Table 3. Treatment effects on plant mass (g/10 plants) at three sampling stages and final grain yield (kg/ha).

Treatment[y]	First sampling[z]	Second sampling[z]	Third sampling[z]	Grain Yield
AN	30.55 cd	11427 a	13400 a	14880 a
BO	25.85 e	9360 de	12447 abc	13213 bcd
C	20.56 g	9787 cde	11827 bcd	13824 b
CAN	30.26 d	10780 abc	12247 abcd	13504 bcd
CR	25.85 e	10580 abc	12413 abc	13251 bcd
ECO	21.58 fg	10090 bcde	13373 a	13620 b
EXT	24.00 ef	10647 abc	12180 abcd	13529 bc
MB	40.96 a	11140 ab	13180 ab	12538 e
MF	33.81 bc	9447 de	11680 cd	12269 ef
N	22.08 fg	9053 e	10960 d	11751 b
OB	24.06 ef	9847 cde	11527 cd	12855 de
S	22.80 efg	9927 cde	11487 cd	13566 bc
SF	31.39 cd	9060 e	11313 cd	12386 ef
SW	20.62 g	10327 bcd	12520 abc	13432 bcd
T	36.97 b	10547 abc	12533 abc	12895 cde
LSD (0.05)	**3.36**	**1074**	**1438**	**671**

[y]See Table 1 for description of treatments

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

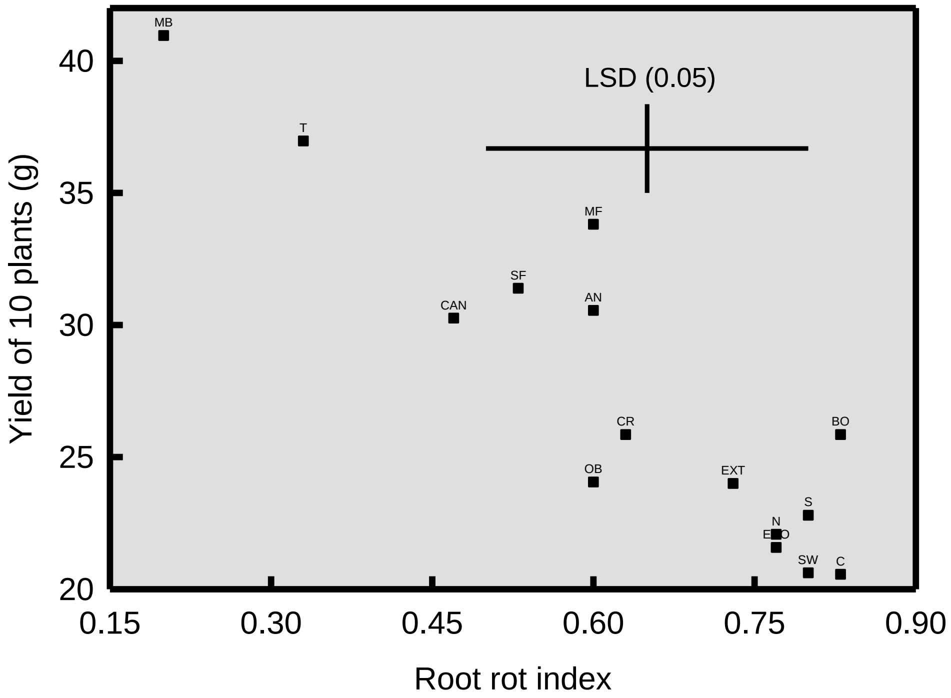

Fig. 4. The relationship between yield and root rot 21 days after planting (vertical and horizontal lines provide LSDs for Y-and X-axes, respectively).

At the second sampling, 70 days after planting, an interesting shift in the order of performance had occurred. Only AN and MB plots had maintained their statistically significant superiority over the control (C), and the fallow treatments (MF & SF) had dropped to a yield class no better than C. Treatments CAN, T, CR and EXT were in an intermediate class and the remainder were little different from the control. It appears that crown and root diseases were responsible for this marked change in performance. As is evident in Figs. 5 & 6, the six highest yielding treatments (AN, CAN, MB, CR, T & EXT) had markedly lower crown and root rot ratings than the five poorest performers (BO, C, MF, N & SF). The poor performance of the BO and fallow treatments is particularly interesting, as the involvement of wheat can be excluded.

