Long-term effects of stubble management on the incidence of infection of wheat by *Fusarium graminearum* Schw. Group 1

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Summary. The effect of 3 stubble management regimes (burning after harvest, incorporation with a disc plough, retention on the surface) on the incidence of infection of wheat with *Fusarium graminearum* Schw. Group 1 was studied for 5 seasons at 2 sites at Moree, New South Wales. One site had high initial incidence (site A) and the other low initial incidence (site B).

There were no differences in incidence of infection between retained and incorporated treatments. Stubble burning reduced the increase in incidence of infection in 2 of 5 years at site A and 3 of 4 years at site B. Failure of control in other years was attributed to susceptible weed hosts and poor burns. When stubble was retained on the plots at site B that had been burnt, incidence of infection in the next season increased to a level not significantly different from the retained or incorporated treatments. Incidence of infection at the fourth consecutive wheat crop at both sites was close to the maximum recorded, which was 92% at site A and 65% at site B. There was no evidence of a decline in incidence by the time of the most recent season assessed (eighth year of continuous wheat cultivation at site A, and sixth year at site B). In most years, the differences in yield between treatments were not significant.

Introduction

Crown rot caused by *Fusarium graminearum* Schw. Group 1 is one of the main diseases limiting yields of wheat in northern New South Wales and Queensland (Murray and Brown 1987). The increased incidence and economic importance of the disease has been linked to the adoption of stubble retention, since the fungus survives as mycelium in infested residues (Wearing and Burgess 1977).

Previous work has shown that burning stubble after harvest leads to a significantly lower incidence of infected plants in the following wheat crop than if stubble is retained on the surface or incorporated into the surface soil over the fallow period (Klein *et al.* 1988; Dodman and Wildermuth 1989; Summerell *et al.* 1989). These studies were limited to 1 or 2 seasons on sites with high initial levels of the disease, and little is known of how stubble management affects the build-up of disease from low initial levels. There is some evidence that the incidence of infection with *F. graminearum* Group 1 within a field may decline with time (Klein *et al.* 1991), but long-term trends in disease incidence have not been studied widely for this or any other *Fusarium* crown or foot rot of cereals.

The incidence of whiteheads is the disease parameter most strongly correlated with potential yield loss in the current season (Klein *et al.* 1991), but whiteheads and the other main symptom, stem browning, are highly dependent on soil moisture conditions for their expression. In some years, more than half of all infected plants can remain symptomless (Klein *et al.* 1991). The extent of colonisation of infected plants, and, hence, the quantity of inoculum produced, is independent of disease severity as measured by stem browning (Summerell *et al.* 1989). Quantifying pathogen populations directly is difficult because the fungus survives in infected residues, which differ significantly in size from virtually intact straws to fragments <1 mm in length (Wearing and Burgess 1977). However, the incidence of infection, estimated by the frequency of isolation of the pathogen from the stem base and subcrown internode, can act as an assay of the relative inoculum potential after different management treatments, as well as being an indication of the amount of inoculum available to be carried forward into the next season.

This study was done to determine the consistency of the effects of stubble management on crown rot disease over longer periods of continuous wheat cultivation, and the effect of stubble management on the increase in incidence from low initial levels. The experiment of Summerell *et al.* (1989) on a site with a high initial incidence of crown rot was continued for 5 seasons, and a second stubble management trial was established on a site with a low initial incidence. This paper reports changes in incidence of infection over 5 years of stubble treatments at each site.

Materials and methods

The trial sites were located at the University of Sydney's Livingston Farm, Moree, New South Wales. The soil is a neutral, self-mulching, grey clay (Summerell and Burgess 1988). Site A, which had a more sodic soil, had been cleared of native pasture and used for 3 consecutive wheat crops, with stubble retained during the fallows, before stubble management treatments were first applied in the summer fallow before the 1986 season. Site B was slightly more elevated and better drained than site A. Two sorghum crops, followed by a 12-month fallow, preceded a wheat crop in 1986. Stubble management treatments were first applied at site B before the 1987 season. Plots were 20 by 50 m and separated by an 8-m buffer at site A, and 45 by 225 m and separated by an 11-m buffer at site B. Three treatments were arranged in a randomised complete block design with 4 replicates at both sites. The effects of differential stubble treatments were followed from 1986 to 1990 at site A and from 1987 to 1991 at site B.

