THE EFFECT OF WHEAT FOLIAR DISEASES ON ROOT GROWTH, WATER USE AND YIELD

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ABSTRACT

The diseases speckled leaf blotch and stripe rust reduced total green leaf area of wheat in two seasons. Yield was reduced by 13% in the first season, attributable to a reduction in grain number/m² and individual grain weight. Disease control during grain filling led to an increase in individual grain weight. In the second season, the full disease treatment reduced yield and grain number/m². Irrigation of early disease plots at GS 83 reduced the effect on yield.

The root length of diseased crops was reduced by 35% at GS 91 in the first season and by 29% and 40% at GS 31 and 92, respectively, in the second season. Control of the late epidemic phase (the early disease treatment) in the second season increased root length compared to the full disease treatment by GS 80. From GS 80 to GS 92 there was no further increase in the root lengths of plants from the early disease treatment and the length was similar to full disease treatment plants at GS 92.

Water use was not affected by disease in the second season, but water use efficiency was reduced. The data are discussed in relation to the hypothesis that reduced root growth, caused by early disease, prevents compensation by later growth, even in the absence of disease, because of water constraints.

***Additional Key Words:** water use efficiency, speckled leaf blotch, stripe rust, yield compensation.*

INTRODUCTION

Cereal yield reductions caused by foliar diseases are well documented. However, the physiological effect of disease on plant growth and yield is not fully understood, especially with respect to root growth and function. Yield loss is often analysed by its effect on individual yield components, i.e., tillers/m², grains/ear and individual grain weight, determined at various stages of growth (Kirby, 1974, 1977). Therefore, the component most affected by disease depends on the growth stage at which infection occurs (Williams and Jones, 1972; Jones and Rowling, 1976) and the duration of disease. Disease epidemics during early growth stages (up to GS 31) reduced grain number (Doodson *et al.*, 1964; Lim, 1982). In some circumstances this reduction may be offset by compensatory grain growth later in the season. In Canterbury cereal crops however, it has been shown that compensation does not always occur (Gaunt *et al.*, 1982; Lim, 1982).

Foliar disease reduced root development of cereal plants grown in pots, decreasing root weight (Gough and Merkle, 1977; Ayres and Zadoks, 1979), and length (Martin and Hendrix, 1974; Walters and Ayres, 1981). The effects of disease and soil water status on growth were additive (Ayres and Zadoks, 1979). However, in glasshouse studies root development and soil volume is limited and sufficient water is usually supplied to minimise soil and plant water deficits.

There is, however, little information on what occurs in the field. Disease at early growth stages (seedling to tillering) may result in a smaller root system being established by the crop (Martin and Hendrix, 1974). A reduced root system may be of importance in later growth, especially if soil water deficits occur (Unger *et al.*, 1981). Plants may not be able to compensate by later growth, even in the absence of disease, because of water constraints. Irrigation was applied to diseased and healthy crops to test this hypothesis. The effects of foliar diseases on cereal growth and yield may be dependent on season and the extent of water constraints. This interaction is of relevance to the economics of wheat production.

MATERIALS AND METHODS

Two field trials, in 1979-80, and 1981-82, were carried out on a Templeton silt loam soil near Lincoln College. Kopara wheat seed, treated with captan (100 g a.i./100 kg seed), was sown (100 kg/ha) on 15 May 1979 and on 4 June 1981. Single superphosphate (250 kg/ha) was applied at sowing.

The first trial consisted of three randomised treatment plots (12.5 x 6.0 m) in four replicate blocks. Each block was separated by a 10 m untreated buffer. The treatments were nil, early and full disease. Sprays of a mixture of benomyl and mancozeb (250 g and 1600 g a.i./ha) were applied to control the development of speckled leaf blotch (*Mycosphaerella graminicola* (Fuckel) Schroeter) in the nil disease treatment at GS 22, 23, 24, 25, 33, 41, 57, 61 and 75 (Zadoks *et al.*, 1974). The early disease treatment received sprays only after GS 33.

The second trial consisted of six randomised treatments (12 x 10 m) in four replicate blocks. The treatments were nil, early and full disease, with and without irrigation. Sprays of triadimefon (250 g a.i./ha) were applied to control speckled leaf blotch and stripe rust (*Puccinia striiformis* Westend) in the nil disease treatment at GS 23, 24, 30, 32, 37, 65 and 85, while the early disease treatment was sprayed after GS 31.