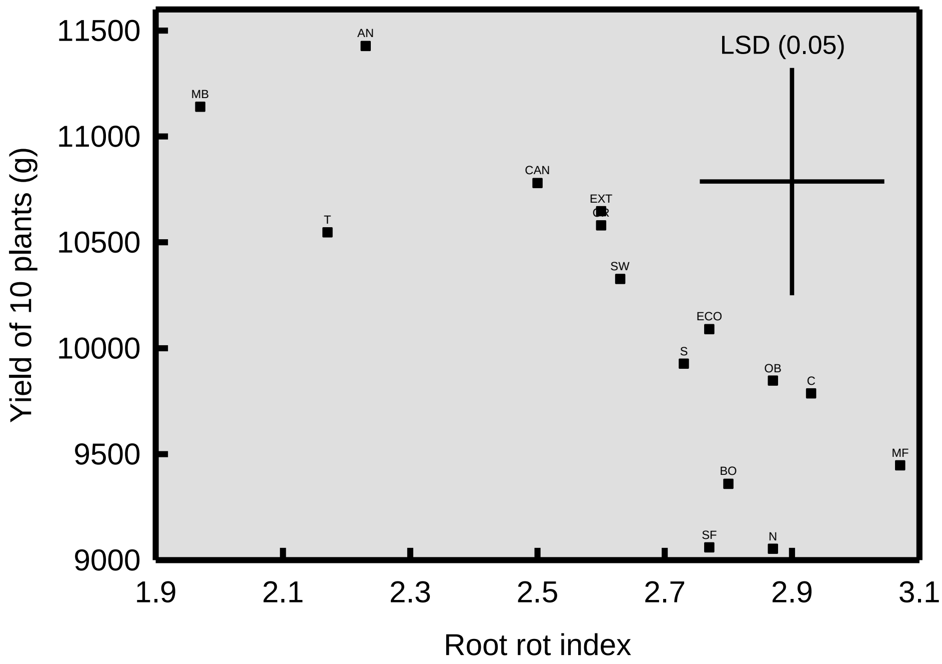

Fig. 5. The relationship between yield and root rot 70 days after planting.

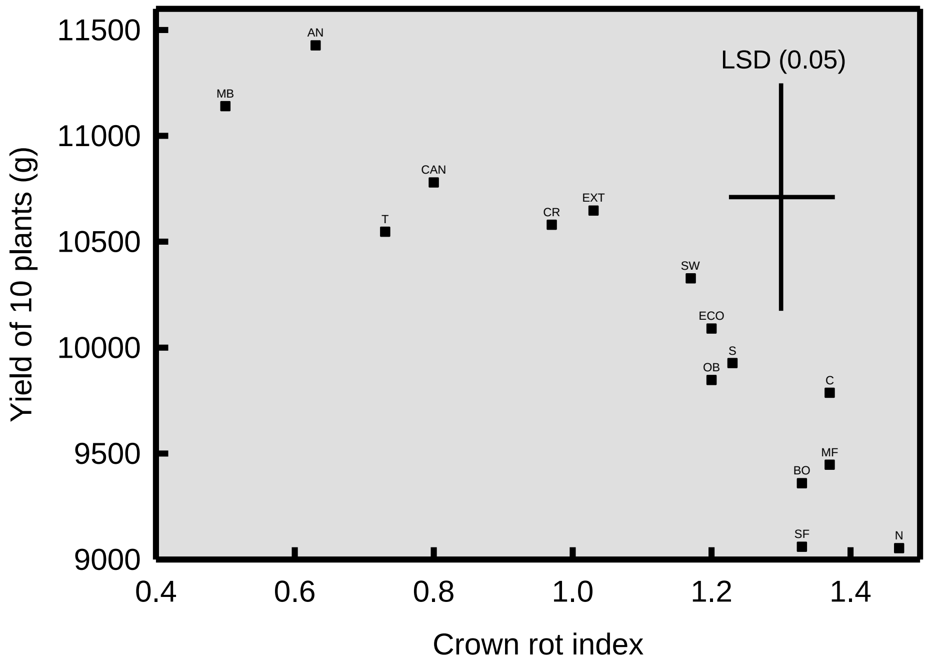

Fig. 6. The relationship between yield and crown rot 70 days after planting.