Three stubble management practices were imposed in December or January each year, following harvest in November. The treatments were stubble burning followed by ploughing to 10 cm with an offset disc plough; incorporation of unburnt stubble in the top 10 cm of soil with a disc plough; and stubble retention with subtillage with a blade (sweep) plough. The latter treatment caused a minimum of soil disturbance and left the stubble standing upright. A second tillage operation using a blade plough on retained plots, and a blade, disc, or chisel plough on incorporated and burnt plots, was done in February or March to control weed growth if required; otherwise, weeds were controlled with chlorsulfuron or glyphosate as necessary in all plots. Stubble was not burnt at site B in the fallow preceding the 1991 season because of unfavourable weather conditions.

Stubble levels were measured before sowing in 1989 at site A and in 1989, 1990 and 1991 at site B, by collecting stubble and soil to 5 cm from 4 quadrats (36 by 36 cm) per plot. Stubble was separated by wet sieving and dried overnight at 80°C before weighing. Presowing stubble levels at site A in 1986 and 1987 have been published (Summerell *et al.* 1989).

Wheat was sown in June each year (19 July in 1991) at 20 or 25 cm row spacing, using seed drills adapted for sowing through stubble. Cultivar Sunstar was sown at both sites in all years except 1986 at site A when alternate strips of Sunstar and Suneca were sown (Summerell *et al.* 1989), and 1991 at site B when Janz was used following the withdrawal of Sunstar as an approved variety. In keeping with district practice, no fungicides were used.

Incidence of infection with *F. graminearum* Group 1 was assessed by isolation of the fungus from plant tissues. Fifty plants were collected at random from each plot between late dough development and harvest maturity. The basal 2 cm of the main stem, together with the subcrown internode, was removed, surface sterilised, and plated onto modified potato dextrose agar as previously described (Summerell *et al.* 1989).

Plots were harvested in November each year and grain yield was determined. Yield was not measured at site A in 1985 and 1988. Weather data were obtained from the Bureau of Meteorology Station, Moree, 8 km from site A and 5 km from site B.

Statistical analyses

Before analysis, arcsine ($\sqrt{x}$) transformation was used on isolation frequency data, and $\log_{10}$ transformation on stubble levels. Yields were analysed without transformation. Analysis of variance was used to determine significance of treatment effects within each year, and the least significant difference was used to

Table 1. Rainfall (mm) at Moree in 1985–91 and long-term mean rainfall from Bureau of Meteorology records

Fallow and total rainfall were measured from December of previous year

	Fallow rainfall		Growing season rainfall		Total rainfall
	Dec.–Feb.	Mar.–May	June–Aug.	Sept.–Nov.	Dec.–Nov.
1985	130	107	191	148	576
1986	196	82	133	208	619
1987	122	116	125	79	442
1988	211	272	157	132	772
1989	130	249	110	144	633
1990	104	191	94	58	447
1991	211	215	60	67	553
25-year mean	197	135	111	137	580

Table 2. Effect of stubble management treatments on dry weight of wheat stubble (t/ha) remaining before sowing at two sites

Values are untransformed means of four replicates
Within columns, means followed by the same letter are not significantly different at $P = 0.05$ by least significant difference of log-transformed data

Treatment	Site A 1989	Site B 1989	Site B 1990	Site B 1991
Retained	3.39a	3.45a	1.93a	1.41a
Incorporated	1.73b	3.14a	0.86b	0.50b
Burnt[A]	0.87c	0.73b	0.19c	1.28a

[A] Stubble retained in 1991 only.

separate means when treatment was found to be significant at $P = 0.05$. When appropriate, comparisons between years within treatments at each site were made using *t*-tests with a significance level of $P = 0.05$, or by calculating the apparent infection rate, *r*, using the logistic model of Vanderplank (1963).

Results

Total rainfall was close to average in most years (Table 1), although 1987 and the latter half of 1990 and 1991 were drier than average. Rainfall in 1988 was higher than average. Rainfall during the first 3 months of fallow, when temperatures are high and stubble decomposition should be most rapid, was average or below in most years. Above-average total fallow rainfall in 1988, 1989, and 1991 was due to heavy falls in April and May, resulting in wet starts to these seasons.

