement of earthworm populations.

Comparison of the controlled rip (CRI) with the anhydrous ammonia minus extra cover (ANM) is complicated by the fact that moisture and temperature comparisons are only available for the third sampling (Table 12). As is evident in Table 9, yields of CRI plots 28 DAP were significantly higher than those of ANM plots or, in fact, any of the anhydrous ammonia treatments. Conceivably, this resulted from an initial inhibitory effect of anhydrous ammonia on growth. This has been observed previously and this season was clearly evident visually. It was possibly aggravated by the gas not being applied deeply enough. At 64 and 140 DAP, this negative effect was no longer evident, but this may well have resulted from the compensatory effect of anhydrous ammonia on soilborne diseases (see discussion to follow). At 135 DAP (Table 12) there was no difference between these treatments in terms of moisture content and, while the temperature difference was significantly higher in the CRI plots, this could possibly have resulted from the very markedly increased root lodging and radiant exposure in the CRI plots. In terms of final grain yields, the CRI treatment was more than 2000 kg/ha lower than that of the ANM treatment. This is gratifying and indicates that the ripping action associated with anhydrous application did not play a meaningful role.

Apart from the effects of anhydrous ammonia on Mn availability, which have been discussed previously, soil and plant analyses did not meaningfully contribute to the issues discussed here.

Crown and root rots

Crown and root rots in TP plots were significantly fewer than in control (C) plots 64 DAP, but not at the final sampling 140 DAP (Tables 11 & 12). There were significant differences between MBM and TM, but not between MBP and TP with regard to crown and root rot 64 DAP. At the final sampling there were no significant differences in crown rot severity between TM and MBM treatments, but root rot severity differed significantly. Significant differences in crown and root rot severity were recorded for the TP and MBP treatments at the final sampling. Disease severity in the fumigated plots was consistently lower. There were no significant differences in crown and root rot severity between the ANM and CRI treatments except for significantly less root rot recorded for the ANM treatment compared to CRI at the final sampling

Fungi associated with crowns and roots

Soil disturbance did affect the incidences of *F. graminearum* in roots but not crowns. The incidences of the fungus in roots of the no-till (C) treatment were significantly higher than incidences in roots from plants where the soil was disturbed before planting (CRI, ANM, MBM, TM). During the previous seasons (2007, 2008 and 2009) soil disturbance also significantly reduced the incidences of *F. graminearum* in roots. In crowns, a significantly higher incidence of this fungus was recorded for the TM treatment compared to the other treatments 140 DAP, but 64 DAP there were no significant differences in the incidences recorded in crowns of these treatments (Table 18). It is difficult to explain the high incidence of the fungus is crowns of maize subjected to the TM treatment.

Similar to the previous season, the incidences of *F. oxysporum* in maize crowns and roots from undisturbed soil (C treatment) and disturbed soil (CRI, ANM, MBM, TM) did not differ significantly. Incidences of the fungus for treatments C and TM, CRI and ANM, MBM and TM treatments did also not differ significantly (Table 17).

The incidences of *P. terrestris* in roots from the different treatments did not differ. During previous seasons it appeared that tillage increase the incidences of *P. terrestris*, but this was not the case this season. *Pythium* spp. were significantly more frequently isolated from roots of maize subjected to the ANM treatment than the other treatments. This is, however, difficult to explain and needs to be confirmed in future studies. Also difficult to explain is the significantly higher incidence of *Phialophora* spp. recorded in crowns of maize subjected to the TM treatment compared to the other treatments (Table 18).

During the previous season, *Trichoderma* spp. were significantly more frequently isolated from roots of plants from the MBM treatment than the CRI, TM and ANM treatments, but incidences of the fungi in roots of the MBM treatment did not differ significantly from that in roots from the C treatments. During this season there were no significant differences in the incidences of these fungi in roots, but in crowns, significantly more *Trichoderma* spp were isolated from the MBM than the C, CRI, TM and ANM treatments. Also in the roots, although not significant, incidences of these fungi were notably higher for the MBM compared to the other treatments (Table 17).

