RESEARCH REPORTS

Fungi associated with basal stalk rot and root rot of dryland grain sorghum in New South Wales

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Summary

Surveys in 1977–78 and 1978–79 indicate that *Fusarium moniliforme* is the fungus most commonly associated with basal stalk rot of dryland grain sorghum in New South Wales, Australia. *Macrophomina phaseolina* and *Nigrospora sphaerica* were also isolated but our data suggest that these two fungi have a minor rôle in the development of basal stalk rot on the clay soils which predominate in this sorghum-growing area. Basal stalk rot was most common in crops grown with favourable soil moisture until anthesis and then subjected to moisture stress between anthesis and maturity. The disease was not observed in crops grown under near-optimal conditions of soil moisture from planting until maturity.

Root rot was not usually a significant problem before anthesis, although obvious superficial lesions were often present on the nodal roots. However, severe root rot developed rapidly and was invariably associated with the appearance of basal stalk rot in plants subjected to moisture stress after anthesis, during grain formation. *Fusarium moniliforme* and *Periconia circinata* were the fungi most commonly isolated from necrotic root tissue. Isolation data indicate that the former species is likely to be the more important root pathogen. It is unlikely that *P. circinata*, the cause of milo disease, is important because the majority of modern grain sorghum hybrids is resistant to it.

The isolation data further indicate that *F. moniliforme* can infect the roots or crowns of sorghum plants at any time during the growing season but that rapid and extensive colonization usually occurs only after anthesis and then only when the plants are subjected to moisture stress.

Introduction

Grain sorghum *(Sorghum bicolor* (L.) Moench) is an important summer crop in New South Wales where it is grown as either a dryland or an irrigation crop. Dryland crops are grown mainly in the northern, summer-dominant rainfall areas of the grain belt, whereas irrigated crops are grown in both the central and northern regions (Figure 1). Dryland crops are often subjected to moisture stress because rainfall is unreliable. Stress can occur at any time during the growing season but is usually more common late in the season, probably because sorghum is normally planted only if there is a reasonable reserve of subsoil moisture. During the past decade the average area planted in New South Wales was 172 000 hectares per annum with an average production of 360 000 tonnes per annum.

Basal stalk rot of sorghum, first reported in New South Wales in 1949 (Anon. 1949), is considered to be a major disease of hybrid grain sorghum (Stovold 1978; Dale *et al.* 1979; Burgess *et al.* 1981). *Macrophomina phaseolina* (Tassi) Goid and *Fusarium moniliforme* Sheldon were reported as the fungi most commonly associated with the disease. The name basal stalk rot has been adopted by the authors to distinguish between stalk rot of the base of the stalk and that associated with weak neck, a rot of the peduncle (Burgess *et al.* 1981). Both diseases may lead to lodging. The typical symptoms of basal stalk rot and weak neck have been described elsewhere (Tullis 1951; Burgess *et al.* 1981; Trimboli 1981).

Reports of sorghum root rot are rare in Australia. Mayers (1976) noted the occurrence of milo disease, caused by *Periconia circinata* (Mangin) Sacc. in grain sorghum and other sorghum species in Queensland and in grain sorghum from Western Australia, New South Wales and Victoria. He suggested that *P. circinata* may have been present in Australia for many years and stated that root rot of grain and forage sorghum had been observed for many years in Queensland. Stovold (1978) also reported that root rot of sorghum is widespread in New South Wales and that *P. circinata* is often associated with the disease.

Basal stalk rot caused extensive lodging in sorghum in New South Wales during the 1975–76 growing season. A questionnaire requesting information on stalk and root rot, lodging and relevant agronomic data was distributed to all growers registered with the Grain Sorghum Marketing Board of New South Wales and replies were received from 788 growers.