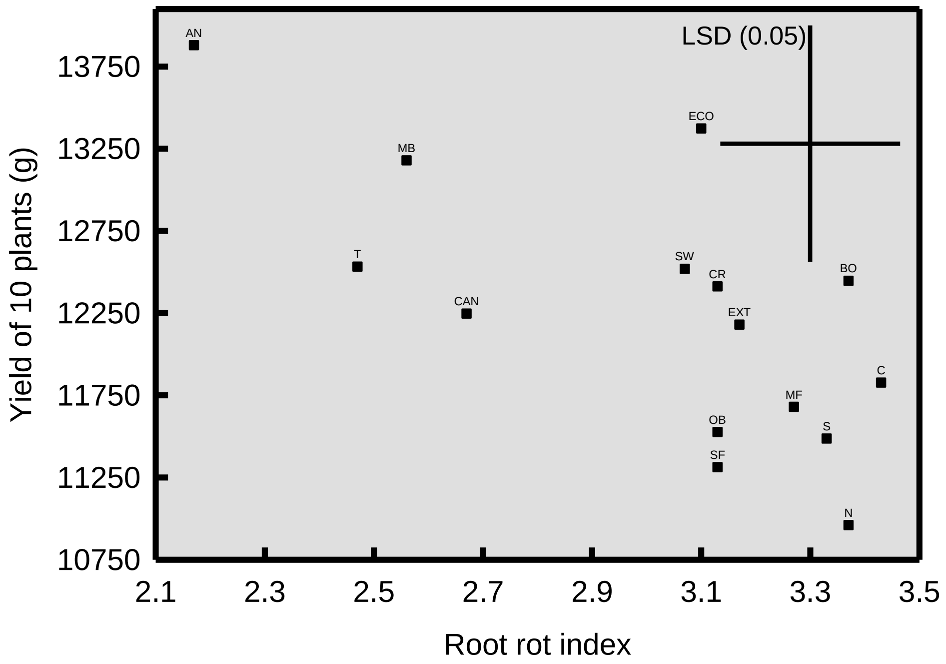

Fig. 7. The relationship between yield and root rot 100 days after planting.

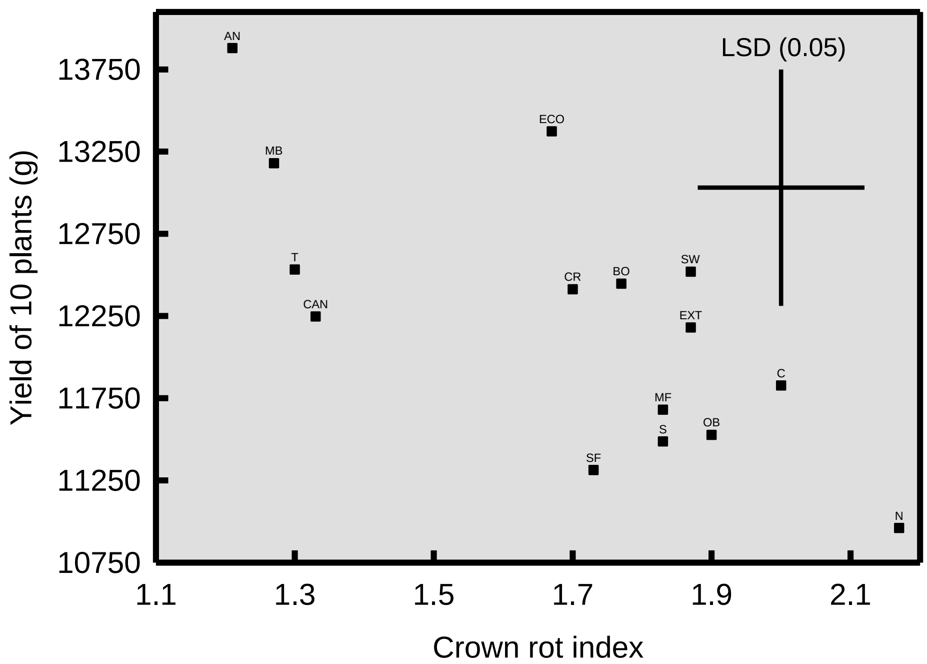

Fig. 8. The relationship between yield and crown rot 100 days after planting.

