Chapter 14

TILLAGE AND SOIL-BORNE ROOT DISEASES OF WINTER CEREALS

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When reduced-tillage practices were adopted in Australia in the mid-1970s there was little information from overseas on the effects of tillage on root diseases of cereals, and none from Australia. However, it is now clear that soil-borne root diseases impose a major constraint on cereal production using reduced tillage in southern Australia, especially in sandy soils (Rovira and Ridge, 1983). This chapter discusses the effects of tillage on the major soil-borne diseases of cereals in Australia, which are listed in Table 14.1.

Table 14.1 The root diseases of cereals[a]

	Root disease	Pathogen
Southern Australia		
Major	Cereal cyst nematode	*Heterodera avenae*
	Take-all (hay die)	*Gaeumannomyces graminis* var. *tritici*
	Bare or purple patch[a]	*Rhizoctonia solani*
Minor	Common root rot	*Cochliobolus sativus (Helminthosporium sativum, Bipolaris sorokinianum)*
	Crown rot	*Fusarium graminearum*
	Pythium root rot	*Pythium* spp.
Northern New South Wales and Queensland		
Major	Common root rot	*Cochliobolus sativus*
	Fusarium	*Fusarium graminearum*

[a] *Rhizoctonia* also affect legume crops.

OVERSEAS STUDIES

Because of the paucity of Australian research this chapter is introduced with a brief review of overseas experience.

Take-all

Overseas studies on the influence of tillage on take-all have produced conflicting results - in England, Hood (1965), Jeater (1965), Brooks and Dawson (1968), and Lockhart *et al.* (1975) reported a lower incidence of take-all with direct drilling than with cultivation. Moore (1978) and Moore and Cook (1984) in the Pacific north-western USA reported a higher incidence and greater severity of take-all in no-till wheat than in wheat sown following cultivation. In England, Yarham and Hirst (1975) reported that results varied from season to season and with sites - in one season at two of four sites and in the next season at six of seven sites there was a slightly lower incidence of take-all (percentage of plants infected) with direct drilling;

however, the severity of attack was slightly higher with direct drilling. This greater severity of disease may have been linked to the distribution of inoculum, for Hornby (1975) found that the deep mouldboard ploughing conducted in England distributed the inoculum throughout the top 20 cm whereas in direct drill plots the inoculum was concentrated in the top 2.5 cm of soil. Although this difference in inoculum distribution influenced the infectivity down the soil profile at the beginning of the season, there were no differences between tillage treatments in the infectivity of the soil down to 20 cm at crop maturity. This result suggests that the take-all fungus spreads down the roots of the wheat equally well under the two tillage treatments.

In view of this divergence of results on take-all with different tillage systems by different workers, and the great differences in soils, climates and cropping practices between Australia and overseas countries, there seems little point in trying to apply overseas findings on take-all to Australian conditions.

Cereal cyst nematode

Although this pathogen is widespread throughout Europe there are no published descriptions of experiments on the effect of cultivation.

Rhizoctonia

Rhizoctonia root rot, which causes 'bare patch' in cereals in Australia, has been reported in the United Kingdom (Murray, 1981) and South Africa (Scott *et al.*, 1979) but it is not regarded as a major problem of cereals in these countries. Recently, Weller *et al.* (1985) reported a greater incidence of patches due to *Rhizoctonia solani* in direct drilled small grain crops than when sown following cultivation. This was the first report of losses due to this pathogen in the Pacific north-west of the United States. The finding of Sumner (1977) and Sumner *et al.* (1981) that there was less rhizoctonial root rot of peas following either subsoiling to a depth of 40-46 cm or mouldboard ploughing to 27-30 cm compared with 'no-till' (disc harrowing to 10-15 cm) has little relevance to Australian cereal-growing areas, where ploughing or cultivation for cereals varies from 5-10 cm and is generally conducted with either tines or discs.

Bean seedling mortality and damage from *R. solani* were found to be greatly reduced when soil was ploughed to 20-25 cm deep compared with discing of soil to 5-7 cm (Papavizas and Lewis, 1979). Although such ploughing is not practical in Australian cereal growing, it is interesting to note that the saprophytic growth of *R. solani* was six to seven times greater in disced soil than in ploughed soil and that the activity was concentrated in the top 5 cm of soil. In cereal cropping in southern Australia most cultivation is confined to the top 5-10 cm but the effect of cultivation to this depth on *Rhizoctonia* compared with direct drilling may be similar to that between the two more extreme forms of cultivation of Papavizas and Lewis (1979).

AUSTRALIAN STUDIES

Cereal cyst nematode

Cereal cyst nematode (CCN) is a major pathogen of cereals, affecting over two million hectares in Victoria and South Australia (Brown, 1984) and occurs in many areas where farmers are moving towards conservation farming.

Life cycle

Cereal cyst nematode oversummers in the soil as eggs within a thick-walled cyst. Following the autumn rains and a fall in soil temperature to below 15°C some 40-60% of the eggs hatch and the nematodes move through the moist soil. The nematodes enter the root in the zone of elongation immediately behind the root tip. This can stop elongation and lead to a proliferation of lateral roots, the tips of which may also be attacked by nematodes, resulting in further proliferation of laterals. The symptoms are illustrated in Figure 14.1, on which the 0-5 rating system used by Simon (1980) is based.