These responses were analysed on a geographic basis with the sorghum-growing areas being divided into three zones (Figure 1). Zone A represents central New South Wales, an area characterized by red-brown earths and irrigated sorghum, where 6000 ha were

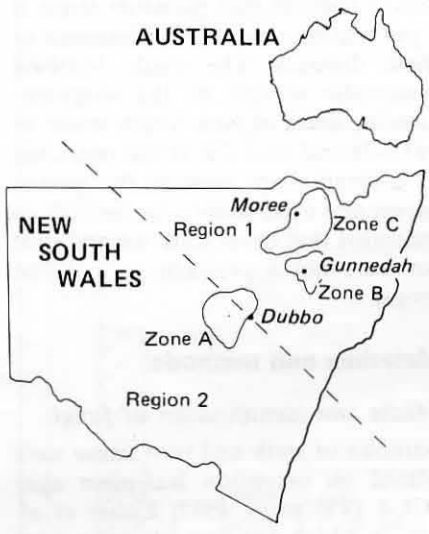

Figure 1 The three major agroclimatic zones (A, B and C) where sorghum is grown in New South Wales. The broken line indicates the transition zone between the summer-dominant rainfall region (Region 1) and the winter-dominant rainfall region (Region 2).

sown in the 1975–76 season. Zone B includes the Liverpool Plains area which has mainly grey to black clay soils, relatively reliable summer rainfall and extensive areas of dryland sorghum, 50 000 ha being grown in the 1975–76 season. Zone C encompasses the northern areas, again characterized by grey to black clay soils, but with a less reliable summer rainfall and mainly dryland cropping with 18 000 ha of sorghum being grown in 1975–76.

The responses to the questionnaires indicated that 4%, 3% and 16% of the area sown to sorghum in zone A, B and C respectively (Figure 1) was affected by stalk rot and lodging in the 1975–76 season. Many growers reported serious losses in at least one crop and indicated that stalk rot and lodging were more severe in dryland crops in areas where summer rainfall is less reliable. Many growers also indicated that stalk rot was associated with moisture stress and that the disease did not occur in irrigated crops. The stalk rot condition described by most growers was basal stalk rot. The responses to the questionnaire did not provide information on root rot.

Since there had been no systematic surveys of basal stalk rot and root rot of grain sorghum in New South Wales, the authors initiated a study to assess the relative frequency of isolation of the various fungi associated with these diseases in dryland crops and to obtain qualitative information on seasonal conditions favouring disease development. The primary objective was to rank these fungi in order of importance for testing of pathogenicity and thus ultimately determine which should be used in tests for resistance or tolerance to the disease. The secondary objective was to confirm that moisture stress is a pre-requisite for the development of these diseases. The study involved systematic surveys of the sorghum-growing areas of New South Wales in 1977–78 and 1978–79. It was restricted to dryland crops because the grower survey and observations by the authors indicated that basal stalk rot and root rot were not a problem in irrigated crops.

Materials and methods

Media and identification of fungi

Samples of stalk and root tissue were plated on carnation leaf-piece agar (CLA (Tio *et al.* 1977; Fisher *et al.* 1982)) which consists of water agar (2% agar in water w/w) containing pieces of carnation leaf sterilized by γ-irradiation. Preliminary studies had shown that all fungi known to be associated with basal stalk rot and root rot of sorghum could be isolated on this medium and it had been used successfully in a similar survey on fungi associated with stalk rot of maize (Francis and Burgess 1975).

Such taxonomically diverse fungi as *Fusarium graminearum* Schwabe Groups 1 and 2 (Francis and Burgess 1977), *M. phaseolina, Drechslera* spp., *Rhizoctonia solani* (Kuhn), *Sclerotium rolfsii* (Sacc.) and *Pythium* spp. have been isolated from diseased tissue plated on CLA. Tissue segments are plated on the water agar of the CLA plate, to minimize the growth of bacteria. The carnation-leaf pieces promote sporulation of many species which form conidia on discrete conidiophores, in pycnidia or in acervuli. The leaf pieces also promote the formation of perithecia by some members of the Pyrenomycetes (Fisher *et al.* 1982).

All fungi were identified from cultures grown on plates of CLA and slopes of potato dextrose agar from germinated single spores or hyphal transfers from colonies on the CLA isolation plates. Isolation plates and all cultures for identification were incubated under controlled conditions of alternating temperature 25°C day/20°C night and a photoperiod of 12 h. Light was provided by cool white fluorescent tubes and black light tubes located 35 cm above the cultures (Burgess and Liddell 1983).