By the third sampling, 100 days after planting, differences were less obvious in statistical terms, but AN and ECO were significantly better than the control and MB was nearly so (Table 4, Figs.7 & 8). It is particularly interesting to note that ECO had shifted from one of the five worst performing treatments during the first sampling to the second best treatment. The improvement in performance of this treatment became visually evident after the second application a month after planting. This suggests that the recommended rate of application for maize – half that applied in this instance – has not been properly established. The effect is not readily explainable, but conceivably is related to an effect on nematodes and pathogenic fungi (see sections on fungal diseases and nematodes later in this report).

At harvest, with the notable exception of anhydrous ammonia (AN), none of the other treatments was superior to the control (Table 4). In view of the results obtained at earlier samplings, this was unexpected, but was possibly associated with the climatic and cover effects already mentioned. It will be noted (Table 4) that grain yields in plots without cover (MB, T, MF & SF) were all significantly lower than the control, in spite of the fact that they were the four best performing treatments at the first sampling (Table 4 & Fig. 4). This unexpected result is contrary to conventional wisdom and has revealed a phenomenon, which is potentially very important to our understanding of no-till systems. The effect of the absence of cover near maturity is dramatically depicted in Fig. 9 where a soyabean-fallow-maize (SF) plot is compared to an adjacent soyabean-wheat-maize (SW) plot. The final grain yield differential between these two treatments was over 1000 kg/ha (Table 4) and it is an effect with very appreciable practical significance. The SF and MF treatments are general practice in dryland no-till systems in which no winter crop is planted.

Fig.9. A soyabean-fallow-maize plot (left) adjacent to a soyabean-wheat-maize plot (right) close to maturity.

In the interests of clarity it is the intention now to examine individual treatments and groups of treatments in more detail.

The relationships depicted in Figs. 4 – 8 provide important information with regard to the effects of treatments on growth up until the third sampling 100 days after planting. Quite clearly, particularly with regard to yields determined 21 and 70 days after planting, root and associated crown rots played an extremely important role. Such strong relationships are uncommon in field experimentation and indicate that the assessment procedures used were very effective. There can be no doubt about the fact that soilborne diseases are likely to play an extremely important role in no-till maize production.

Comparison of Fig. 4 with Figs. 5 – 8 clearly illustrates the rapid fall-off in the performance of the bare fallow plots (MF & SF) and the decline in the performance of MB plots and those tilled, but not fumigated (T). Also evident, is the deterioration of CAN plots after 70 days, in spite of disease ratings considerably better than most other treatments, and the marked improvement of Eco-T (ECO), in spite of these plots having disease ratings little better than the control (C) plots. Another striking and important feature of the data presented in these figures is the substantial improvement in anhydrous ammonia (AN) plots in terms of both yield and disease ratings. From being no better than the control in terms of root rot index 21 days after planting (Fig. 4) and inferior to the fallow plots (MF & SF) in terms of yield, the performance of this treatment improved to a point 100 days after planting (Figs. 7 & 8) where it was the best in terms of root and crown rot index and of yield. At harvest, the grain yield was significantly superior to all other treatments (Table 4) and out yielded the MB treatment, that intended to provide a base line of the yield potentially attainable, by over 2300 kg/ha. Unfortunately, no information was acquired regarding the incidence of fungi after the third sampling, but nematode counts performed after harvest very clearly showed that nematode populations had not played a meaningful role in the collapse of MB plots. Presumably, then, further build-up of fungal pathogens in MB plots must have occurred in the later part of the season, that period of growth when carbohydrate withdrawal by the cob renders the plant particularly susceptible to disease infection. Similarly, there was no evidence to suggest that nematode populations were responsible for the deterioration of tilled (T) plots relative to AN plots (see nematode section for details). It seems possible, however, that they did in the case of the fallow plots (MF & SF) in which the yield decline occurred much sooner and certain nematode species had increased dramatically by the third sampling (see nematode discussion).

