INFLUENCES OF CROP ROTATION, TILLAGE, RESIDUE MANAGEMENT AND WINTER COVER CROP ON TAKE-ALL IN SPRING WHEAT

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ABSTRACT

The effects of soil and residue management factors (tillage, post-harvest crop residue management and winter cover crops) and crop rotation (wheat following two barley crops, wheat following ryegrass) on take-all were compared in a 3-year field trial in Canterbury. Incidence of take-all was very high in plots that had previously grown barley, and very low in plots that followed ryegrass. Take-all incidence was also much greater in plots that were disced than in plots that were direct-drilled. Differences in soil pH and in plant emergence were also recorded between disced and direct-drilled plots, but there was no evidence that they caused the increased levels of take-all. There was a tendency towards reduced yields in the disced plots that had severe levels of take-all.
Keywords: wheat, take-all, crop rotation, tillage.

INTRODUCTION

New Zealand cropping farmers are coming under increasing pressure to crop their land more intensively. For instance, in a survey of 40 fields in Canterbury, New Zealand, over an 11-year period to 2001, wheat or barley were sown as 45% of main crops (G.S. Francis, unpublished data). To achieve this intensity of cropping it is essential that farmers manage their soils to maintain adequate soil organic matter contents. Management options chosen to maximise soil organic matter may increase or decrease the risk of soil-borne diseases.

Wheat and barley are susceptible to the soil-borne disease take-all (caused by *Gaeumannomyces graminis* var. *tritici* (Ggt)), with frequent crop rotations of wheat or barley crops being at greatest risk (Polley & Thomas 1991; Hardwick et al. 2001). Inoculum of Ggt can build up rapidly in a susceptible crop, but it is not a good soil competitor (Shipton 1981) and survives between susceptible crops on crop residues and on crop volunteers and susceptible grass weeds (Cotterill & Sivasithamparam 1988b).

Soil management practices can influence the carry-over of Ggt inoculum between susceptible crops. Tillage (minimum or conventional) when compared to direct drilling (also known as no-tillage) was reported in some situations to aid the breakdown of residues and lead to lower infection levels (Roget et al. 1996; Ennaifar et al. 2005). In some other studies, direct drilling has been associated with reduced take-all, particularly when compared with conventional plough-based tillage (Yarham 1981; Bailey et al. 1992). However, a substantial proportion of studies, including some trials of multiple years (Sutton & Vyn 1990; Bailey et al. 2001; Schroeder & Paulitz 2006), have reported no or inconsistent differences in the level of take-all infection between minimum tillage and direct drilling.

These inconsistent results and the changing soil management practices in New Zealand have highlighted the need for better understanding of the factors that affect management of take-all. This paper reports on a 3-year field trial that investigated the effects of soil and residue management factors (tillage), post-harvest crop residue management, winter cover crops and crop rotation on the incidence of take-all disease.

MATERIALS AND METHODS

A field trial was established on a farm near Darfield, Canterbury, in April 1999 in an area that had a history of arable cropping. The trial was a randomised block design with three replicates of 12 treatments (Table 1), consisting of two tillage types (discing, direct drilling), two post-harvest residue management treatments (retained, removed) and three winter cropping regimes (none, 'Massif' greenfeed oats, 'Quartet' ryegrass seed). 'Optic' barley was grown as the main crop in 1999/2000 and in 2000/2001. 'Sapphire' wheat was grown as the main crop in 2001/02. For all plots, the same tillage and residue treatments were applied to each successive winter and main crop. The exceptions to this were the ryegrass plots, which remained uncultivated from sowing in April 1999 until September 2001 when the wheat crop was sown.

For each crop, the disced plots were disced twice, cultivated twice with a maxitill at right angles to level the plots and then Cambridge-rolled before sowing. In 2000/01, plots were only disced once before secondary cultivation. For the winter crops, the plots were tilled in March or April; for the main crops, the plots were tilled in September or October. In each year, all crops were sown using a Great Plains Disc with fertiliser applied adjacent to the seed. Each year the oats plots were grazed once in August. The ryegrass plots were not grazed in their first year (1999/2000), but were grazed three times in the second year and twice in the third year.

In the first year, residue treatments were applied in April and in subsequent years they were applied after harvest of the main crop in March. Ryegrass straw was either evenly spread over the plots (i.e. residue retained) or removed to the edge of the plots (i.e. residue removed) by hand. For the barley plots, residues were either evenly spread across the plots or burned on the plots. The entire site was irrigated (with about 55 mm) once each year in late December. Hydrated lime was applied to the entire site at 1.7 t/ha on 29/5/99 and at 2.0 t/ha on 26/8/99. To control weeds and foliar diseases, agrichemicals were applied as required throughout the trial.