Stubble management had a significant effect on the quantity of stubble present before sowing (Table 2). Except in 1989 at site B, incorporation significantly reduced the dry weight of stubble on the plots. Burning caused a further significant decrease in stubble cover in all years measured.

The progress of infection of wheat with *F. graminearum* Group 1 at the 2 sites is shown in Fig. 1. There was no significant difference in the frequency of isolation of *F. graminearum* Group 1 between the stubble retained and incorporated treatments at either site in any year.

At site A, incidence of infection was significantly lower in the burnt treatment than the other 2 treatments in 1986 and 1987, but not in subsequent years (Fig. 1). At site B, incidence of infection was significantly lower in the stubble burnt treatment from 1987 to 1990. However, the incidence of infection in the burnt plots increased significantly, from 4% in 1987 to 21% in 1988, and the apparent infection rate was as high for this treatment as for the other 2 treatments over the same period, indicating that stubble burning had failed to control the disease in 1988. When stubble was retained before the 1991 season on the plots that previously had been burnt, incidence of infection rose significantly ($P<0.05$) from 15 to 43%.

The incidence of infection with *F. graminearum* Group 1 in retained and incorporated plots at site B increased almost linearly from 1986 to 1989, the first 4 wheat crops, with little change in 1990 or 1991 (Fig. 1). At site A, the incidence of infection was close to maximum by 1986, the fourth wheat crop after native pasture (Fig. 1). This suggests that about 4 seasons are needed for crown rot to build up from low levels to maximum incidence under continuous wheat cultivation with retention of stubble in this environment.

At neither site was 100% infection recorded, even in the eighth consecutive wheat crop at site A. Infection levels appeared to reach a plateau at about 60% at site B, and at 70–85% at the poorer drained site A. The incidence of infection was lower in all treatments at site A in 1987 than in either 1986 or 1988, and these differences were significant when the incidence in each year was compared for the individual treatments using *t*-tests.

There was no evidence of a decline in incidence after 8 years of continuous wheat at site A. Although incidence in the retained and incorporated plots at site B appeared to decrease slightly in 1991, the incidence of infection in each treatment was not significantly different from either 1989 or 1990 when compared using *t*-tests.

In most years, the effect of differences (even large ones) in incidence of infection on yield was quite small (Table 3). Only in 1990 and 1991 at site B was there a significant effect of treatment on yield. In 1990, yield from the burnt treatment was significantly ($P<0.01$) higher than from the other 2 treatments, while the

Table 3. Effect of stubble management on grain yield at two sites (t/ha)

At site B, mean of all plots in first wheat crop before stubble management treatments was 4.49 t/ha
Values are means of four replicate plots at each site
Within site and year, means followed by the same letter are not significantly different at $P = 0.05$ by Fisher's protected l.s.d.

Treatment	1986	1987	1988	1989	1990	1991
			Site A			
Retained	2.37a	2.08a	n.d.	1.06a	1.38a	—
Incorporated	2.75a	2.11a	n.d.	1.10a	1.39a	—
Burnt	2.60a	2.29a	n.d.	1.06a	1.63a	—
			Site B			
Retained	—	1.31a	2.68a	1.61a	1.07a	0.63a
Incorporated	—	1.43a	2.82a	1.60a	1.32a	0.96b
Burnt	—	1.43a	2.93a	1.79a	2.18b	0.89ab

n.d., not determined.