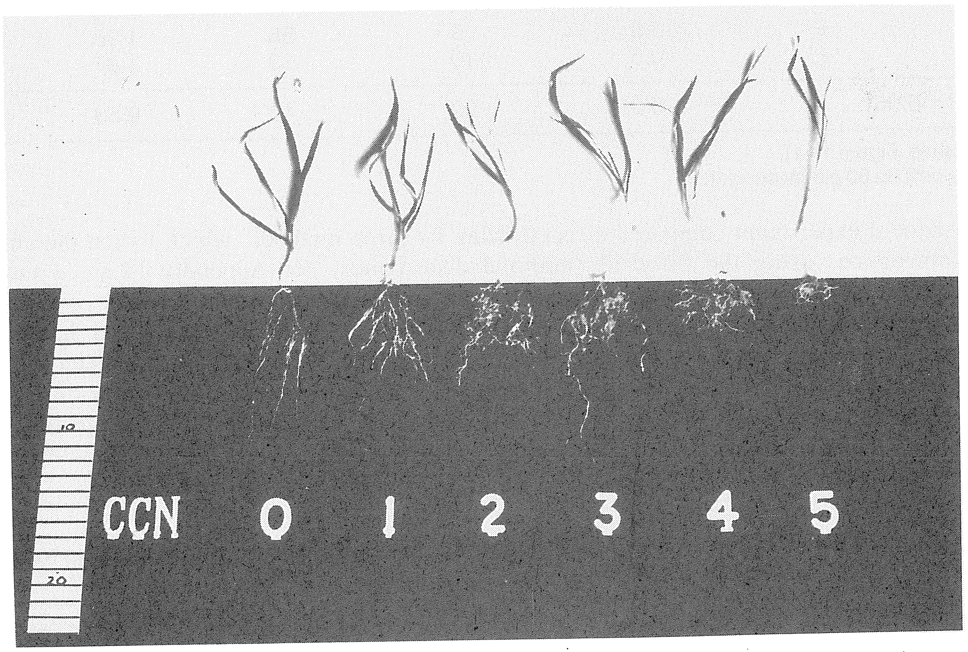

Figure 14.1 Root-damage rating on wheat for cereal cyst nematode, *Heterodera avenae* (Simon, 1980)

Some of the nematodes inside the roots develop into females, which protrude from the root. After being fertilised, these females grow to 0.5-1 mm in diameter and become filled with eggs. When the cereal plant is at the flowering stage, these 'immature females' are white and can be separated readily from the roots for counting. The females turn brown as they mature. By the time the cereal crop is ripe these females have become cysts filled with eggs.

Effects of direct drilling on CCN in South Australia

Research by CSIRO in South Australia (Appendix 14.1) has shown that direct drilling with a combine modified so as to give minimal soil disturbance (see appendix) will reduce CCN damage to roots, will result in a lower build-up of females, and will improve plant growth (Table 14.2), Roget and Rovira (1985). The beneficial effect of direct drilling was not as great as when using the nematicide Aldicarb applied at 2 kg ha^{-1} (in row), an uneconomical rate that virtually eliminates CCN damage. The improved growth with direct drilling was, however, comparable to that obtained with nematicides applied at commercial rates in other experiments (Rovira and Simon, 1982).

Table 14.2 Root damage by cereal cyst nematode (CCN) and growth of wheat sown by conventional cultivation (CC) and by direct drilling (DD)—results are the mean of three levels of nitrogen

Tillage	Nematicide (Aldicarb at 2 kg ha^{-1} in row)	Root damage by CCN[a]	Number of CCN females (per plant at flowering)	Plant growth		
				Plant dry wt[b]		Grain yield (t ha^{-1})
				Seedling (mg)	Flowering (g)	
CC	–	4.2	67	30	0.74	0.81
DD	–	2.7	24	47	0.90	1.32
CC	+	1.0	9	56	1.90	1.89
DD	+	0.5	10	59	1.87	1.87
LSD($P = 0.05$):		0.8	29	12	0.53	0.27

[a](0–5 rating, Figure 14.1).
[b]Means of 50 to 80 plants per plot.

A subsequent experiment compared direct drilling by three methods, which varied the amount of soil disturbance: using the Sirodrill (minimal disturbance, see Appendix 14.1), a cultivating seed drill with 3 cm points, and one with 15 cm points. These methods were compared with conventional cultivation. The results are given in Table 14.3. Despite the lower level of CCN damage compared with the previous experiment, and severe drought conditions, which limited the ability of plants to take advantage of reduced CCN attack, the experiment demonstrated that direct drilling with a cultivating seed drill still reduced CCN root damage comparable to that from the Sirodrill, which gave minimal soil disturbance (Table 14.3). Both of these experiments were at Calomba, South Australia, on a soil that was heavily infested with CCN.

Table 14.3 The effect of three direct-drilling methods and cultivation on CCN damage to wheat roots and plant growth

Tillage	Nematicide (Aldicarb at 2 kg ha^{-1} in row)	Root damage by CCN[a]	Number of CCN females (per plant at flowering)	Plant growth	
				Seedling dry wt (mg)	Grain yield (t ha^{-1})
CC	–	2.7	71	11	0.85
DD—15 cm points	–	1.4	48	12	0.99
DD—3 cm points	–	2.3	36	12	0.87
DD—Sirodrill	–	1.6	32	13	0.85
CC	+	0.4	8	16	1.03
DD—15 cm points	+	0.2	10	14	0.95
DD—3 cm points	+	0.4	10	12	0.94
DD—Sirodrill	+	0.2	10	16	0.96
LSD ($P = 0.05$) Tillage:		0.6	NS	2.6	NS
Nematicide:			39		

[a](0–5 rating, Simon, 1980)
CC = conventional cultivation.
DD = direct drilled.
NS = not significant.

These results have been confirmed in an experiment by R. Fawcett (personal communication) at Lamaroo, South Australia, where the levels of CCN in reduced-tillage treatments have been consistently lower than in long-fallow (cultivated) plots.

At another site (Avon, South Australia), CCN was barely detectable in the soil in 1977 at the beginning of rotation x tillage investigations (Rovira *et al.*, 1981). However, in the 6th year of the experiment (1982) treatment effects on CCN were evident (Table 14.4).