Fungicides were applied using a hand-held 3 m boom (first trial) and a tractor mounted 6 m boom (second trial), both with hollow cone nozzles (D2-25), at a rate of 300 l/ha at 3.45 x 10^5 N/m^2 pressure. From GS 21, ten plants in each plot were sampled at random from rows at least one metre from the edge of the plots to avoid the effects of interplot interference (James *et al.,* 1973). Percentage leaf area occupied by disease was recorded on all green leaves of the main stem using standard area diagrams (Anon, 1972). Area of leaves was measured using a leaf area meter and green leaf area was assessed using standard area diagrams as the proportion of leaf occupied by lesions, associated senescense and natural senescence. Total green leaf area was calculated as described by Lim and Gaunt (1981).

Three soil cores per plot, 50-75 cm in length, were extracted at GS 91 in the first trial, and at GS 24, 31, 80 and 92 in the second trial. The cores from each plot were bulked, the roots washed from the soil and measured by the grid intercept method (Marsh, 1971). Root length (cm) was calculated per unit area (cm^2). In the second trial only, volumetric water content at 10 cm intervals to a depth of one metre was measured by neutron moderation weekly from GS 25 to harvest. Water use was calculated as described by French *et al.* (1973). At GS 83, 230 mm water was applied by trickle irrigation to those plots designated to be irrigated.

At maturity, plants in 10 (first trial) and 15 (second trial) 0.1 m^2 quadrats per plot were removed for analysis of yield and yield components. A central strip (1.5 m wide) was machine harvested, weighed and the yield determined at 14% moisture content.

RESULTS

The first symptoms of speckled leaf blotch in the first trial were observed at GS 22 as light green leaf mottling followed by senescence and the development of pycnidia. Disease was measured as the reduction in total green leaf area (TGLA) compared to the nil disease plants. The TGLA reached a maximum in all treatments from GS 33 to 46 (Figure 1). From GS 24 to maturity, the full disease plants had consistently less TGLA than the nil disease plants. After disease was controlled in the early disease plants by a fungicide spray at GS 33, TGLA increased markedly from GS 41 compared to the full disease plants and, from GS 43, was the same as the nil disease plants. The header yields in the first trial were consistent with those of the quadrat samples (Table 1). Since the latter had a lower variance, the interpretation of results was based on the quadrat samples. The yield of the nil disease plants was greater than both other treatments. Plants exposed to the full disease epidemic yielded 13% less than the nil disease plants. This reduction was attributed to fewer grains per ear and lower individual grain weight. The yield of the early disease plants was reduced compared to the nil disease plants because of a lower grain number per ear. A heavier individual grain weight in the early disease plants increased yield compared to the full disease plants. At GS 91, total root length of the nil disease plants (278 cm/cm^2) and the early disease plants (249 cm/cm^2) was significantly greater than the full disease plants (181 cm/cm^2).

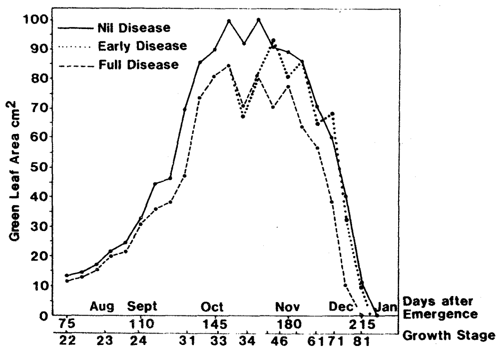

Figure 1: Effect of foliar disease on total green leaf area, 1979-80 Wheat Trial.

TABLE 1: The effects of disease on yield and yield components in 1979-1980.

Variable	Disease treatments			LSD P< 0.05
	Nil disease	Early disease	Full disease	
Header yield (t/ha)	7.15	7.00	6.00	0.12
Quadrat yield (g DM/m^2)	734	705	636	25.2
Ear number/m^2	648	638	641	38.5
Grain number/ear	35.8	33.4	34.1	0.92
Individual grain weight (mg)	31.7	33.1	29.1	1.13

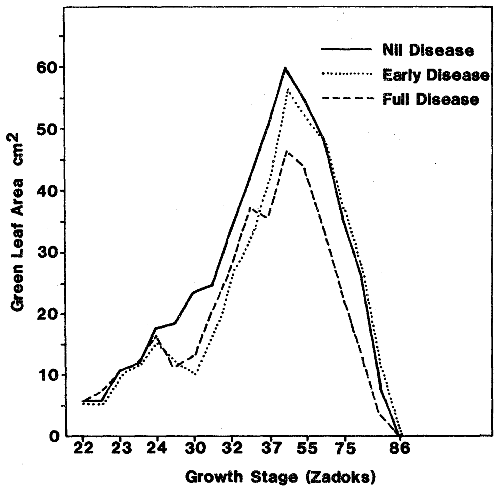

Figure 2: Effect of foliar disease on total green leaf area, 1981-82 Wheat Trial.