TABLE 1: Trial treatments.

Trt	Residue management	Tillage method	Winter 1999	Main 99/00	Winter 2000	Main 00/01	Winter 2001	Main 01/02
1	Retained	Disc	None	Barley	None	Barley	None	Wheat
2	Retained	Disc	Oats	Barley	Oats	Barley	Oats	Wheat
3	Retained	Disc	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Wheat
4	Retained	Direct drill	None	Barley	None	Barley	None	Wheat
5	Retained	Direct drill	Oats	Barley	Oats	Barley	Oats	Wheat
6	Retained	Direct drill	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Wheat
7	Removed	Disc	None	Barley	None	Barley	None	Wheat
8	Removed	Disc	Oats	Barley	Oats	Barley	Oats	Wheat
9	Removed	Disc	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Wheat
10	Removed	Direct drill	None	Barley	None	Barley	None	Wheat
11	Removed	Direct drill	Oats	Barley	Oats	Barley	Oats	Wheat
12	Removed	Direct drill	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Ryegrass	Wheat

In January 2002 during grain filling, 50 plants per plot were randomly selected for disease take-all assessment in the laboratory. Plants were scored as having severe take-all if at least 50% of the root system was affected. Measurements were made of soil factors, but only pH is reported here. Soil cores (six per plot at each of 0-7.5 cm and 7.5-15 cm depths) were taken from each plot immediately prior to sowing wheat. Soil pH was measured on bulked samples for each zone in each plot. Emergence counts of all crops were recorded (in 4 x 0.5 m^2 quadrats) within 4 weeks of their sowing (data not presented). Quadrat cuts (4 x 0.5 m^2) for yield assessment were taken from each wheat plot each February.

Data from each sampling date were examined separately, with analysis of variance (GenStat). Where effects are described as significant, they are significant to at least the 5% level.

RESULTS

In January 2002, the wheat plots that had previously grown barley had very high incidences of take-all at all severity levels, being approximately ten times that of plots following ryegrass (Table 2). Overall, take-all incidence was much greater in plots that were disced (57%) than in plots that were direct-drilled (13%), particularly in plots that followed barley where take-all incidence was 83% and 17% for disced and direct-drilled plots respectively. There was no such difference where wheat followed ryegrass, incidence being uniformly low in all plots.

There was a general trend towards a greater incidence of take-all where residues were retained than where they were removed, but this was not statistically significant. There was no residue effect where wheat followed ryegrass and take-all incidence was uniformly low. Where wheat followed barley, the residue effect trend was greater in direct-drilled plots (22% and 12% plants infected for retained and removed residues, respectively) than in disced plots (87% and 79%, respectively). Similar treatment effects were apparent for the incidence of severe take-all (Table 2).

TABLE 2: Disease incidence (% tillers infected) in wheat in January 2002. Values are main effects means for previous crop, tillage or residue treatments.

	Previous crop (mean of all levels of residue and tillage)			LSD
Disease	Ryegrass	Oats/barley	Fallow/barley	($P<0.05$; df=22)
Take-all (all levels)	5	53	47	8.3
Severe take-all	1	24	22	8.9
	Tillage (mean of all levels of crop and residue)			
	Disc	Direct drill		
Take-all (all levels)	57	13		6.8
Severe take-all	27	4		7.3
	Residue (mean of all levels of crop and tillage)			
	Retain	Remove		
Take-all (all levels)	38	32		6.8
Severe take-all	19	12		7.3

As well as differences in take-all severity, there were differences in soil pH and in plant establishment between no-till and disced plots. The direct-drilled plots had a higher (P<0.05) soil pH than the disced plots, at 0–0.75 cm (5.91 and 5.67, respectively) and a lower (P<0.05) soil pH at 7.5–15 cm (4.76 and 5.13, respectively). In addition, plant populations were greater (P<0.05) following discing than direct drilling (mean 222 plants/m^2 in disced plots, mean 181 plants/m^2 in direct-drilled plots). In order to gauge whether soil pH, plant population, or both may have affected take-all incidence, these factors were compared with take-all in each plot where wheat followed two barley crops (Fig. 1). Wheat plots following ryegrass were excluded due to their uniformly low take-all incidence. The incidence of take-all ranged between 62 and 97% in disced plots and between 2 and 47% in direct-drilled plots, there being no overlap in range of incidence (Fig. 1). There was also little overlap in the incidence of plants with severe take-all, which ranged between 18 and 68% in disced plots and between 0 and 25% in direct-drilled plots.