The comparatively slow yield and disease-suppression response to anhydrous ammonia probably relates to relatively recent advances in elucidating its mode of action in soils (Tenuta & Lazarovits, 2002). Ammonia (NH_3) gas is known to be highly toxic to soil micro-organisms and in the immediate vicinity of the injection zone will essentially sterilise the soil (Eno *et* al., 1955; Havlin *et al*., 1999). As the gas moves from this zone or comes into contact with water, ammonium hydroxide will form ($NH_3 + H_2O \rightarrow NH_4OH$), which results in a sharp pH elevation. Thereafter, nitrification takes place and NH_4-N is converted to NO_2-N and then to NO_3-N. This will occur more slowly in the immediate injection zone due to the initial destruction of nitrifying bacteria. On nitrification or uptake of NH_4^+ by roots, the soil is acidified and the pH of the rhizosphere drops rapidly. This favours the accumulation of HNO_2, which has been shown to be toxic to nematodes and fungi at very low concentrations (Tenuta & Lazarovits, 2002; Conn *et al.*, 2005). Thus, there is a rapid effect due to

NH_3 and a slower, longer-term effect due to HNO_2, the intermediary product of nitrification of NH_4-N to NO_3-N. NH_3 toxicity is dominant at high pH levels and HNO_2 toxicity is favoured by soil pH levels near 5 in KCl, a pH similar to that on this trial site (Table 2). It is likely, then, that while both mechanisms might have been operative in this experiment, the HNO_2 effect would have been dominant. This would explain the slow response to AN noted previously.

No changes in soil chemical properties were apparent at sampling times 1 and 2 (data not shown), but whole plant (21 days after planting) and leaf (70 days after planting) analyses (Tables 5 & 6) strongly support the fact that NH_4-N accumulated and that lethal levels of HNO_2 would have been created. It will be noted in Table 5, that at 21 days striking differences were evident in AN plots. Uptake of K, Ca and Mg had been significantly depressed, due almost certainly to the competitive effect of the NH_4^+ ion. Ammonium fertilizers have been reported as having a depressive effect on several soilborne pathogens (Huber, 1991), due probably, in the light of current knowledge, to rhizosphere acidification and HNO_2 build-up. The effect on Ca and Mg uptake was particularly marked. At this stage, however, there was no clear evidence that root disease incidence had been influenced (Fig. 4). This possibly resulted from the fact that an appreciable percentage of the seedling root system removed would likely have been above the zone of anhydrous ammonia injection. A further noteworthy feature of the data presented in Table 5 is the fact that the N content of plants from AN plots was not significantly higher than that of the majority of other treatments. This tends to discount the possibility that more N was supplied by AN than was by the LAN that other treatments received.

Table 5. Treatment effects on plant composition at the first sampling.

Plant Content	TREATMENT															LSD
	AN	BO	C	CAN	CR	ECO	EXT	MB	MF	N	OB	S	SF	SW	T	(0.05)
N (%)	5.27	4.91	5.13	5.37	5.07	5.10	5.11	5.27	5.00	5.03	5.22	5.12	5.19	5.04	5.09	0.29
P (%)	0.54	0.56	0.61	0.58	0.52	0.62	0.60	0.59	0.52	0.57	0.59	0.62	0.50	0.60	0.57	0.06
K (%)	3.59	4.05	4.28	5.38	4.19	4.79	4.90	5.15	3.84	4.58	4.02	4.45	3.66	4.40	4.95	1.24
Ca (%)	0.45	0.66	0.82	0.60	0.68	0.68	0.70	0.59	0.59	0.73	0.72	0.70	0.64	0.74	0.65	0.13
Mg (%)	0.33	0.53	0.66	0.45	0.56	0.54	0.53	0.34	0.46	0.55	0.58	0.57	0.49	0.57	0.45	0.15
S (%)	0.30	0.33	0.34	0.34	0.32	0.33	0.33	0.33	0.33	0.33	0.34	0.31	0.33	0.33	0.39	0.06
Na (mg/kg)	359.00	145.00	221.00	306.00	200.00	324.00	179.00	218.00	186.00	182.00	305.00	257.00	242.00	418.00	297.00	204.00
Zn (mg/kg)	57.00	56.00	60.00	64.00	56.00	65.00	61.00	54.00	57.00	54.00	53.00	59.00	57.00	54.00	52.00	7.00
Cu (mg/kg)	13.00	12.00	14.00	12.00	12.00	15.00	12.00	9.00	12.00	12.00	13.00	14.00	11.00	13.00	13.00	3.00
Mn (mg/kg)	85.00	100.00	113.00	93.00	90.00	85.00	86.00	82.00	100.00	92.00	91.00	90.00	120.00	85.00	94.00	18.00
B (mg/kg)	4.00	5.00	5.00	4.00	5.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	6.00	4.00	6.00	2.00