TABLE 2: The effects of disease and irrigation on yield and yield components in 1981-1982.

Variable	Disease treatments						LSD P<0.05
	Nil disease		Early disease		Full disease		
	UI*	I	UI	I	UI	I	
Quadrat yield (g DM/m²)	491.7	483.1	455.0	479.7	423.7	435.4	67.9
Ear number/m²	372	368	341	363	352	354	47
Grain number/ear	36.0	35.6	36.5	35.4	33.8	34.2	1.9
Individual grain weight (mg)	36.7	36.8	36.4	37.3	35.5	36.1	1.6

*UI = Unirrigated, I = Irrigated (230 mm was applied at GS 83).

In the second trial, stripe rust was the major disease and was first detected in the crop at GS 22. The disease epidemic reached a maximum severity at GS 30 and declined thereafter. The TGLA of the unirrigated and irrigated plants was similar so only the TGLA of unirrigated plants are presented (Figure 2). The TGLA reached a maximum in all treatments at GS 37. From GS 24 to 32 the early and full disease plants had significantly less TGLA than the nil disease plants. After the control of the late epidemic with a fungicide spray at GS 31, TGLA increased after GS 33 in the early disease plants and was similar to the nil disease plants at GS 37.

The nil disease unirrigated (NDU) plants yielded 492 g/m². In the absence of irrigation, the yield of the full disease plants was reduced by 14%, attributed to a reduction in grain number (Table 2). The yield of early disease unirrigated (EDU) plants was intermediate to these two treatments. There was no response to irrigation in the nil disease and full disease plants. There was a small yield response to irrigation in the early disease plants, (480 g/m² compared to 455 g/m² for the EDU plants, and 492 g/m² for the NDU plants).

Root lengths of the NDU plants increased from GS 24 to 31 (121%), and from GS 80 to 92 (51%). Maximum root length was recorded at GS 92 (Table 3). At GS 31, there was a reduced root length in the EDU and full disease unirrigated (FDU) plants compared to the NDU plants (27% and 39% respectively). In the FDU plants, there was no increase between 31 and 80 and root length was less (37%) than the NDU plants. At GS 92, total root length increased significantly (44%) from the previous sampling (GS 80) in the FDU plants but there was a 40% reduction compared to the NDU plants. There was an increase (37%) in root length in the EDU plants between GS 31 and 80. At GS 80, root lengths of the EDU and NDU plants were similar. However, the subsequent root growth of EDU plants was less than in the NDU plants, such that there was a significant reduction in root length by GS 92. After irrigation, there was no further increase in root length in any of the treatments. At GS 92, root length of all irrigated plants was significantly lower (28%, 60% and 58%) than the NDU plants.

Cumulative water use was calculated from soil water measurements which commenced at GS 24 and from rainfall data up to harvest. The cumulative water use by unirrigated plants for all disease treatments was similar (316-320 mm). The irrigated plants, however, used more water than the unirrigated plants but the cumulative water use was similar in the three irrigated disease treatments (351-364 mm). Water use efficiency was calculated using grain dry matter yields (kg/ha/mm). Water use efficiency of the FDU plants was reduced (13.3 kg/ha/mm) compared to the NDU plants (15.4 kg/ha/mm). There was no significant difference in water use efficiency between the EDU treatment (14.4 kg/ha/mm) and either of the other two treatments. The water use efficiency of the early and full disease irrigated plants was, however, less (12.8 and 12.0 kg/ha/mm) than the NDU plants.

TABLE 3: The effects of disease and irrigation on root length per unit area (cm/cm²) in 1981-1982.

Growth stage	Disease treatments						LSD P<0.05
	Nil disease		Early disease		Full disease		
	UI*	I	UI	I	UI	I	
24	93.0†	89.6	91.0	89.7	87.2	87.0	17.0
31	205.7	169.2	150.0	145.3	126.3	139.6	36.8
80	210.4	225.1	204.9	167.4	133.1	120.0	38.5
92	317.5	229.6	208.7	127.8	191.2	133.2	61.0
LSD P<0.05	65.8	33.4	24.5	48.4	26.7	38.1	

*UI = Unirrigated, I = Irrigated (230 mm was applied at GS 83).
† Root Length extracted from a core length of 50 cm (GS 24 and 31), 70 cm (GS 80), and 75 cm (GS 92).