A considerable amount of information is available on the effects of conservation tillage on ear and stalk rot pathogens of maize. In South Africa, Flett, McLaren & Wehner (1998) reported that mouldboard plough plots consistently had lower incidences of Stenocarpella ear rot than reduced tillage practices. However, Smit (1998) concluded that the effects of tillage practices on soilborne pathogens of maize were inconsistent in trials that she conducted at Bloekomspruit (Gauteng province) and Mmabatho (North West province). Sumner *et al.*, (2002) in the USA reported that conservation tillage can increase Rhizoctonia crown and brace root rot of maize, and according to Scott (1993) minimum tillage promotes black root rot (*Pythium* spp.) in South Africa. It was also suggested by Deep & Lipps (1996) that *P. arrhenomanes* is favoured by poorly drained soil when continuous maize cropping and no-till are practised.

Nematodes

The effect of tillage on nematodes was discussed in detail in the 2007-2008 season report, with emphasize on the apparent contradictory nature of reports in the literature and the dearth of published South African data (Marais & Swart, 2007; Lamprecht *et al.*, 2008; Marais, *et al.*, 2009). At 64 DAP there were no significant statistical differences in the population number of the different herbivore species, but the incidence of herbivores in the tilled plots were consistently lower than in the maize after wheat treatment (Table 8, Fig. 2). The herbivores, therefore, benefited from the tilled and ripped treatments as their numbers were significantly higher than that of the beneficial nematodes (Fig. 1). The tilled minus cover (TM) treatment was one of the few treatments where the beneficial nematodes and not the herbivores, were benefited. Both the incidence and population numbers of the beneficial nematodes were significantly higher than that of the herbivores. This treatment might, therefore, have an increased suppression effect on the herbivores, something that is highly sought after in agricultural soils. The tilled minus cover treatment was also one of two treatments that showed higher population numbers and incidence of fungivores when compared with that of the bacterivores (Fig 1, 2). This treatment benefits fungivores over bacterivores. This is interesting as according to Hendrix (1999) no-tillage management favours foodwebs dominated by fungi and fungivores as well as high numbers of earthworms. In general, more resistant substrates and substrates with higher C : N ratios are more likely to be exploited by fungi than by bacteria. A fungal dominated decomposition pathway and fungal feeding nematodes as predominant secondary composers are expected in systems where cellulose and lignin-rich litter is the main source of nutrient input in the soil food web (Hohberg, 2003). In a paper by Raaijmakers *et al.* (2009) the authors stated that it is difficult to assess the role of tillage on disease suppression as its evaluation is usually combined with the effect of other cultural practices such as organic amendments, residue management or rotation. It therefore appears as if tillage has conflicting effects on disease suppression.

Microbial diversity and activity in soil

No-till practices increase plant residues at the soil surface and promote depth stratification, whereas tillage incorporates organic matter into the soil, thus promoting even distribution (Wander *et al.*, 1998). This results in differences in the vertical distribution of soil biota between contrasting tillage practices. (Frey *et al.*, 1999).

No statistically significant difference could be observed between the number of different bacterial species, and the abundance of bacterial species within soil microbial communities within tillage treatments between 64 and 140 DAP (Table 25).

Table 25. **Diversity Indices of soil microbial populations in tillage treatments 64 and 140 DAP.**

Tillage Treatment	Shannon (H') 64 DAP ^{z}	Shannon (H') 140 DAP ^{z}	Evenness (E) 64 DAP ^{z}	Evenness (E) 140 DAP ^{z}
C_1	2.604^a	2.756^a	0.838^a	0.835^a
TP_1	2.659^a	2.754^a	0.850^a	0.853^a
MBP_1	2.734^a	2.748^a	0.847^a	0.842^a
TP_1	2.659^a	2.754^a	0.850^a	0.853^a
ANM_1	2.680^a	2.525^a	0.836^a	0.839^a
CRI_1	2.722^a	2.571^a	0.849^a	0.867^a
MBM_1	2.580^a	2.250^a	0.855^a	0.831^a
TM_1	2.769^a	2.543^a	0.827^a	0.839^a

^{z}Means within a column followed by the same letter do not differ significantly (P = 0.05).