Basal stalk rot study

Sorghum stalks affected by basal stalk rot were collected from dryland crops selected at random in zones A, B and C in New South Wales (Figure 1) during surveys of basal stalk rot in April 1978 and March 1979. Fourteen crops were sampled in 1978 (mainly in zones B and C) and 18 crops in 1979. The location of each crop is recorded in Table 1 together with information on

Table 1 Severity of basal stalk rot in dryland sorghum crops sampled during surveys in New South Wales in 1977–78 and 1978–79

Crop	Location[A]	Soil type	Hybrid	Severity[B] (%)
		1977–78		
A	Bellata	Grey clay	NK147	25
B	Croppa Creek	Grey clay	SE4	25
C	Somerton	Black earth	220Y	10
D	Gunnedah	Black earth	Pac.001	50
E	Bithramere	Red brown earth	220Y	10
F	Spring Ridge	Black earth	SM12	1
G	Gunnedah	Black earth	NK266	10
H	Croppa Creek	Grey clay	C43	10
I	Narrabri	Black earth	SE4	10
J	Delungra	Black earth	SM10	10
K	Thorn Hill	Chocolate	SE4	25
L	Croppa Creek	Grey clay	NK233	10
M	North Star	Red earth	Pac.007	10
N	Dubbo	Red brown earth	SM8	75
		1978–79		
A	Pine Ridge	Black earth	NK212	10
B	Loomberah	Black earth	E57	1
C	Gunnedah	Black earth	Tex626	25
D	Gunnedah	Red earth	–	10
E	Keepit Dam	Red earth	Pac.001	10
F	Barraba	Brown earth	E57	10
G	Barraba	Brown earth	Goldrush	25
H	Wondabah	Chocolate	–	75
I	Wondabah	Black earth	C43	75
J	Spring Ridge	Chocolate	NK212	10
K	Mullaley	Black earth	Dorado	75
L	Yallaroi	Black earth	C43	75
M	Warialda	Black earth	C43	10
N	Warialda	Grey clay	E57	10
O	Mullaley Sth	Chocolate	NK212	10
P	Parkes	Red brown earth	C43	10
Q	Peak Hill	Red brown earth	NK212	25
R	Narromine	Red brown earth	–	10

[A] Town nearest to crop.

[B] Severity of basal stalk rot is a visual estimate of the incidence of affected plants, both standing and lodged, at a site 50 m from the margin of the crop. Visual assessments were confirmed by splitting representative stalks. Estimate based on an index: 0, 1, 10, 25, 50, 75, 100% plants affected. Plants were collected for isolation studies at this site.

soil type and the hybrid sampled. Ten standing stalks with basal stalk rot were collected from each crop at a site 50 m from the margin of the crop. Stalks were selected only on the basis of externally visible symptoms, i.e. a bleached, straw-coloured appearance of the whole plant. Lodged stalks were not collected because they were extensively colonized by soil saprophytes after lodging. Severity of basal stalk rot was assessed visually at each site and diseased plants that had lodged were included in the estimate. Representative plants were split and examined for the presence of shredded internal tissues to confirm the assessments based on externally visible symptoms. The assessment was based on the following index: 0, 1, 10, 25, 50, 75 and 100% plants affected. The stalks were kept under cool dry conditions during transit to the laboratory where they were stored at 5°C until plated, within 2 weeks of collection.

Immediately prior to plating, the leaf sheaths were removed from the stalks which were then washed and surface sterilized for 10 min in sodium hypochlorite (0.3–0.4% available chlorine) in 10% ethyl alcohol. The stalks were then allowed to air-dry on sterile paper tissues in a sterile work chamber for 30 min. A segment, *c.* 2 x 2 x 2 mm, of internal stalk tissue was then removed from each of the second, fourth and sixth internodes above the nodal (crown) roots of each stalk and plated on CLA in small glass plates, one segment per plate.

Root rot study

Samples of sorghum plants affected by root rot were collected from five dryland crops growing on different soil types in zone B in New South Wales (Figure 1) during surveys for root rot between November and March of 1977–78 and 1978–79. All crops sampled were in paddocks previously cropped to sorghum. The crops were sampled on three occasions—6 weeks after emergence, at anthesis and at maturity. The location of each site, the soil type and hybrid involved are recorded in Table 2. Ten plants were collected at random from each crop at each sampling at a site 50 m from the margin of the crop. Severity of root rot was assessed visually and expressed as a percentage of the root system with obvious discoloration. The index adopted was: 0%, 1%, 10%, 25%, 50% and 100% of root system discoloured. Plants were kept dry and cool during transit to the laboratory where they were plated within 24 h of collection.