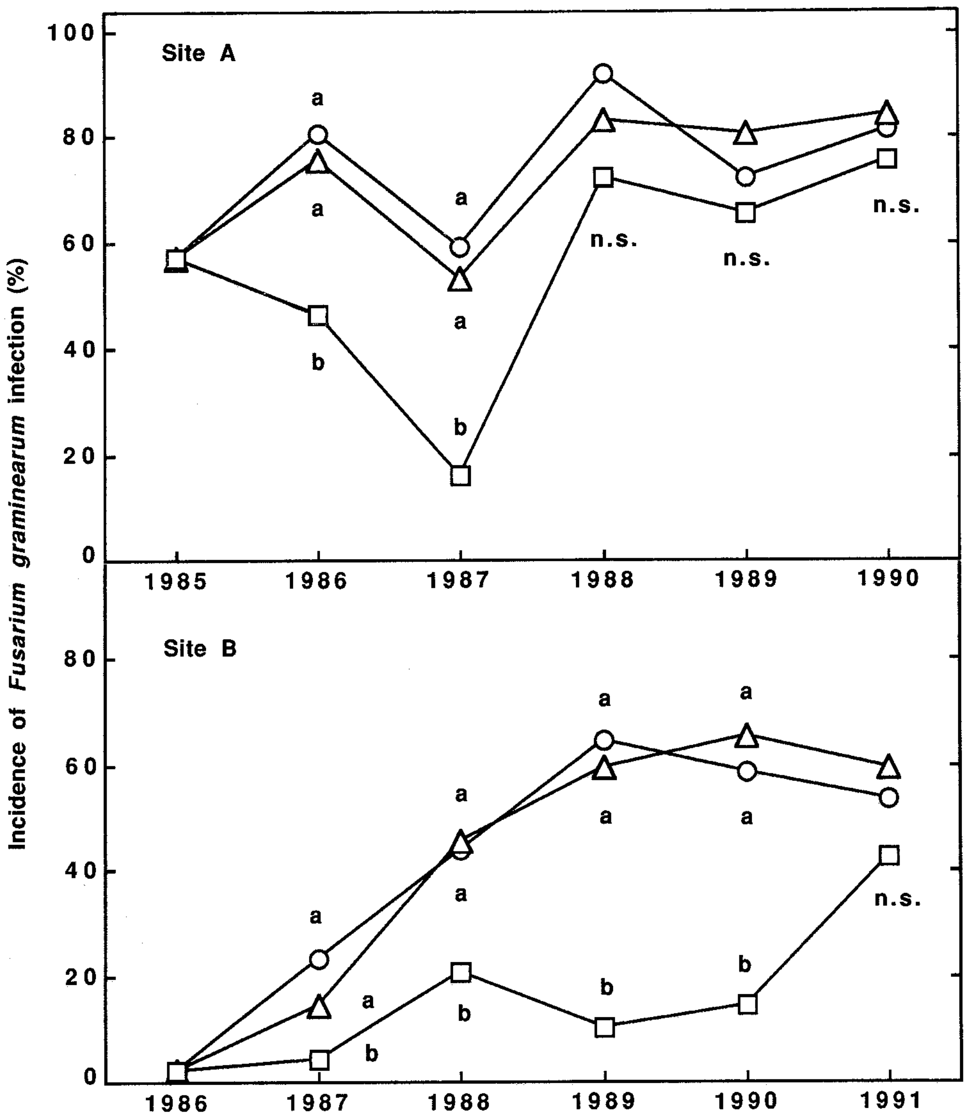

Fig. 1. Effect of three stubble treatments (□ stubble burnt, △ stubble incorporated, ○ stubble retained) on the incidence of infection of wheat with *Fusarium graminearum* Group 1 at two sites. Stubble was not burnt at site B in 1991. Data points labelled with the same letter within a year at one site are not significantly different at $P = 0.05$; n.s., treatment effect not significant.

retained treatment had the lowest yield in 1991. Rainfall was low at the end of these seasons (Table 1) and whiteheads were common, especially in plots where stubble was incorporated or retained. Due to wet conditions early in the season in 1990, the plots could not be sprayed at the optimum time and the retained and incorporated plots became infested with wild oats (*Avena fatua* L.). As a result, it was not possible to determine the relative contributions of crown rot and weed competition to yield depression.

Discussion

The long term trends in infection of wheat by *F. graminearum* Group 1 under the 3 stubble management regimes were consistent with the results of previous short-term experiments (Klein *et al.* 1988; Dodman and Wildermuth 1989; Summerell *et al.* 1989). However, stubble burning failed to limit infection at site A in the years 1988–90 and at site B in 1988. Three factors may have contributed to the ineffectiveness of burning. Firstly, it was difficult to achieve a complete burn after a low-yielding crop (e.g. in 1987 at site B) because of the relatively sparse stubble. Secondly, grassy weeds, especially *Phalaris paradoxa* L. and *Hordeum leporinum* Link, which are hosts of *F. graminearum* Group 1 (Purss 1969), were a problem at site A by 1988 after the long period of continuous wheat cultivation. Infested residues from weed growth during the fallow or within the crop could increase the quantity of inoculum. Thirdly, rainfall in the months preceding sowing (March–May) was above average in 1988–90, with 1988 being especially wet, leading to a longer period in which surface soil moisture conditions were favourable for infection (Liddell and Burgess 1988). This would enhance the ability of any mycelium in the residues of wheat or alternative hosts to infect the crop.