A statistically insignificant reduction in the number of soil microbial species within the soil microbial community could be observed between 64 and 140 DAP in all the tillage treatments, whereas an insignificant increase was observed in the number of soil microbial species in the control (C) plot and fumigated and tilled plots with cover (MBP & TP) (Table 25). The difference in the number of soil microbial species between fumigated and tilled plots with cover (MBP & TP) is not unexpected since more carbon sources (in the form of wheat straw) are being made more readily available to the soil microbial populations through tillage. Aside from the controlled rip (CRI) treatment indicating a slightly higher number of soil microbial species than the ANM treatment, there were no clear statistical significant differences between these two treatments.

Different tillage treatments clearly influenced soil microbial species diversity/variation (Evenness Index) within the soil microbial populations (Table 25). Although not statistically significant, fumigated and tilled treatments without cover (MBM & TM) resulted in opposite species diversity/variation 64 to 140 DAP. Contrary to TM treatments, MBM resulted in a reduction in bacterial diversity. The reduction in MBM diversity can be attributed to the increase in bacterial species dominance resulting from the introduction of maize after fumigation. In other words, the temporary elimination of soil microbes after fumigation resulted in the "repopulation" of the soil with "normal" soil bacterial species. These bacterial species, however, were out competed by soil bacterial species with the ability to utilize specifically the planted maize's root exudates. The same incidence could be observed in fumigated and tilled treatment with cover (MBP & TP). While soil microbial species became slightly more equally abundant in TP treatments, it was less equally abundant in MBP treatments, indicating species dominance and, thus, lower species diversity. Soil microbial species within soil microbial populations in TP were insignificantly more diverse than in C treatments. It is interesting to note that, despite minor differences, soil bacterial species diversity/variation within the soil microbial populations in C, TP, and MBP treatments indicated more "stable" soils with the potential to cope with external disturbances. Contrary to the 2008/2009 season, soil bacterial species diversity in CRI and ANM treatments increased, illustrating an increase in species variation, resulting in less dominance, and, therefore, higher diversity. As shown in Table 25, CRI hosted the highest level of soil bacterial diversity within soil microbial populations 140 DAP.

Table 26. Average microbial enzyme activities in biocontrol plots 64 and 140 DAP.

Tillage Treatment	ß-Glucosidase [z]	Alkaline Phosphatase [z]	Urease [z]
C	$4.28E+06^{bd}$	$2.20E+06^{a}$	$2.01E+01^{a}$
TP	$4.11E+06^{abd}$	$2.05E+06^{a}$	$2.27E+01^{a}$
MBP	$4.69E+06^{d}$	$2.24E+06^{a}$	$1.58E+01^{a}$
ANM	$4.02E+06^{ab}$	$2.09E+06^{a}$	$2.27E+01^{a}$
CRI	$3.55E+06^{ac}$	$3.23E+06^{b}$	$2.16E+01^{a}$
MBM	$3.31E+06^{c}$	$2.11E+06^{a}$	$1.46E+01^{a}$
TM	$3.64E+06^{abc}$	$1.82E+06^{a}$	$1.83E+01^{a}$

[z] Means within a column followed by the same letter do not differ significantly (P = 0.05).