Table 6. **Treatment effects on leaf composition at flowering.**

Plant Content	TREATMENT															LSD
	AN	BO	C	CAN	CR	ECO	EXT	MB	MF	N	OB	S	SF	SW	T	(0.05)
N (%)	2.96	2.96	2.65	2.82	2.73	2.66	2.70	2.51	2.71	2.97	2.53	2.74	2.87	3.03	2.65	0.36
P (%)	0.34	0.31	0.31	0.30	0.30	0.33	0.32	0.29	0.31	0.34	0.30	0.31	0.32	0.31	0.31	0.03
K (%)	2.23	1.80	1.97	2.20	2.04	2.00	2.14	1.95	1.92	1.96	2.03	1.99	1.57	1.84	2.12	0.27
Ca (%)	0.53	0.63	0.56	0.57	0.56	0.58	0.57	0.57	0.61	0.61	0.54	0.59	0.74	0.68	0.55	0.09
Mg (%)	0.24	0.40	0.34	0.30	0.33	0.34	0.35	0.34	0.37	0.38	0.34	0.36	0.52	0.39	.032	0.06
S (%)	0.27	0.26	0.21	0.24	0.20	0.31	0.23	0.20	0.19	0.22	0.23	0.23	0.25	0.23	0.20	0.10
Na (mg/kg)	739.00	289.00	326.00	196.00	308.00	283.00	243.00	308.00	398.00	400.00	161.00	238.00	251.00	395.00	412.00	270.00
Zn (mg/kg)	28.00	23.00	21.00	22.00	22.00	24.00	22.00	19.00	20.00	25.00	21.00	24.00	26.00	22.00	20.00	6.00
Cu (mg/kg)	9.00	8.00	6.00	6.00	7.00	7.00	7.00	6.00	7.00	8.00	7.00	7.00	8.00	7.00	7.00	NS
Mn (mg/kg)	121.00	68.00	59.00	69.00	66.00	70.00	64.00	54.00	67.00	70.00	65.00	70.00	80.00	68.00	58.00	16.00
B (mg/kg)	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	NS

Interestingly, analyses of leaf samples obtained after 70 days (Table 6) indicated that the effects discussed above were still operative. While the level of K was no longer depressed, a likely result of better root development, Ca content was the lowest of all treatments and Mg uptake was still significantly depressed (Table 6). This indicates that the benefits of AN were still being expressed well into the season, confirmation of the effects evident in Figs. 4 – 8. Another striking feature of the plant analysis at this stage is the markedly increased levels of Na and Mn that were present in AN treated plants. The effect on Na uptake cannot currently be adequately explained, but an increase in Mn availability is another expected consequence of rhizosphere acidification. Significantly, Mn is recognised as having fungicidal properties (Graham & Webb, 1991) and this is possibly another mechanism by which AN reduced disease and enhanced growth. At this stage, evidence to discount the effect of N *per se* was confirmed, the N content of plants in AN plots being no different from that of plants in other treatments (Table 6).

Other important objectives of this experiment were to test the effects of alternative rotational systems – maize-wheat-maize (C), soya-wheat-maize (SW), maize-canola-maize (CAN), maize-crambe-maize (CR), maize-black oats-maize (BO), maize-fallow-maize (MF) and soya-fallow-maize (SF) – and the efficacy of a number of biocontrol agents marketed to farmers – Eco-T (ECO), Extrasol (EXT), Spin + Webstarter (S), Fungimax + Organoboost (OB), and Crop Guard (N).