Table 14.4 Effects of 7 years of crop rotations and tillage on root damage from CCN (Rovira *et al.*, 1981)

Rotation	Root-damage rating (0–5 scale)	
	Cultivated	Direct drill
Continuous wheat (7 years)	1.80	0.54
Wheat–grassy pasture–wheat	0.05	0.01
Wheat–legume pasture–wheat	0.23	0.01
Wheat–peas–wheat	0.26	0.01

Although the levels of damage were low, except for continuous wheat conventionally cultivated, the consistently lower level with direct drilling supports the results obtained at Calomba, with its higher, more damaging level of CCN. It indicates that a major benefit of direct drilling where CCN occurs will be the greatly reduced rate of build-up of this disease with continuous or frequent cropping with susceptible cereals.

The mechanisms responsible for the effects of reduced tillage on CCN have not been studied, but several are suggested:

* soil disturbance distributes the cysts and nematodes more uniformly through soil than occurs in undisturbed soils;

* the roots of annual grasses that grow after the autumn rains until killed with herbicide trap the nematodes and reduce the numbers in the soil available to attack the wheat roots;

* movement of nematodes is greater in the cultivated soil because of its lower bulk density and better aeration than uncultivated soil.

Despite not knowing the mechanisms involved, the consistent results at several sites over several seasons indicate that direct drilling could be used to reduce the damage to cereals by CCN and, more importantly, to reduce the rate of build-up of this pathogen with cereal cropping.

Take-all

Gaeumannomyces graminis, the fungus that causes take-all, has been a problem for wheat and barley growers since the early days of colonisation of South Australia (Anon., 1868). At that time the disease mainly took the form of seedling blight resulting in early death of the plant - hence the name 'take-all'. With improvement in the phosphate and nitrogen status of soils from superphosphate and nitrogen input by legume pastures, the disease now manifests itself more at flowering to early maturity as premature ripening or 'hay-die'. Take-all may also cause considerable yield losses in its subclinical form (without above-ground symptoms) by reducing root growth and function and restricting water uptake during the critical grain-filling stage.

Life cycle

There are two varieties of *G. graminis* pathogenic to cereals, *G. graminis* var. *tritici*, which attacks wheat and barley, and *G. graminis* var. *avenae* which attacks oats as well as wheat and barley. Both varieties of take-all fungus are widely distributed but *G. graminis* var. *tritici* (Ggt) is more common.

The host range of Ggt is restricted to wheat, barley and grass weeds such as *Hordeum leporinum* (barley grass) and *Lolium rigidum* (annual ryegrass). The fungus has relatively poor competitive saprophytic ability. The fungus survives in the roots and crowns of grasses, wheat or barley, which were colonised while alive, but the fungus has difficulty colonising plant residues in soil. Once inside roots or crowns, the fungus is protected from microbial competition. As the dead plant tissue does not decompose during the southern Australian summer because of the dry conditions, the pathogen survives into the following season. Growth of the fungus and its competitors begins following the autumn rains, but unless Ggt finds a living host root in the form of grass, wheat or barley roots soon after its emergence from the propagule it will not survive. Survival and pathogenicity of the fungus depend on propagule size; that is, they are greater with inoculum in the crowns rather than on the smaller roots or fragments of the crowns (Hornby, 1975; Moore and Cook, 1984).

These attributes of Ggt, namely, the effect of propagule size on survival and infectivity, and dependence of the pathogen on roots of grasses for growth and survival, should favour reduction of take-all by cultivation. Cultivation breaks up crowns and reduces the survival of inoculum. It also prevents grass weeds from growing in autumn, which could otherwise host the pathogen up to sowing time.

Effects of tillage on take-all in southern Australia

Although cultivation should reduce take-all, the results from tillage studies in three States of Australia are not consistent. In Western Australia, G.C. MacNish (personal communication) has found less take-all in wheat from direct drilled plots compared with cultivated plots. J.F. Kollmorgen (personal communication) in a series of extensive trials on a range of soil types with different rainfalls in Victoria obtained varying effects of tillage on take-all. At some sites he found less disease with cultivation while at other sites he found the reverse or no differences due to tillage.

The results obtained at Avon, South Australia, have been more consistent in showing that the incidence of take-all, viz. percentage of plants with infected roots at tillering, was greater with direct drilling in 3 out of 4 years (Figure 14.2). With the medic-wheat and peas-wheat rotations, this higher incidence of take-all with direct drilling may have been associated with the higher populations of *H. leporinum* observed in direct drilled plots.

The amount of take-all in a crop may be affected by conditions in the previous season because Ggt prefers wet soil conditions (Cook and Papendick, 1972). This may explain the higher disease incidence in 1980 (following the wet 1979) compared with 1981 and 1982, each of which followed drier than average seasons. Levels of take-all in the wheat at tillering were significantly correlated (negatively) with yield in both 1979 and 1982, but not in 1980 and 1981.