Although no conclusive trend could be drawn from data obtained from only two samplings, it is interesting to note that there were no statistically significant differences in enzyme activities between C & TP, TP & MBP, MBM & TM, and ANM & CRI treatments 64 and 140 DAP (Table 26). ß-glucosidase and alkaline phosphatase activity in C, TP and MBP were relatively higher compared to the TM and MBM treatments, with MBM illustrating the lowest enzyme activity (Fig. 8a). Higher ß-glucosidase activity could be observed in ANM treatments, compared to CRI, whereas CRI demonstrated the highest alkaline phosphatase activity of all the tillage treatments (Fig. 8a). Despite fluctuations between tillage treatments, urease activity increased from 64 to 140 DAP in all the tillage treatments (Fig. 8b). Fumigated plots either with or without cover (MBP & MBM), had slightly lower levels of urease activity compared to tilled treatments with or without cover (TP & TM). Although C & TP, and CRI & ANM treatments demonstrated slightly higher urease activities compared to the other tillage treatments, the latter treatments demonstrated the highest urease activity. Seemingly, tilled and controlled rip treatments have a slightly higher potential to degrade or transform substrates, compared to fumigated treatments (Fig. 8).

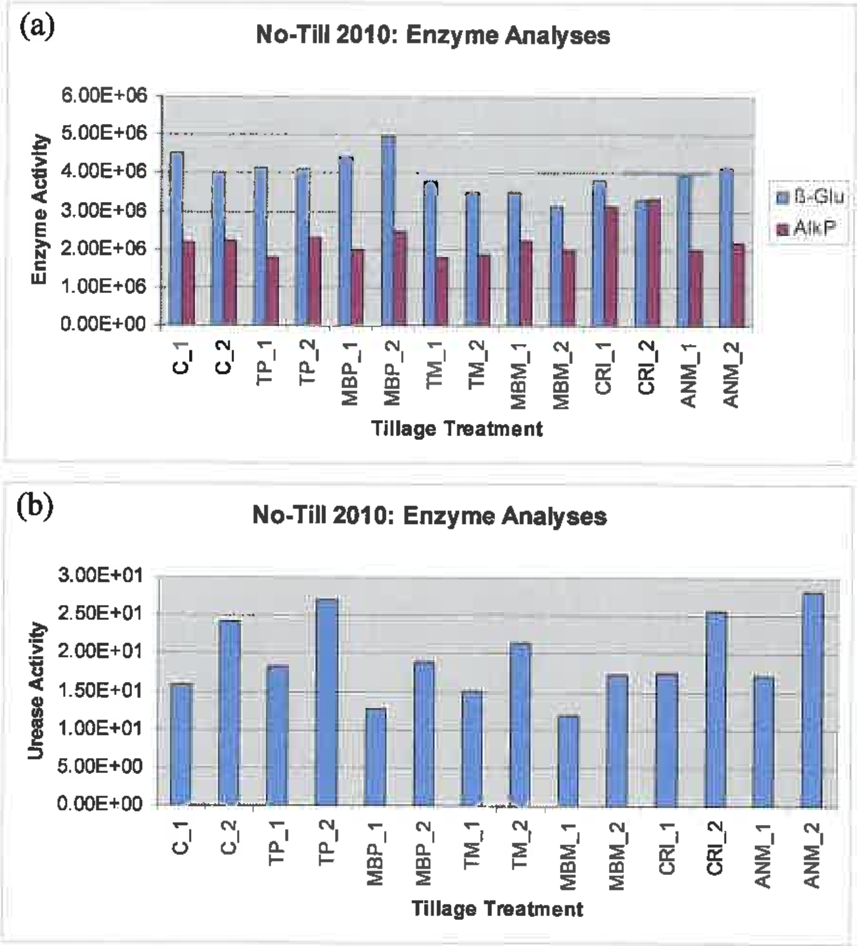


Fig. 8. **ß-glucosidase and alkaline phosphatase (a), and urease (b) activity for tillage treatments at 64 ("_1") and 140 ("_2") DAP.**

For more reliable answers, any effect of a management system on soil quality and productive capacity is best evaluated using long-term trials (Subbian *et al.*, 2000).