Table 2 Severity of root rot in samples of sorghum plants collected during surveys of dryland crops in New South Wales in 1977–78 and 1978–79

Crop	Location[A]	Soil type	Hybrid	Severity[B] (%) Sampling Number[C] 1	2	3
		1977–78				
A	Pine Ridge	Black earth	SM8	10	10	25
B	Spring Ridge	Black earth	NK212	1	10	25
C	Spring Ridge	Chocolate	NK212	10	10	10
D	Spring Ridge	Black earth	NK212	10	10	10
E	Breeza	Black earth	NK212	1	1	10
		1978–79				
A	Spring Ridge	Black earth	SM8	1	10	25
B	Pine Ridge	Black earth	NK212	1	10	50
C	Loomberah	Red earth	NK212	1	25	25
D	Loomberah	Red earth	NK212	1	50	50
E	Premer	Black earth	NK212	1	25	25

[A] Town nearest to crop.

[B] Severity of root rot is a visual estimate of the percentage of the root system with discoloration based on an examination of the 10 root systems collected for isolation studies. The index adopted was: 0, 1, 10, 25, 50 and 100% of root system discoloured.

[C] Sample numbers 1, 2 and 3 corresponded to 6 weeks after planting, anthesis and maturity respectively.

Immediately prior to plating, excess soil was washed from the roots and the leaf sheaths were removed from the stalks. Roots with lesions were washed for 30 min in running tap water and surface sterilized for 4 min in sodium hypochlorite (0.3–0.4% available chlorine) in 10% ethyl alcohol. The root pieces were allowed to air-dry on sterile paper tissues in a sterile work chamber for 20 min. One segment, *c.* 2 mm long, was removed from each of four root lesions and plated on CLA (one segment per plate). One section, *c.* 3 x 3 x 4 mm, of internal stalk tissue was also removed from the second and fourth internode above the nodal roots and plated.

Results

Basal stalk rot study

Isolation data Three fungi, *F. moniliforme, M. phaseolina* and *Nigrospora sphaerica* (Sacc.) Mason were commonly isolated and the recovery of these species is summarized in Figure 2. All three fungi have been isolated from plants affected by stalk rot by other workers (Livingston 1945; Tullis 1951; Tarr 1962). Other fungi were isolated occasionally, including *Alternaria alternata* (Fr.) Keissler, *Drechslera rostrata* (Drechslera) Richardson & Frazer, *D. sorokiniana* (Sacc.) Subram & Jain, *Fusarium equiseti* (Corda) Sacc., *F. oxysporum*

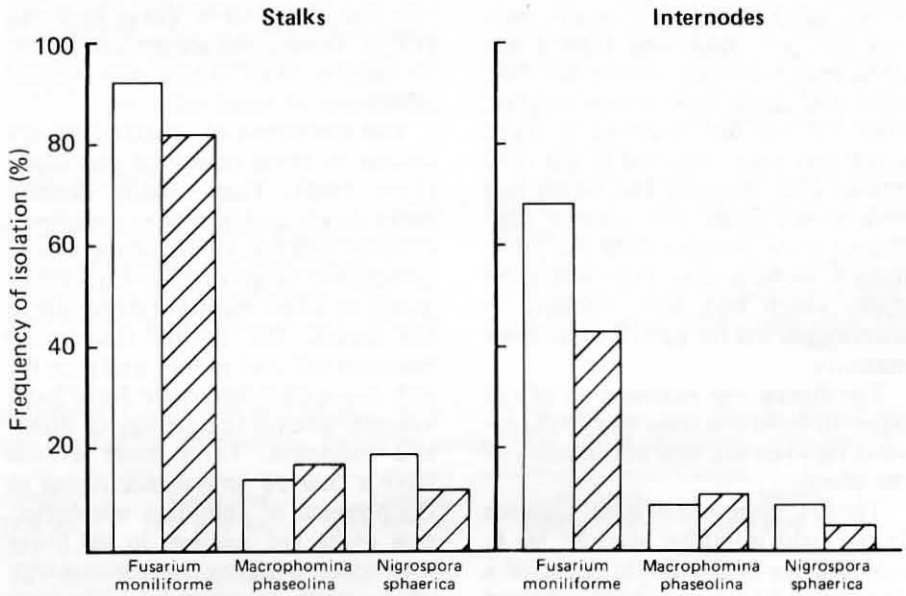

Figure 2 Frequency of isolation of *Fusarium moniliforme, Macrophomina phaseolina* and *Nigrospora sphaerica* from sorghum stalks and internodes affected by stalk rot and collected in New South Wales in 1977–78 (plain bars) and 1978–79 (hatched bars).