The effects of the different rotational systems, some of which have already been discussed, proved to be disappointing. It is relevant to point out, however, that plant nutritional differences were not involved (Table 6). Also, in spite of the fact that effects were not evident in terms of grain yield, there was clear evidence that CAN, CR and SW treatments had depressed root and crown rot incidence 70 and 100 days after planting (Figs. 5 - 8). This is encouraging and it is possible that more meaningful yield responses will occur in the absence of moisture and temperature effects similar to that experienced this season.

The effects of the biocontrol agents tested were, with the exception of ECO and EXT, not encouraging. S, OB and N at no stage proved superior to the control (C) in terms of disease incidence or yield, however, EXT did reduce root and crown rot 70 days after planting and ECO significantly depressed disease and increased yield at 100 days. In terms of leaf analysis at flowering, ECO also significantly increased plant S content, but since all treatments contained adequate S levels (Table 6), it is unclear whether this could have played any meaningful role. No other effects on plant composition as a result of biocontrol applications were evident.

Sucker counts conducted 46 days after planting generally support the yield data already discussed, especially with regard to the two best performing treatments at the second and third samplings (Figs. 10 & 11). Considering the fact that sucker development had ceased some appreciable time before counts were done, it is perhaps rather surprising to see that the relationship between sucker counts and yield remained reasonable for as much as 100 days after planting. Relationships between sucker counts and root and crown rot ratings (data not shown) were equally good and clearly sucker counts can provide a useful and very easily obtained indication of root health. Perhaps, too, farmers should be less concerned about suckering than is usually the case.

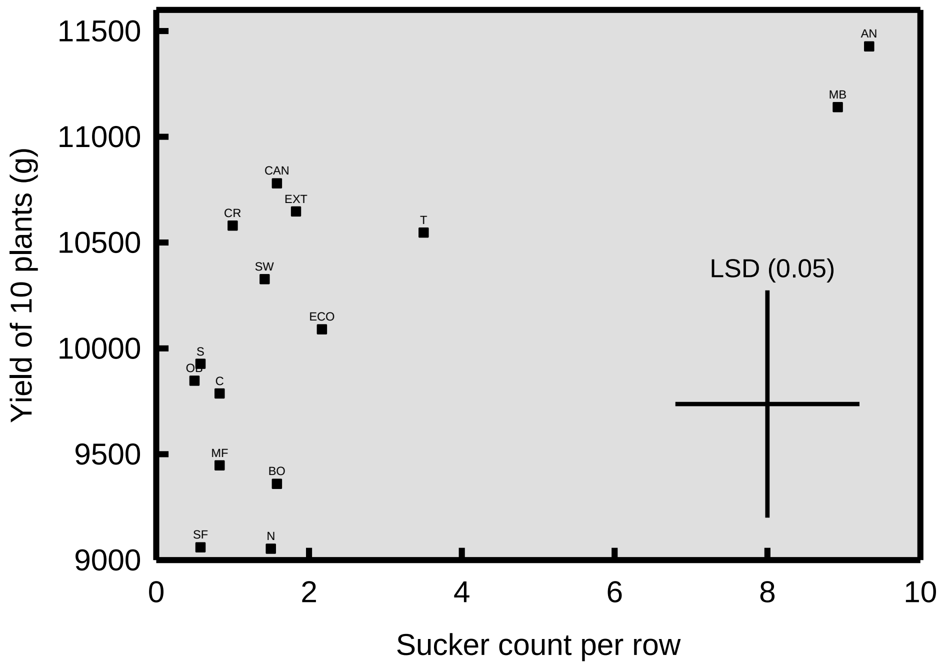

Fig. 10. **The relationship between suckering at 46 days and yield 70 days after planting.**