WHEAT STRAW COVER EFFECTS

In an agronomic sense this section is considered to be the most important of the aspects thus far discussed. Only in the exceptionally favourable 2007/2008 season did the effects of other factors discussed (rotations, biocontrol products, chemical biocides and tillage) have effects on crop performance as profound as those attributable to cover in subsequent seasons (Table 13). The summer phase of this experiment has intentionally been conducted in a fashion which will as closely as possible, simulate dryland conditions. Supplementary irrigation has only been applied where it was considered absolutely necessary in order to avoid potential crop failure and consequent loss of time and money or where it was required for Crop Guard application (Lamprecht *et al.*, 2007 & 2008). The picture that is emerging strongly supports this decision and renders the findings more widely applicable. It is probable, however, that in an excellently managed irrigation system, the effects to be discussed here would be somewhat less overwhelming in their impact.

Growth, plant and soil analysis

The treatment sets within which comparisons are to be made are ANM and ANP, BF, FM and FP, MBM and MBP, and TM and TP. In all instances, other treatments within a set were common. Anhydrous ammonia plots (ANM and ANP), those tilled and either fumigated (MBM and MBP) or left unfumigated (TM and TP) were cropped to winter wheat, while the fallow plots (BF, FM and FP) were similarly irrigated, but were not cropped. The bare fallow (BF) was included in the fallow treatment set in order to simulate situations where residues are heavily grazed, baled or even burnt (Fig. 9. With the exception of the BF, treatment differences were only imposed 18 DAP, when wheat straw was added to plus-cover analogues in each set.

Heavily grazed soyabean residues. **Heavily grazed maize residues.**

Baled wheat residues. **Burnt wheat residues.**

Fig.9 . Common examples of situations in which needless waste of cover occurs.

As a group, the treatment sets cannot be compared to one another, as there are differences in chemical biocide treatment and tillage, which have the potential to impact markedly on crop growth. The aim here is to compare the effects of cover *per se* within each treatment set.

In order to make this section more easily read, relevant data already presented in Tables 10, 11 and 12 have been extracted and presented in Tables 27, 28 and 29, which are dedicated to the plus- and minus-cover treatments and control (C). Recently acquired infiltration-rate data has also been included in Table 29.

At 28 DAP, 10 days after the wheat straw was applied to plus-cover analogues of the treatments involved, significant yield differences were only evident in the case of plots rotovated, but not fumigated (TM & TP) (Table 27). However, differences between rotovated and fumigated treatments (MBM & MBP) also approached statistical significance, the minus-cover plots being superior. Differences in soil temperature were not significant, but minus-cover plots were in all cases somewhat warmer and it seems likely that this favoured emergence and early growth (Triplett & Dick, 2008). In the case of soil moisture content, however, the differences between treatment analogues were highly significant in all cases, plots without extra cover being considerably dryer than those with wheat straw cover. Since the experiment received 50 mm of irrigation only 10 days prior to the measurements being made, such large differences are perhaps quite surprising. They certainly highlight the effects of evaporative moisture loss in the absence of cover. These results are consistent with those obtained the previous season (Lamprecht *et al.,* 2009).

Table 27 Wheat straw cover effects on relative yield 28 DAP and on soil temperature and moisture content 42 DAP.

TREATMENT[♦]	RELATIVE YIELD (%)	SOIL TEMPERATURE (° C)	SOIL MOISTURE (%)
ANM	60	29.9	7.5
ANP	64	28.5	15.2
BF	80	29.3	12.9
FM	72	28.6	18.6
FP	71	28.1	23.4
MBM	100	29.6	5.6
MBP	87	27.9	11.8
TM	96	29.0	4.8
TP	76	28.5	9.6
C	52	26.8	20.6
LSD (0.05)	17	NS	3.8

[♦] **See Table 2 for description of treatments.**

M = minus extra cover.
P = plus extra cover.