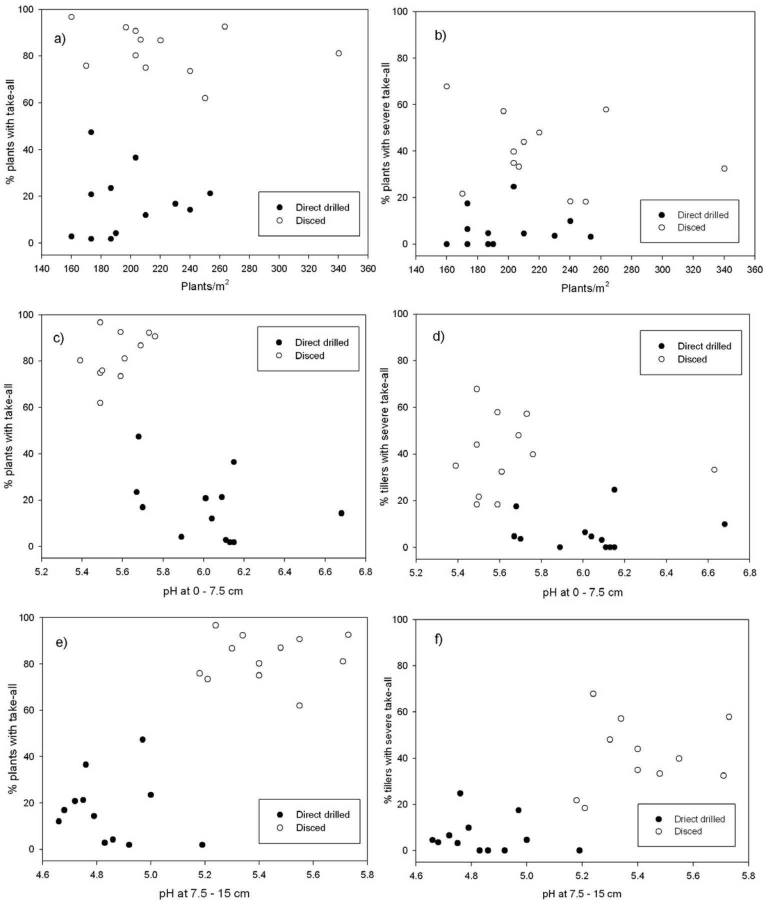

FIGURE 1: Take-all incidence (% plants with disease) in relation to (a-b) plant density, (c-d) soil pH at 0–7.5 cm and (e-f) soil pH at 7.5–15 cm in wheat plots sown after two barley crops (individual plot values).

There was no evidence (no correlation r value was greater than 0.26) for a relationship between plant population and take-all incidence or incidence of plants with severe take-all in either direct-drilled or disced plots (Figs 1a & 1b). The range in plant density was similar for direct-drilled or disced plots, but take-all incidence was higher in disced plots than in direct-drilled plots irrespective of plant density (Fig. 1a). Amongst disced plots, there was greater variation in incidence of severely infected plants than in total disease incidence (which was high in all plots) but, again, there was no evidence for a relationship between plant population count and take-all (Fig. 1b).

There was no evidence (no correlation r value was greater than 0.35) for a relationship between soil pH at 0–7.5 cm and take-all in the set of direct-drilled plots (where pH ranged from 5.6 to 6.2, with one outlier plot at 6.7) or in the set of disced plots (where pH ranged from 5.4 to 5.8, with one outlier plot at 6.6) (Figs 1c & 1d). There was a small overlap in 0–7.5 cm soil pH between the tillage treatments (over the range 5.7–5.8), where there were three instances for each tillage treatment. Incidence of take-all, or severe take-all, was considerably greater in each of the disced plots than the direct-drilled plots.

There was no evidence (no r correlation value was greater than 0.28) for a relationship between soil pH at 7.5–15 cm and take-all in the set of direct-drilled plots (where pH ranged from 4.6 to 5.2) or in the set of disced plots (where pH ranged from 5.2 to 5.7; Figs 1e & 1f). It is possible that there is a relationship between pH and take-all incidence when the full range of pH values are examined. However, it is not possible to separate the influence of pH from a direct effect of tillage, because there is very little overlap between pH readings for the two tillage treatments.

Wheat grain yield was not affected by any treatment ($P>0.05$) (Table 3). There was a trend towards greater yields following discing than direct drilling, although this was not statistically significant. Straw yield was greater ($P<0.05$) following ryegrass than the other crops and greater following direct drilling than discing.

TABLE 3: Wheat grain and straw yields (kg DM/ha) at harvest. Values are main effects means for previous crop, tillage or residue treatments.