The similarity in incidence of disease between the stubble retained and incorporated treatments confirms earlier reports that tillage does not by itself reduce disease incidence (Klein *et al.* 1988; Dodman and Wildermuth 1989; Summerell *et al.* 1989). This is surprising, since stubble incorporation has a number of effects that may be expected to influence disease compared with stubble retention. Retaining stubble on the surface would be expected to favour maximum carryover of the fungus, since this treatment leads to the slowest decomposition of stubble; in contrast, incorporating stubble accelerates decomposition (Summerell and Burgess 1988). In most years during this and previous studies (Summerell *et al.* 1989), stubble weight was reduced by half in incorporated plots compared with retained plots. However, incorporation does not necessarily reduce the survival of *F. graminearum* Group 1 within individual stubble pieces compared with retention on the surface (Summerell and Burgess 1988).

The principal site of penetration also differs between retained and incorporated treatments, reflecting the distribution of inoculum. Penetration occurs mostly through the crown and lower stem when stubble is retained on the surface, and through the subcrown internode and crown when the stubble is incorporated (Summerell *et al.* 1990). The relationship between size or distribution of inoculum and infection of wheat plants is unknown, making it difficult to predict the effects of tillage and stubble breakdown on disease incidence. This is an area that requires further study.

At neither site was 100% incidence of infection recorded in the retained or incorporated plots. This probably reflects the uneven distribution of *F. graminearum* Group 1 propagules (Wearing and Burgess 1977), which are principally mycelia in residues (Cook 1968; Wearing and Burgess 1977). Klein *et al.* (1991) also found that crown rot had a clustered distribution in many fields. Residue becomes fragmented and redistributed by tillage and sowing operations, but it may not be spread with sufficient uniformity to be in proximity to every plant. The tines of seed drills, for example, tend to push the residue away from the planted rows. At site B, the smaller quantity of stubble in the 1990 and 1991 seasons may also have limited increase in incidence.

There was no evidence of a decline in disease incidence. In the best documented example of a cereal disease decline, that of take-all caused by *Gaeumannomyces graminis* (Sacc.) von Arx and Olivier var. *tritici* Walker, the decline is seen after 3–5 years of increasing disease incidence (Walker 1975). Foot rot of wheat caused by *F. culmorum* (W. G. Smith) Sacc. has also been reported to decline after 1–2 severe seasons in some areas of Washington State, U.S.A. (Cook 1980). At site A, incidence of crown rot was high until the eighth crop after pasture, and it appears unlikely that suppression of crown rot will occur at this site.

The apparent decline in incidence of crown rot in continuous wheat at several sites in northern New South Wales reported by Klein *et al.* (1991) was due mostly to a low incidence in 1 year (1981). A similar decrease in incidence in 1 year was seen at site A in 1987, but this was probably due to the effect of seasonal conditions rather than a disease decline of the type reported for take-all. Although *F. graminearum* Group 1 is a poor saprophytic competitor (Burgess and Griffin 1967), it is probably protected from antagonism by its prior occupancy of the straw and location of much of the residue above the soil surface.

This study demonstrates that crown rot will continue to be a problem in continuous wheat production unless the inoculum can be removed effectively (e.g. by burning stubble after harvest). However, stubble burning controlled disease in only 5 of the 9 site–year combinations in which it was practised in these trials. Stubble retention is being actively promoted for soil conservation purposes, especially where water erosion is a problem, so stubble burning is no longer a practical option for many growers. Break crops provide an alternative strategy for disease reduction, but long-term studies are required to assess their effectiveness, since inoculum of *F. graminearum* Group 1 may survive in infected residue for at least 2 years (Summerell and Burgess 1988). Further studies are required to determine whether removing stubble by harrow burning at the end of the fallow will control disease, since this would allow protection of the soil from erosion and increase water storage (Marley and Littler 1989) while reducing inoculum before sowing.

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