One feature of the 1982 (Phase II) results (Figure 14.2) is the greater decline in take-all with continuous wheat sown with cultivation than when sown by direct drilling. This difference did not occur in the pasture-wheat rotation. This trend persisted into 1983 when there was a lower incidence of take-all on crowns from cultivated than from direct drilled plots. This suggests that suppression of take-all is occurring with cultivation, possibly stimulated by the breaking up of wheat roots and crowns that had been infected by Ggt and on which the suppressive bacteria had proliferated during the previous growing season (Rovira and Wildermuth, 1981). No such

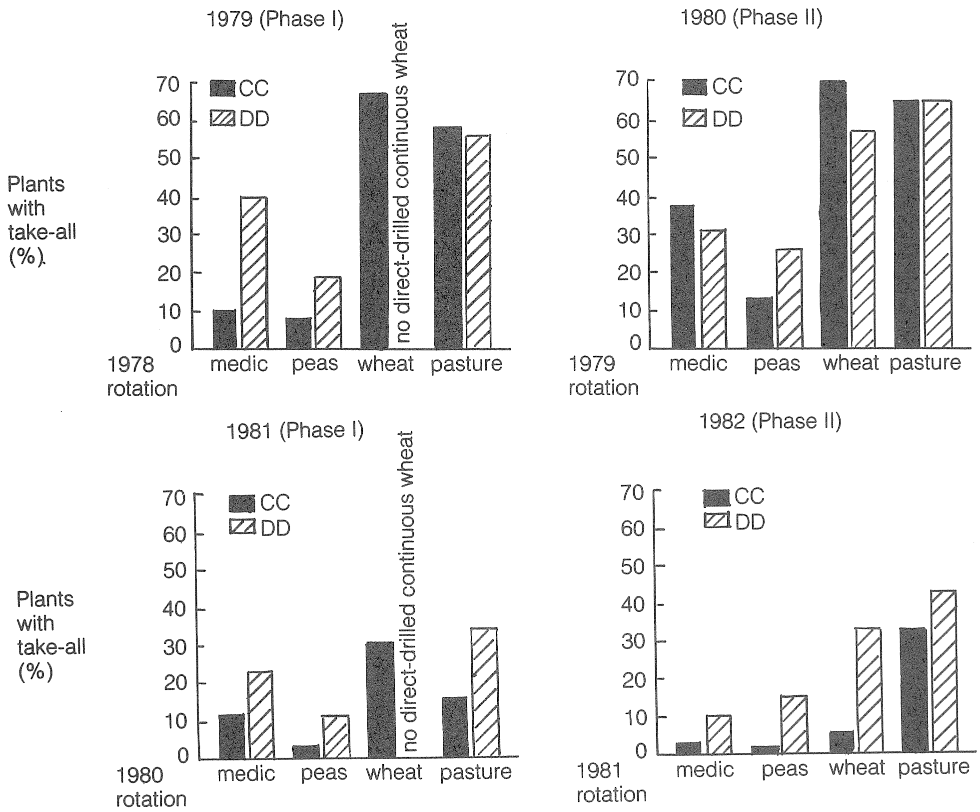

Figure 14.2 The effect of tillage (CC = conventional cultivation, DD = direct drilled) and rotation on the incidence of take-all on wheat roots at tillering over four growing seasons

fragmentation or spreading of suppressive bacteria would occur in direct drilled wheat. However, an alternative possibility is that, with direct drilling, the roots of young barley grass and ryegrass (*L. rigidum*) plants that grow until 1-3 days before spraying with herbicide prior to seeding may act as 'carriers' for the pathogen.

In 1984, at the Avon Experimental Site, counts of *H. leporinum* plants were made in the plots to be direct drilled; there were up to 10 000 seedlings m^{-2} and, in a glasshouse experiment, 41% of such seedlings transmitted Ggt to roots of wheat. Such results clearly indicate the tremendous inoculum level generated by the *H. leporinum* growing between the autumn rains and plants being sprayed with herbicide.

It is likely that soil type and seasonal conditions as well as rotation history, numbers of cultivations, and the prevalence of grasses prior to the spraying of herbicide will all be important factors influencing the response of take-all to tillage. The results by Kollmorgen in particular point to the sensitivity of the take-all fungus to its environment and the difficulty, at this stage, of drawing up general principles from which management strategies (apart from rotation) can be devised for the control of take-all with different tillage methods.

Rhizoctonia

Description

Rhizoctonia 'bare patch' in cereals is essentially a seedling disease and is caused by

Rhizoctonia solani Kuhn (*Thanatephorus cucumeris* (Frank) Donc., Talbot and Warcup). Unlike CCN and take-all, the host range of which is restricted to cereals and grasses, *Rhizoctonia* spp. have an extremely wide host range across most plant families. However, within the fungi designated *R. solani* there is some specificity in pathogenicity on particular plant species.

Figure 14.3 Seedlings affected by *Rhizoctonia* root rot to produce 'bare' or 'purple' patch in direct drilled wheat (scale 1:10)

Figure 14.4 Foreground—direct drilled wheat severely affected by *Rhizoctonia*
Background—wheat sown following cultivation

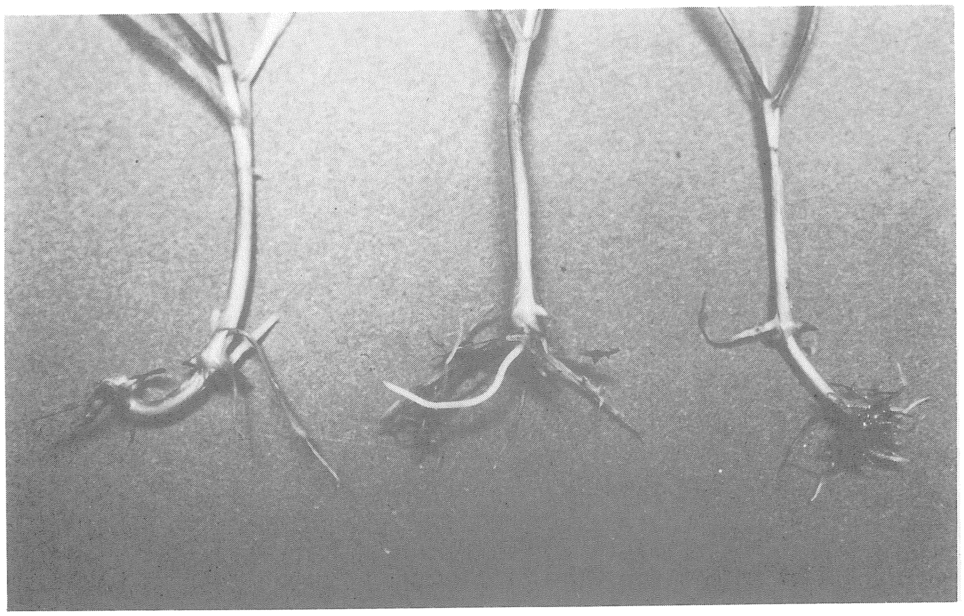

Figure 14.5 Wheat roots severely affected by *Rhizoctonia*—severity scale rating of 5 (McDonald and Rovira, 1985)