Schlect, *F. semitectum* Berk & Rav., *F. graminearum* Schwabe Group 2 (Francis and Burgess 1977), *Melanconium* spp. and *Trichoderma* spp.

Fusarium moniliforme was isolated more frequently than *M. phaseolina* and *N. sphaerica* from all internodes (Table 3). *Fusarium moniliforme* was isolated more frequently from the sixth internode than from the second and fourth internodes. In contrast, *M. phaseolina* was isolated more commonly from the second internode and less commonly from the sixth. *Fusarium moniliforme* was invariably isolated from stalks colonized by *M. phaseolina*. *Nigrospora sphaerica* was isolated at a similar frequency from each internode.

The decrease in the isolation of all fungi in 1979 is attributed to the greater absorption of surface sterilant by the very dry stalks. These stalks were more desiccated and thus more porous than those collected in 1978.

Fungi were not isolated from stalks exhibiting the hard, dry, brittle stalk syndrome described by Tullis (1951). He also failed to recover fungi from such stalks.

Table 3 Frequency of isolation of *Fusarium moniliforme, Macrophomina phaseolina* and *Nigrospora sphaerica* from selected internodes of sorghum stalks collected from 14 crops in 1977–78 and 18 crops in 1978–79 in New South Wales

Species	Year	Frequency of isolation[A]		
		Internode[B]		
		2	4	6
Fusarium moniliforme	1977–78	54	68	79
	1978–79	29	49	57
Macrophomina phaseolina	1977–78	13	9	2
	1978–79	13	10	7
Nigrospora sphaerica	1977–78	9	10	9
	1978–79	6	3	7

[A] Frequency of isolation = proportion of internodes from which fungus was isolated, expressed as a percentage.
[B] Internodes numbered from basal internode which was taken as the first internode above the nodal roots.

Symptoms of stalk rot Basal stalk rot was most common in crops grown with favourable soil moisture until anthesis and then subjected to moisture stress between anthesis and maturity. It should be noted that crop moisture status was not monitored quantitatively but regular observations were made of crops in each region during each growing season. In general, stalk rot was more severe in the 1978–79 growing season (Table 1). Rainfall in this season (Table 5) was inadequate and many crops were subjected to late stress. Some of our observations indicate that wet conditions after a late stress may accelerate disease development and cause more severe lodging. Stalk rot was not observed in crops which had been subjected to wet conditions after maturity and which had been grown under near-optimal conditions from planting until maturity. Indeed, we have seen crops with solid stalks which had been standing in waterlogged soil for up to 8 weeks after maturity.

The disease was recorded on all soil types surveyed and there was no correlation between soil type and severity of the disease.

The first symptom of basal stalk rot in the field in stalks infected by *F. moniliforme* is the development of a distinctive bleached, straw-coloured appearance of the whole plant. At this stage, the lower stalk and nodal roots are spongy in texture and a deep purple to cherry red discoloration is usually apparent in the pith tissue. Subsequently the purple-red discoloration fades as the pith tissue disintegrates, leaving the vascular strands loose inside the outer cylinder of the stalk, a condition which Tullis (1951) described as 'shredded'. By this stage fruiting bodies of several stalk rot fungi are often visible on the loose vascular strands. Lodging usually occurs at the fourth node, *c.* 5–10 cm above the crown, at any time after the stalk tissue becomes soft and spongy. However, the stalk is most susceptible to lodging after the pith tissue has disintegrated.

The above sequence of symptom development is normal in New South Wales. Under very dry conditions, however, soft-spongy stalks desiccate rapidly, becoming hard and constricted with no evidence of pith disintegration. This brittle stalk condition was also observed in Texas by Tullis (1951). These stalks are less susceptible to lodging than stalks with typical symptoms of basal stalk rot.