	Previous crop (mean of all levels of residue and tillage)			LSD
Disease	Ryegrass	Oats/barley	Fallow/barley	($P<0.05$; df=22)
Grain	6188	6262	6183	436.7
Straw	9382	8597	8553	625.4
	Tillage (mean of all levels of crop and residue)			
	Disc	Direct drill		
Grain	6351	6070		356.5
Straw	8442	9247		510.6
	Residue (mean of all levels of crop and tillage)			
	Retain	Remove		
Grain	6110	6311		356.2
Straw	8770	8919		510.6

When averaged over all the treatments, there was a poor relationship between the incidence of severe take-all in the wheat crop and grain yield ($r= -0.10$, $n=36$). This poor relationship was primarily a result of the large variation in yield amongst the direct-drilled plots that was unrelated to take-all incidence, which was low in most plots (Fig. 2a). In contrast, the disced plots showed a moderate relationship between the incidence of severe take-all and grain yield (r= -0.61, n=18; Fig. 2b), with grain yield tending to decrease with increased take-all incidence.

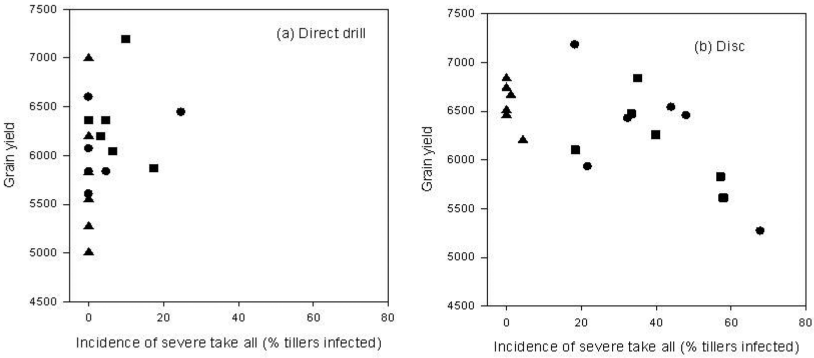

FIGURE 2: The incidence of severe take-all (% tillers infected) in relation to wheat grain yield (kg DM/ha) in 2002 for (a) direct-drilled and (b) disced soil (individual plot values) for ex. fallow/barley (●), ex. ryegrass (▲) and ex. oat/barley (■) plots.

DISCUSSION

Take-all was severe in some plots in the third year of the trial, when all plots were sown in wheat. The incidence of take-all was high where wheat followed two barley crops and low where it followed two ryegrass crops. Crop rotation is known to have a major influence on take-all, with severe disease often seen in wheat crops that follow barley, and ryegrass usually being a suitable break crop to reduce disease risk (Hardwick et al. 2001; Cromey et al. 2006).

After the effect of previous crops, the greatest difference in take-all was between plots that had been disced, where incidence and severity were high, compared with plots that had been direct-drilled, where incidence and severity were low. The majority of studies, including trials in New Zealand in 2004 and 2005 (Bithell et al. 2006), have reported no differences in the level of take-all between direct drill and minimum tillage (Sutton & Vyn 1990; Bailey et al. 2001; Schroeder & Paulitz 2006). Where differences were reported between minimum tillage and direct drill, it was largely direct drill that was associated with higher take-all (Roget 1988; Bockus & Shroyer 1998). This was thought to be due to increased residue breakdown by tillage (Moore & Cook 1984; Roget et al. 1996), although such tillage effects appeared to be restricted to environments where moisture levels were limiting for residue breakdown (Murray et al. 1991; Quemada 2004). Increased microbial activity was also cited as a contributing factor to lower take-all in tilled plots (Bockus & Shroyer 1998).

It was unexpected to find higher levels of take-all in disced than direct-drilled plots. However, some studies have reported less take-all in direct-drilled plots but often in comparison to ploughing or deep cultivation (Yarham 1981). For example, Cotterill & Sivasithamparam (1988a) reported less take-all in direct-drilled plots than in shallow (7 cm) or deep (25 cm) rotary hoe cultivated plots. The higher take-all in cultivated plots was thought to be caused by both greater inoculum distribution and deeper inoculum causing more disease. That study also highlighted the fact that complex interactions can occur between soil factors and disease expression, since shallow cultivation had both lower inoculum and infectivity levels at all soil depths than both direct drill and deep cultivation. Given the many factors involved with differing tillage systems, including inoculum (distribution, infectivity and survival), soil (bulk density, pore size and mineralisation) and stratification (nutrients and biological activity), complex interactions with variable results can be expected (Yarham 1981). This sensitivity is highlighted by the work of Roget et al. (1996) who reported that slightly different drilling tips on the same direct drill produced different levels of take-all in different years and sites.