The strong competitive saprophytic ability of *Rhizoctonia* spp. in soil allows them to colonise particulate organic matter. Thus, farming practices in which organic matter is conserved on or near the surface could be expected to favour this pathogen.

The disease was first described in South Australia by Samuel (1928) and Samuel and Garrett (1932) as 'bare patch' in wheat and oats growing in highly calcareous sandy soils with 300-400 mm annual rainfall. In their publication, Samuel and Garrett described patches, of size 1-10 m^2, of stunted seedlings, with a purple hue on the stem and leaves, surrounded by relatively healthy plants.

The disease in this form has been a problem for many years on cultivated calcareous sandy soils of South Australia; but with the advent of reduced cultivation the disease has been reported in areas where it was not previously a problem - in New South Wales (K.J. Moore, personal communication), Victoria (J.F. Kollmorgen, personal communication) and Western Australia (G.C. MacNish, 1983, 1984, 1985, personal communication and R. Jarvis, personal communication).

Effects of tillage and crop rotation on *Rhizoctonia*

A suite of rhizoctonial-type fungi was isolated from roots of young seedlings showing these symptoms in direct drilled wheat at Avon, South Australia. The most pathogenic isolates were multinucleate; these were identified as *Rhizoctonia solani* according to the description by Parmeter and Whitney (1970). Binucleate rhizoctoniae, probably *Ceratobasidium* spp., isolated from infected roots were weakly pathogenic on wheat roots.

The root-damage rating was greater in direct drilled wheat than in wheat planted following cultivation. The average root-damage rating on direct drilled wheat was not affected by rotation

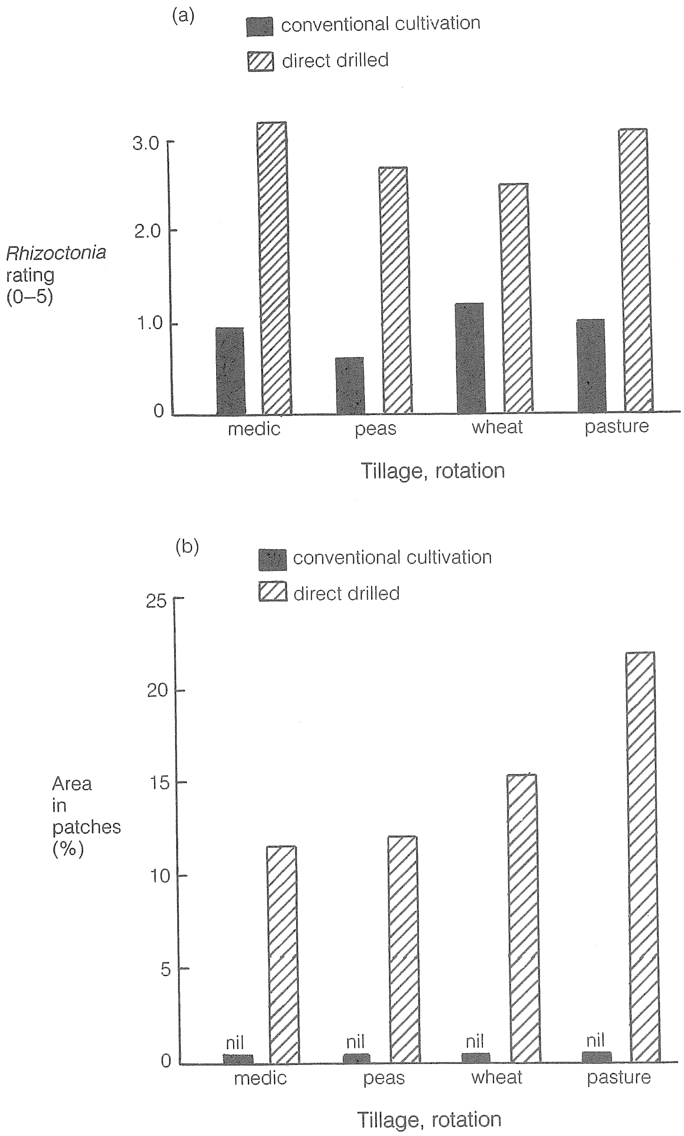

Figure 14.6 The effect of tillage and rotation on:
(a) the root damage caused by *Rhizoctonia* (severity scale 0–5, McDonald and Rovira, 1985)
(b) the area of crop affected by *Rhizoctonia* to produce patches of stunted seedlings

(Figure 14.6a) but the area lost to 'patches' was significantly greater in direct drilled wheat following the naturally regenerated grass-medic pasture than following sown medic, pasture or peas (Figure 14.6b).

The effect of soil type on the amount of root damage and the area of patches was assessed over a 50 m distance where there was a transition from a sandy-loam to a clay-loam soil. Table 14.5 shows that although the level of root damage caused by *Rhizoctonia* was not affected by soil texture, the effect on top growth, measured as the area of patches of poor growth, decreased as clay content increased.