The symptoms of charcoal rot are similar to those described previously (Tarr 1962). They usually develop more slowly and later than symptoms of basal stalk rot. Charcoal rot is more common in crops that have been subjected to severe moisture stress late in the season. The internal stalk tissue becomes soft and spongy and then the pith tissue disintegrates to leave loose vascular strands in a stringy or shredded condition. These loose strands have a charred appearance owing to the presence of abundant microsclerotia which are confined to the lower internodes, a finding that concurs with observations reported by Livingston (1945). The external symptoms of charcoal rot are identical to those of basal stalk rot associated with *F. moniliforme*.

Occasionally dark green to black areas are found in the stalks of plants affected by severe basal stalk rot. These discolorations are usually associated with the presence of *N. sphaerica*.

Root rot study

Isolation data Two fungi, *F. moniliforme* and *P. circinata* were commonly isolated and the recovery of these species is summarized in Table 4. Both fungi have been associated with root rot by other workers (Leukel 1948; Tullis 1951; Mayers 1976; Burgess *et al.* 1981).

A number of other fungi was isolated occasionally. These included *Alternaria alternata, Drechslera pedicellata* (Henry) Subram. & Jain, *D. sorokiniana, F. equiseti, F. oxysporum, M. phaseolina, Penicillium* spp. and *Periconia macrospinosa* Lefebvre & A.G.Johnson.

Fusarium moniliforme was isolated more frequently than *P. circinata* during the surveys in 1977–78 and 1978–79. The frequency of isolation of both fungi varied among crops in both seasons.

Fusarium moniliforme was isolated occasionally from stalks which were not affected by stalk rot. *Periconia circinata* was not isolated from stalk tissue.

Symptoms of root rot Root rot was recorded in all hybrids in all soil types sampled in the survey (Table 4). The severity and nature of root rot symptoms varied with the growth stage of the crop and soil moisture status. Severe root rot was not observed in young plants prior to anthesis. Superficial lesions, however, were observed. These appeared to cause minor damage to the cortical tissue.

Table 4 Frequency of isolation of *Fusarium moniliforme* and *Periconia circinata* from roots and stalk bases from five sorghum crops sampled at three growth stages in New South Wales in 1977–78 and 1978–79

Sample Number[A]	Frequency of isolation from root lesions[B] (%) *Fusarium moniliforme* 1977–78	1978–79	*Periconia circinata* 1977–78	1978–79	Frequency of isolation of *Fusarium moniliforme* from stalk bases[C] (%) 1977–78	1978–79
			Crop A			
1	50	0	4	8	30	0
2	70	6	4	22	0	0
3	82	6	0	2	0	10
			Crop B			
1	37	64	40	12	30	10
2	58	16	20	64	0	0
3	58	50	48	2	0	30
			Crop C			
1	12	4	2	0	10	0
2	46	10	0	14	0	0
3	52	8	18	8	30	0
			Crop D			
1	8	56	2	0	0	0
2	14	98	2	0	0	0
3	2	90	34	0	0	20
			Crop E			
1	28	52	20	0	0	30
2	0	72	16	2	0	0
3	26	72	26	14	0	0

[A] Sample numbers 1, 2 and 3 correspond to 6 weeks after planting, anthesis and maturity, respectively.

[B] Frequency of isolation = proportion of root lesions from which fungus was isolated, expressed as a percentage. Based on isolations from a total of 40 segments of lesioned root tissue per site per sampling.

[C] Frequency of isolation = proportion of stalk bases from which *F. moniliforme* was isolated, expressed as a percentage. Based on a total of 20 segments from the bases of the stalks of the 10 plants in each sample of the root study (B). *Periconia circinata* was not isolated from stalk bases.

Because of the deep pigmentation accompanying lesion formation, the superficial lesions may give a casual observer the impression that the roots are severely damaged. These lesions developed from small lesions (*c.* 0.5–4 mm), deep purple to dark red in colour, on one side of the cortex. With time they girdled the root and extended linearly for several centimetres, though rarely affecting the stele. Further studies on the importance of these superficial lesions are warranted.

Severe root rot was sometimes noted on large nodal roots after anthesis, mostly in crops grown in soil which had a history of sorghum production. This root rot developed from superficial progressive necrotic lesions on the outside of the cortex. These eventually girdle the root, necrosis extends into the stele and the cortex may slough away. These severe lesions may extend along the root and cause collapse of lateral rootlets. We do not know the factors that favour this type of lesion development.