In this trial, the higher take-all levels in wheat plots after discing than with direct drilling may have been due to one or more factors. Tillage may have directly affected the severity of disease in various ways. It may have spread the inoculum in the soil, leading to greater opportunities for infection, as suggested by Cotterill & Sivasithamparam (1988a), although it may also have enabled more rapid breakdown of residues, thus reducing inoculum and therefore disease. Tillage may also have had indirect effects on take-all severity in this trial. For instance, soil aeration has been demonstrated to increase the severity of take-all (Brassett & Gilligan 1990), possibly due to a longer period of saprophytic survival in light, as opposed to compact, soil (Garrett 1985).

Soil pH differences were recorded between tillage treatments and mean plant density was lower in direct-drilled plots ($P<0.05$). The role of pH on take-all infection levels has been linked to indirect effects, such as the availability of trace elements important in plant defences declining with increasing pH in the above range (Reis et al. 1983; Huber & McCay-Buis 1993). In particular, declining manganese levels were associated with reduced wheat root lignification responses to infection by take-all (Huber & Wilhelm 1988). In this trial, the lower pH in disced plots than for the direct drilled plots at depths of 0–7.5 cm and higher pH at depths of 7.5–15 cm were probably the result of the hydrated lime being incorporated by discing. Recent liming has been reported to result in more severe take-all (Christensen & Brett 1985), with the severity of take-all increasing from a pH of 4.5 to 8.5 (Reis et al. 1983). In this trial, the pH range (4.6 to 5.8) was substantially less than that recorded by Christensen & Brett (1985) and the effects were considered to be less clear-cut. Comparisons of individual plots at 0–7.5 cm in direct-drilled plots indicated that the higher pH values were probably not responsible for the lower take-all incidence, compared to the disced treatments. In contrast, at 7.5–15 cm the consistently higher soil pH in disced plots than in direct-drilled plots was at least partly responsible for the difference in disease. However, the absence of an overlap in pH between these two sets of data makes it impossible to separate pH from any other effects associated with tillage method. It certainly appears that there was little or no effect of pH over the range 4.6 to 5.2 (the direct-drilled plots), where incidence was low, and between 5.2 and 5.8 (the disced plots), where incidence was high.

There have been reports that higher plant densities can increase the level of take-all (Colbach et al. 1997), probably due to increased secondary spread from plant to plant associated with an increased density of roots in the soil. The consistently higher incidence of take-all in disced plots than direct-drilled plots over the same range of plant population suggests that plant population was not associated with take-all in our trial.

There appeared to be other, smaller treatment effects on take-all. The slight increase in take-all where a winter green-feed oat crop was grown rather than being left fallow may have been due to a slight host effect. Cropping of oats as a main crop is consistently reported to reduce take-all (Huber 1981), but when used as a short-duration break crop, results appeared less clear-cut. For example, oats as a summer break crop were as effective as a fallow when followed by ploughing, but not direct drill, in reducing take-all in a following wheat crop (Ennaifar et al. 2005). Ggt has also been observed as a saprophyte on oat roots, and although survival studies reported lower survival of Ggt under oats than under fallow, 33% of wheat straws under oats still yielded Ggt after 12 weeks of burial (Chambers 1971). The oat break in this study may have provided a weak host for Ggt to survive on in addition to its survival in wheat residues.

Take-all incidence was also slightly higher where residues were retained rather than removed. Burning residues could be expected to have a minor effect on the risk of take-all, since Ggt is present mostly on roots and stem bases, and it is the straw (low in Ggt) that is burnt. Other multiple-year trials have reported no differences in take-all following burning in comparison with removal of straw (Colbach et al. 1997).

The extent of severe take-all reported here in the wheat plots that followed barley would normally have been expected to reduce crop yield (Gutteridge et al. 2003). Although there was a tendency towards reduced yields in the disced plots that had severe levels of take-all, the effect was not significant and not seen in the direct-drilled plots. However, it appeared that the epidemic was late since the wheat crop had no height difference between the different tillage treatments. Conditions were also cool and moist during the grain filling period, which would have minimised any water stress effect caused by take-all. In other minimum tillage and direct drill trials in New Zealand, where the level of take-all did not differ between tillage treatment, there were small but consistently higher yields in minimum tilled than direct drill plots (Bithell et al. 2006).

This trial has clearly demonstrated that crop rotation has a major influence on the incidence and severity of take-all in wheat. The results of the trial indicate that tillage can also affect the incidence of take-all. However, it is likely that soil or other factors will influence the nature of this effect.

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