The effect of soil disturbance on *Rhizoctonia* was demonstrated on the Avon sand hills where the annual pasture grew until one day before spraying with Spray.Seed, and then barley was sown with

Table 14.5 Effect of soil texture on rhizoctonial damage and yield of direct-drilled wheat at Avon, SA

Soil type	Soil composition		*Rhizoctonia* damage		Yield (t ha^{-1})[b]
	Clay (%)	Coarse sand (%)	Rating (0–5)[a]	Patches (% area)	
Sandy loam (Gc1)	17	35	2.9	53	1.55 (2.48)[c]
Intermediate soil	21	31	2.9	30	1.79 (2.41)[c]
Clay loam (Gc2)	25	20	2.7	0	1.83 (2.22)[c]

[a] *Rhizoctonia* root-damage rating (0–5), McDonald and Rovira (1985).
[b] Based on m^2 quadrats.
[c] Yield from cultivated plots with *Rhizoctonia* ratings < 1.0.

varying degrees of soil disturbance using the Sirodrill, the cultivator seed drill with 3 cm points, and the cultivator seed drill with 15 cm points, with and without one prior cultivation with a tine cultivator. The results demonstrate that soil disturbance directly reduced the rhizoctonial damage and area of patches, with significant increases in grain yield (Table 14.6).

Table 14.6 The effects of cultivation and direct drilling on *Rhizoctonia* damage to barley

Cereal	Tillage system[a]		*Rhizoctonia* root damage (0–5 max.)[a]	*Rhizoctonia* patches (% area)	Grain yield (t ha^{-1})
Barley cv. Galleon	Single cultivation with 15 cm shares on day of seeding		1.43	11.3	2.26
	Combined cultivator seed drill with 15 cm shares	direct drilled	1.53	20.5	2.32
	Combined cultivator seed drill with 3 cm shares	direct drilled	1.68	19.6	2.31
	Sirodrill	direct drilled	2.06	28.5	1.95
LSD ($P = 0.05$)			0.46	8.9	0.18

[a] *Rhizoctonia* root-damage rating (0–5), McDonald and Rovira (1985)

The timing and numbers of cultivations in relation to sowing were studied by Moore (1983a) and MacNish (1983; 1985). MacNish (1985) reported that the area of rhizoctonia patch in barley was reduced to the same level by a single cultivation 7 or 18 days before seeding as with two cultivations at 7 and 18 days. However, Moore (1983a) reported that one cultivation reduced rhizoctonia patches, but two cultivations were necessary to eliminate the patches. Jarvis (1984) reported that by using a seed drill modified to cultivate 10 cm deep and seed shallow in one pass, patches were reduced and yields increased by 0.44 t ha^{-1} compared with direct drilling with a triple-disc drill; even with the improvement with the modified seed drill yields were 0.57 t ha^{-1} below those achieved with conventional cultivation.

Neate (1984) found that the distribution of propagules of *Rhizoctonia* in a calcareous sandy loam in South Australia was extremely variable over the areas of his plots but most propagules were associated with particulate organic matter in the soil. Neate's study showed that dead grass debris carried most propagules of *Rhizoctonia* (Table 14.7a). In direct drilled plots, most propagules were between 0.71 and 2 mm in diameter while in cultivated soil most were between 0.25 and 0.71 mm. Their vertical distribution in the direct drilled soil is given in Table 14.7b.

Table 14.7(a) The association of *Rhizoctonia* propagules with organic components in the 0–5 cm layer of soil of direct-drill plots following grass–medic pasture (Neate, 1984)

Organic component	*Rhizoctonia* propagules (number/100 g soil)
Gramineae shoots	5.42
Gramineae roots	1.36
Medicago roots	0
Medicago pods	0.48
Medicago tops	no data
Unidentified organic matter	0.95

Table 14.7(b) Vertical distribution of *Rhizoctonia* propagules between 0.25 and 2 mm in diameter in a direct-drilled wheat crop (Neate, 1984)

Depth of soil (cm)	Propagules (number/100 g soil)
0–5	8.63
5–10	2.32
10–15	0.17

Reasons for the beneficial effect of cultivation

There appear to be at least two mechanisms responsible for the beneficial effect of cultivation where rhizoctonia is a problem: the direct effect of soil disturbance, and the reduction of inoculum build-up on grass roots.

Dubê (1971) reported from glasshouse trials that the severe root damage seen on roots of field-grown plants could not be reproduced unless soil from rhizoctonia patches was sampled and tested as undisturbed cores rather than mixed soil. Similar observations have been made in Western Australia (MacNish, 1984) and South Australia by A. Simon (personal communication) and McDonald and Rovira (1985). It is not known why disturbance causes such a reduction in disease. Possibly hyphae that have ramified through soil depend on the original propagule as a food base and, once severed from their food base, these hyphae may be more prone to suppressive activity by antagonistic soil microflora after disturbance.

A further possibility, following Neate's observations on the vertical distribution of propagules of *Rhizoctonia* may be the dilution of surface (0-5 cm) soil high in *Rhizoctonia* with deeper soil lower in the pathogen.

Possible agronomic solutions to *Rhizoctonia*

The work in Western Australia by Jarvis (1984) indicates that it may be possible to modify direct drilling practice to reduce damage by *Rhizoctonia*. This experiment indicates the importance of soil disturbance and surrounding the seed (seedling) with loose soil in reducing rhizoctonial damage - the faster root growth in loose soil, higher daytime soil temperatures near the surface, and the earlier emergence and earlier photosynthesis with shallow sowing could all account for the reduced damage. However, this technique depends on adequate rainfall to ensure that the soil around the seed remains moist.

A chemical fallow to control annual grasses during autumn before sowing will also reduce numbers of *Rhizoctonia* in direct drilled crops. At Avon, an autumn fallow using Spray.Seed and Bladex reduced root damage and increased plant dry weight and grain yield (Table 14.8). The herbicides had no effect on *Rhizoctonia* nor yields in cultivated plots.