Yet another type of root rot developed in plants approaching maturity and which had been subjected to moisture stress after anthesis. The nodal roots of these plants became light brown, soft and finally hollow as the cortex and stele disintegrated and dehydrated. This syndrome developed rapidly and was invariably associated with basal stalk rot.

Discussion

Fusarium moniliforme was the fungus most commonly isolated from sorghum stalks during surveys in 1977–78 and 1978–79 in New South Wales (Table 3). *Macrophomina phaseolina* and *N. sphaerica* were isolated less frequently than *F. moniliforme* and the results indicate that these two fungi have a minor role in the development of basal stalk rot in New South Wales. Thus we suggest that experimental studies on basal stalk rot in New South Wales should mainly involve *F. moniliforme*. Further field studies on the relative importance of *F. moniliforme* and *M. phaseolina* are justified however, as frequencies of isolation do not necessarily refflect the relative degrees of disruption of plant tissues by the various fungi involved in a disease complex.

Fusarium moniliforme was invariably isolated from stalks infected with *M. phaseolina*. The isolation of these two fungi from the same section of stalk tissue has been reported by other workers (Lutrell 1950; Tullis 1951; Hsi

Table 5 Monthly rainfall (mm) data for Dubbo, Gunnedah and Moree, New South Wales, for October to March in 1977, 1978 and 1979. (The average rainfall for each month, based on period 1931–60, is provided for reference)

	October			November			December			January			February			March		
	1977	1978	Av.	1977	1978	Av.	1977	1978	Av.	1978	1979	Av.	1978	1979	Av.	1978	1979	Av.
Dubbo	21	25	51	2	74	51	21	62	36	201	11	64	10	4	72	75	46	46
Gunnedah	29	20	60	38	53	57	28	75	51	225	28	68	40	13	77	57	82	37
Moree	39	8	52	11	85	54	26	44	44	136	56	68	54	51	76	47	81	51

1956). Vock (1978) noted that charcoal rot and Fusarium stalk rot often occur together in the same plant. Lutrell (1950) concluded that *F. moniliforme* was of secondary importance to *M. phaseolina* in the stalk rot complex. However, our results suggest that *M. phaseolina* is of secondary importance to *F. moniliforme* in the clay soils of the northern grain belt of New South Wales. We base this conclusion on the fact that we isolated *F. moniliforme* more frequently than *M. phaseolina* and the former was isolated more commonly than the latter from the upper internodes of the stalk. Furthermore, *M. phaseolina* was generally isolated only from stalks that had lodged or from stalks which were severely rotted. In contrast, *F. moniliforme* was isolated from incipient stalk rot infections and occasionally from symptomless stalks. Thus in the area surveyed it would appear that *M. phaseolina* is a secondary invader which colonizes stalks already colonized by *F. moniliforme*. This conclusion concurs with the findings of Tullis (1951) and Hsi (1956).

It must be emphasized that these surveys mainly involved heavy and medium-heavy clay soils. The frequency of isolation of *M. phaseolina* from the few samples of diseased stalks collected on light soils was significantly greater than that from stalks collected on heavy soils. This finding agrees with that of Hsi (1956) who found that charcoal rot was more prevalent on sandy as compared to heavy soils in New Mexico.

The frequency of isolation of *F. moniliforme* and *N. sphaerica* was slightly lower in 1978–79 than in 1977–78. There are two possible explanations. Many crops were subjected to moisture stress after anthesis in 1978–79 (January and February 1979) whereas rainfall was more favourable in 1977–78 (January 1978) (Table 5). The stalks affected by stalk rot in 1978–79 were extremely dry and porous and partially absorbed the surface sterilant which could have killed some of the stalk rot fungi and hence reduced the frequency of their isolation. It is also possible that the dry conditions were inimical to the formation and dispersal of spores of *F. moniliforme* and *N. sphaerica* and infection and colonization of sorghum stalks. Both fungi are dispersed in the atmosphere (Hooker and White 1976; Ooka and Kommendahl 1977).