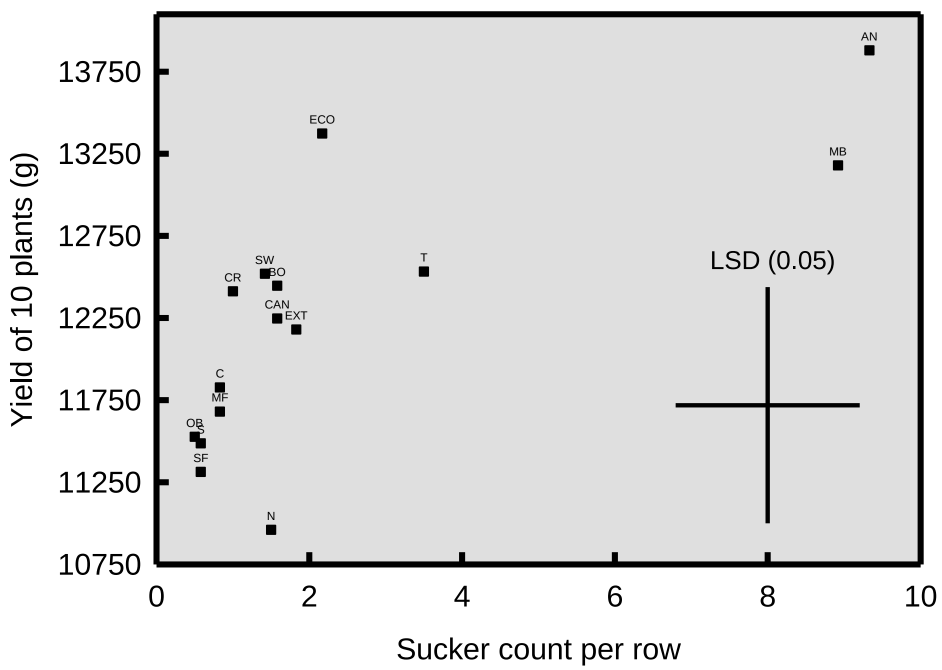

Fig. 11. **The relationship between suckering at 46 days and yield 100 days after planting.**

Crown and root rot severity

Treatments significantly affected crown and root rot severity. No crown rot was recorded on plants collected at the first sampling time. At the second and third sampling times, the lowest crown rot severities were recorded for the MB, AN, T and CAN treatments. The lowest root rot severities were recorded for MB, T and CAN at the first sampling time, and for MB, T, AN and CAN at the second and third sampling times (Table 7, Figs. 12a – 12j).

Table 7. **Treatment effects on crown and root rot severity of maize at three sampling times.**

Treatment[x]	**Crown rot**[yz]		**Root rot**[yz]		
	ST2	**ST3**	**ST1**	**ST2**	**ST3**
AN	0.63 hi	1.21 d	0.60 a-d	2.23 ef	2.17 d
BO	1.33 abc	1.77 bc	0.83 a	2.80 abc	3.37 ab
C	1.37 ab	2.00 ab	0.83 a	2.93 ab	3.43 a
CAN	0.80 g	1.33 d	0.47 cde	2.50 de	2.67 c
CR	0.97 f	1.70 c	0.63 abc	2.60 cd	3.13 ab
ECO	1.20 cd	1.67 c	0.77 ab	2.77 bcd	3.10 b
EXT	1.03 ef	1.87 bc	0.73 abc	2.60 cd	3.17 ab
MB	0.50 i	1.27 d	0.20 e	1.97 f	2.57 c
MF	1.37 ab	1.83 bc	0.60 a-d	3.07 a	3.27 ab
N	1.47 a	2.17 a	0.77 ab	2.87 abc	3.37 ab
OB	1.20 cd	1.90 bc	0.60 a-d	2.87 abc	3.13 ab
S	1.23 bcd	1.83 bc	0.80 ab	2.73 bcd	3.33 ab
SF	1.33 abc	1.73 c	0.53 bcd	2.77 bcd	3.13 ab
SW	1.17 de	1.87 bc	0.80 ab	2.63 cd	3.07 b
T	0.73 gh	1.30 d	0.33 de	2.17 f	2.47 cd
LSD (0.05)	0.16	0.24	0.30	0.29	0.33

[x]ST = Sampling time
[y]See Table 1 for description of treatments
[z]Means within a column followed by the same letter do not differ significantly (P = 0.05)