The importance of roots of annual grasses in the *Rhizoctonia* problem in direct drilled crops was further demonstrated in a pot experiment in which field soil (from Avon) was inoculated with

Table 14.8 Effect of chemical fallow, with and without cultivation, on *Rhizoctonia* root damage and grain yield

Tillage	Chemical fallow:	*Rhizoctonia* root damage[a] –	*Rhizoctonia* root damage[a] +	Plant growth: Dry wt (g) at 8 weeks –	Plant growth: Dry wt (g) at 8 weeks +	Plant growth: Grain yield ($t\ ha^{-1}$) –	Plant growth: Grain yield ($t\ ha^{-1}$) +
CC		0.97	1.00	2.46	1.99	2.61	2.61
DD		2.85	2.13	0.65	2.26	1.22	2.21
LSD ($P = 0.05$)		0.70		0.70		0.68	

CC = conventional cultivation.
DD = direct drilled.
[a] *Rhizoctonia* root-damage rating (0–5), McDonald and Rovira (1985).

Table 14.9 Effect of annual ryegrass (*Lolium rigidum*) on *Rhizoctonia* damage to roots of wheat

Rhizoctonia propagules[a] (number added to soil)	Ryegrass	*Rhizoctonia*-damage rating
0	0	0.1
	3	0.3
	6	1.1
16	0	0.7
	3	2.8
	6	4.0
LSD ($P = 0.05$):		0.6

[a] Soil was inoculated with *Rhizoctonia* propagules (prepared from dead millet seeds on which *R. solani* had been grown) and incubated for 6 weeks. Ryegrass was grown in the incubating soil for 0, 3 or 6 weeks before being killed with Spray. Seed. The soils were then sown to wheat and *Rhizoctonia* root damage rated on a 0–5 scale (McDonald and Rovira, 1985).

propagules of *R. solani* (McDonald and Rovira, 1985). Ryegrass was grown in the soil for 0, 3 or 6 weeks before sowing wheat. Rhizoctonial damage to the wheat was assessed after 4 weeks. The damage caused by *Rhizoctonia* increased with the period of ryegrass growth (Table 14.9).

Common root rot and crown rot

Common root rot (*Cochliobolus sativus*) and crown rot (*Fusarium graminearum* Group 1) are serious pathogens of wheat in northern New South Wales and southern Queensland. There is little information on the effects of tillage on these pathogens, but L.W. Burgess (personal communication) has observed increased crown rot under wheat-stubble retention systems, and following killing of *H. leporinum*, *Avena fatua* and *Phalaris* spp. with herbicides or sub-tillage (blade ploughs and rod weeders).

However, Moore (1983b) reported that in northern New South Wales crown rot was not affected by tillage. As the experiment was conducted on fallow it can be assumed that the grassy weed conditions described by Burgess for the build-up of crown rot did not exist.

Experiments on black-earth soils at Warwick and Allora, Queensland, by R. Dodman, J. Littler and J. Marley (G.B. Wildermuth, personal communication) showed that burning of residue reduced the incidence of crown rot but there was no consistent effect of cultivation with either tined implements or a 30 cm blade. Opposite results were obtained in an experiment by G.B. Wildermuth, D.M. Freebairn and R.B. McNamara on a black earth at Greenwood, Queensland (G.B. Wildermuth, personal communication) in 1980/1981. It was found that residue retention *per se* had little effect on crown rot but sowing without prior tillage (i.e. 'no-till') increased infection: 54% of tillers were diseased compared with 8-17% in the other residue-handling and tillage treatments. These conflicting results from Queensland and New South Wales indicate the need for further field research on the effects of tillage on crown rot.

No information could be obtained for this review on how common root rot is affected by tillage.

INTERACTIONS BETWEEN HERBICIDES AND CEREAL ROOT DISEASES

The interactions between soil-borne root diseases of cereals and herbicides used in direct drilling has not attracted the attention of scientists in Australia despite the widespread use of herbicides and the reports that some herbicides exacerbate root diseases (Tottman and Thompson, 1978; Altman, 1985).

In studies with Spray.Seed and glyphosate, Neate (1984) showed that, although these chemicals were toxic to Ggt and *Rhizoctonia* in culture, they did not affect these pathogens in soil when applied at commercial rates.

In 1983 a number of farmers reported that patches of poor crop growth indicative of rhizoctonia root rot were more abundant in parts of fields treated with the herbicide Glean. Glean is recommended at rates of 15-20 g ha^{-1} for direct drilling of wheat or triticale together with Spray.Seed or glyphosate or for incorporation into soil before sowing wheat and triticale. Breakdown of Glean in soil is affected by pH. In alkaline soils (pH 7.6-8.6) it persists at levels that kill *Medicago* spp., *Trifolium* spp. and peas for up to 22 months. Dupont recommends that barley can be planted 9 months after applying Glean. However, an investigation of two commercial crops of barley (cv. Galleon) planted 12 months after applying Glean to control *L. rigidum* in wheat and oats showed greater areas of crop affected by *Rhizoctonia* where Glean had been applied than in untreated areas in the same fields. Both fields were heavily infested with

Table 14.10 Areas of *Rhizoctonia* patches and yields of Galleon barley in fields, parts of which were treated with Glean[a] 12 months before planting

Field	Soil	Glean	Severe *Rhizoctonia* patches[b] (% area of crop)	Grain yield[c] ($t\ ha^{-1}$)
1	Calcareous sandy	–	23	3.33
	loam (Gcl)	+	81	1.79
2	Calcareous sandy	–	37	2.23
	loam (Gcl)	+	78	1.53

[a] Glean applied at 15 g ha^{-1} in April 1982 for control of annual ryegrass in wheat (cv. Condor) in Field 1 and in self-sown oats (cv. Avon) in Field 2. Galleon barley planted by direct drilling with a cultivating seed drill in May 1983 in both fields.
[b] Grain yields obtained from m^2 quadrats at maturity were:
Inside most severe *Rhizoctonia* patches: 0.35 t ha^{-1}
Outside *Rhizoctonia* patches: 2.54 t ha^{-1}
[c] Based on a machine harvest over 70 × 7 m (wide) strips. Six replicate strips from Glean-treated areas and three from untreated areas.