The lack of recovery of fungi from some internodes can probably be attributed to the absorption of the surface sterilant by the desiccated stalk tissue. The lower internodes in the stalk were more desiccated and absorbed surface sterilant more readily. Fungal recovery was lower from these lower internodes. We therefore suggest that stalks should be surface sterilized by swabbing lightly with 95% ethyl alcohol prior to plating. In addition, the infected stalks should be examined microscopically for the presence of fructifications of *F. moniliforme* (as illustrated by Burgess and Liddell 1983), the sclerotia of *M. phaseolina* and the characteristic conidia of *N. sphaerica*.

Many investigators have suggested that moisture stress during grain development is a major factor predisposing sorghum to stalk rot (Livingston 1945; Tullis 1951; Hsi 1956; Dodd 1978). Stalk rot was severe in 1977–78 and 1978–79 in each sampling zone. Rainfall was below average in many areas during February 1978 and January and February 1979 when grain development occurred (Table 5). This observation supports the theory that environmental stresses such as moisture stress predispose sorghum to infection and colonization by stalk-rotting fungi by inducing premature senescence in the plant. This theory, called the photosynthetic stress-translocation balance concept, has been discussed by Dodd (1978) and Burgess *et al.* (1981).

Fusarium moniliforme was isolated more frequently than *P. circinata* from sorghum roots during surveys in 1977–78 and 1978–79. The differences among the crops in respect to the rate of recovery of both fungi may have been the result of differences in susceptibility of the hybrids sampled, differences in environmental conditions, or the cropping history of the soil.

Root rot severity increased as plants approached maturity and recovery of *F. moniliforme* was usually higher from the second and third samplings. The recovery rate of *P. circinata* did not increase in the latter samplings. These results therefore indicate that *F. moniliforme* was the major cause of root rot. Thus if milo disease (caused by *P. circinata*) exists in New South Wales, then it does so in a mild form and is not as serious as the rot caused by *F. moniliforme*. This is to be expected because the majority of modern female sorghum inbreds used in hybrid combinations is genetically based on the kafir sorghums which are resistant to milo disease (White, personal communication).

Fusarium moniliforme and *P. circinata* may be isolated from the same lesion and in such cases it is difficult to suggest which fungus caused the lesion. It is possible that both fungi infect simultaneously or at separate locations on the root. Alternatively, one fungus may be able to colonize a lesion initiated by the other. *Periconia circinata* was never isolated from stalk tissue.

Our field observations indicate that root rot is not usually a significant problem before anthesis. Prior to anthesis superficial lesions are sometimes common on the root system and give the appearance of severe root rot. However, these lesions normally affect only the outer part of the cortex and the stele is not damaged. Severe root rot develops rapidly after anthesis if the plant is subjected to severe moisture stress. The resulting disruption of the root system would impose greater moisture stress on the stalk and inflorescence. Stalk rot develops soon after severe root rot becomes evident. The visual assessments of root rot severity reported in Table 2 were based on the extent of discoloration of the root system. We do not believe this is a satisfactory method of assessment because it does not discriminate between superficial lesion formation and necrosis of both the cortex and stele.

In summary, our results indicate that *F. moniliforme* is able to infect the roots and crown of sorghum plants grown in the absence of obvious stress at any time during the growing season. The onset of moisture stress between anthesis and maturity results in rapid and extensive colonization of the root system and stalk tissue by *F. moniliforme* and later by other fungi. Presumably stress at this stage leads to the rapid depletion of assimilates from root and stalk tissue and their translocation to the developing grain (Dodd 1978; Burgess *et al.* 1981). We suggest that this rapid depletion of assimilates is associated with a decrease in the ability of stalk and root tissue to resist colonization by *F. moniliforme* and other fungi.

Since these surveys were completed the authors have investigated the rôle of moisture stress in basal stalk and root rot development in glasshouse studies with *F. moniliforme*. Typical basal stalk rot and root rot were reproduced for the first time with *F. moniliforme* under controlled conditions (Trimboli and Burgess 1983). The diseases developed in plants which were grown under near-optimal conditions of soil moisture from planting until late anthesis and were then subjected to moisture stress. Stalk rot did not develop in plants grown under near-optimal conditions of soil

moisture from planting until harvest maturity. Further studies are planned to develop reliable methods for testing sorghum hybrids for resistance to stalk rot associated with *F. moniliforme,* in field plots.

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