Rhizoctonia, but the patches of poor seedling growth were more than doubled where Glean had been used (Table 14.10). Despite many plants with roots affected by *Rhizoctonia* recovering following spring rains, yield differences of 0.50 and 1.54 t ha^{-1} between treated and untreated areas in the two fields occurred (Table 14.10).

Controlled-environment experiments have since confirmed that Glean, incorporated into soil at the time of seeding, can increase the amount of rhizoctonia damage to wheat roots from both the low background level of *Rhizoctonia* in the soil, and from propagules of *Rhizoctonia* added to soil (Table 14.11).

Table 14.11 Effect of Glean on *Rhizoctonia* damage to roots of wheat, cv. Condor, in calcareous sandy loam

Propagules (number added per kg soil)	Glean applied (g ha^{-1})	*Rhizoctonia* root damage rating
0	0	0.14
	5	0.51
	10	1.01
	20	1.72
16	0	0.78
	5	1.48
	10	1.96
	20	2.36
Effect of Glean and inoculation significant at 0.01 %	LSD (P = 0.05):	0.85

The interaction between Glean and *Rhizoctonia* occurred with a calcareous soil with pH 8.3, which is approaching the upper limit (pH 8.6) above which Glean is not recommended because of long-term residual effects against legumes. Nevertheless, as the problem has been reported in the field and substantiated under controlled-environment conditions further investigations are needed. Other experiments have shown that most *R. solani* isolates from wheat are highly pathogenic to medic and peas, which further complicates the residue problem with Glean.

With the limited information available, the management strategy suggested where Glean has been used in *Rhizoctonia*-prone soils of high pH would be to cultivate before sowing in preference to direct drilling.

In another experiment where take-all inoculum was added to soil Glean did not affect the severity of disease on wheat.

CONCLUSIONS

In this paper considerable evidence is provided that tillage affects three of the major root diseases of wheat, barley and oats. Only for one disease, CCN, is there consistent evidence of a reduction of the disease with direct drilling. With *Rhizoctonia*, the evidence is consistent from four States that root damage is reduced by cultivation. However, despite this consistent finding, more research is needed to establish the mechanisms and general principles involved so that sound farming practices can be developed to reduce damage from *Rhizoctonia* with reduced cultivation. Some progress has been made with agronomic management, notably by disturbing the soil to a greater depth than is usual with direct drilling.

With take-all, variable effects of tillage have been obtained by J.F. Kollmorgen at different sites in Victoria, while G.C. MacNish (WA) and A.D. Rovira (SA) reported opposite effects. In many ways, such a confusion of results is not surprising due to the sensitivity of this fungus to the presence of suitable hosts, soil conditions and biological control.

From this state of apparent chaos research strategies need to be developed to investigate the fundamental principles involved within the range of Australian soils and climates for each of the major root diseases. More information is needed on the effect of soil type, disease level in the soil, density and types of annual pasture species (especially grasses) before herbicide treatment, time between spraying and sowing, soil bulk density, soil moisture and temperature at sowing on the development of disease as the season progresses.

With both take-all and *Rhizoctonia* there is little doubt of the importance of grasses in building up these diseases, both in the pasture year preceding the cereal and in the pasture that regenerates following the autumn rains. Thus, a key to the success of reduced cultivation for wheat and barley will be grass control and pasture management.

Overseas results on take-all and *Rhizoctonia* have little relevance to southern Australia because the conditions under which cereals are grown here differ so markedly from most of Europe and North America.

This all points to the need for more intensive work at a number of sites in southern Australia representative of the major cereal-farming areas. To understand the effects of tillage on the complex ecology and epidemiology of soil-borne root diseases of cereals a great deal of collaboration and consultation will be required from the scientists involved.

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Appendix 14.1: RESEARCH IN SOUTH AUSTRALIA BY CSIRO

Most of the CSIRO research described in this paper was undertaken at Avon, 100 km north of Adelaide, on calcareous sandy loams of pH 8.4, classified as Gc1.12 (Northcote *et al.*, 1975). Long-term average rainfall is 350 mm, which is winter dominant. The annual rainfall for the 4 years of results described in this paper were 427 mm (1979), 250 mm (1980), 240 mm (1981) and 164 mm (1982).

The studies on CCN were conducted at Calomba (15 km SE of Avon) on a similar soil. In 1980, when the experiments described in this chapter were carried out, the site received 316 mm.

The design for these experiments is given by Rovira and Venn (1985).

The tillage treatments in these studies were:

* Conventional cultivation - This was the district practice of three cultivations to a depth of 5-7 cm with a tine cultivator between the 'opening' autumn rain and sowing.

* Direct drilling - Most of the experiments were done with the Sirodrill, which sows with minimum soil disturbance and has fluted coulter discs, which cut through plant residues to produce a 7 cm deep slit in the soil. This is 2 cm deeper than the depth of penetration of the following tines. Sowing with the Sirodrill was done 1-3 days after the annual pasture was sprayed with Spray.Seed at 2 L ha^{-1}

  Two trials were conducted in which direct drilling was done with a modified cultivator seed drill using 3 cm and 15 cm wide shares to increase soil disturbance.