DISCUSSION

The main objective of this study was to determine the effect of disease on root growth, yield and yield components and to explain the lack of compensation in some seasons for yield reductions caused by early disease. In the nil disease plants, the yield in the first trial was 49% greater than in the second trial. The yield reductions caused by a full disease epidemic in the two seasons were similar (13% and 14%). In the first trial the reduction was attributed to a lower grain number and individual grain weight. In the early disease plants, a lower grain number was compensated for by heavier individual grain weight. This compensatory grain growth was associated with an unusually high rainfall (44% greater than average) during the grain filling period. Compensatory grain growth was not, however, evident in the second trial. Irrigation may have been applied too late (GS 83) in the season for yield responses to occur.

Root growth of field-grown wheat was affected by foliar diseases. This supports the evidence from pot-grown plants (Martin and Hendrix, 1974; Gough and Merkle, 1977). The effects of a reduced root system on yield may have been offset by rain during the grain filling period. Early disease reduced root development in the second trial (Table 3). After disease control was initiated in the early disease treatment (GS 32) however, root length increased by 26% up to GS 80. Root length of the full disease plants did not increase over the same period. This indicated that the plants were able to produce more roots after disease constraints were removed to offset earlier reductions in root growth. The increased root growth after GS 32 is an additional demand for photosynthates during this period and may therefore constrain growth and the development of spikelets and florets. Gallagher *et al.* (1975, 1976) and Bidinger *et al.* (1977) reported that some photosynthates required for grain filling were translocated from stem reserves. It is possible that photosynthates required for root growth, after the alleviation of disease, may also be translocated from stem reserves, or current photosynthates may be used. The use of such reserves for root growth may limit the amount of photosynthate available for further root growth, or grain filling at later growth stages. In the NDU and FDU plants there was a net increase in root length from GS 80 to harvest. This indicated that soil water deficits during later growth stages may have necessitated further root growth to meet the water requirements of the plants. There was no increase in root growth after GS 80 in the EDU plants, probably because available resources were used for increased root growth earlier. The application of irrigation at GS 83 presumably reduced soil water deficits as in all the irrigated treatments, root lengths did not differ between GS 80 and 92.

Cumulative water use alone does not indicate the efficiency of water use by crops which is better expressed as water use efficiency. Water use efficiency was reduced, by 14%, in the absence of irrigation in the full disease plants compared to the nil disease plants. When early disease constraints were alleviated, water use efficiency in the unirrigated plants was not significantly different to that of the nil disease plants. The low water use efficiency of irrigated plants may be attributed to irrigation being applied too late in crop growth (GS 83) to be of any significant benefit.

Foliar diseases in wheat reduced root growth. This reduction may have prevented the plants from extracting water from larger volumes of soil (Balasubramaniam, 1985). These studies partially supported the hypothesis that lack of compensation for the effects of early disease by later determined components (e.g. Lim, 1982) is caused by water constraints. The reduction in root development caused by disease could be counteracted by irrigation. The application of water may be a useful research tool to study the effect of disease constraints on the yield of wheat.

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REFERENCES

Anon., 1972. "Guide for the Assessment of Cereal Diseases". Plant Pathology Laboratory, Harpenden, Herts: Ministry of Agriculture, Fisheries and Food, United Kingdom.

Ayres, P.G., Zadoks, J.C. 1979. Combined effects of powdery mildew disease and soil water level on the water relations and growth of barley. *Physiological Plant Pathology 14:* 347-361.

Balasubramaniam, R. 1985. The effects of foliar diseases and irrigation on root development, yield and yield components of wheat (*Triticum aestivum* L.) Ph.D. thesis, Lincoln College, University of Canterbury, New Zealand. 187 p.

Bidinger, F., Musgrave, R.B., Fischer, R.A. 1977. Contribution of stored pre anthesis assimilate to grain yield in wheat and barley. *Nature 270:* 431-433.

Doodson, J.K., Manners, J.G., Myers, A. 1964. Some effects of yellow rust (*Puccinia striiformis*) on the growth and yield of a spring wheat. *Annals of Botany 28:* 459-472.

French, B.K., Long, I.F., Penman, H.L. 1973. Water use by farm crops. I. Test of the neutron meter on barley, beans and sugarbeet 1970. *Rothamsted Experimental Station Report for 1972, Part 2:* 5-42.

Gallagher, J.N., Biscoe, P.V., Scott, R.K. 1975. Barley and its environment. V. Stability of grain weight. *Journal of Applied Ecology 12:* 319-336.

Gallagher, J.N., Biscoe, P.V., Hunter, B. 1976. Effects of drought on grain growth. *Nature 264:* 541-542.

Gaunt, R.E., Lim, L.G., Thomson, W.J. 1982. The identification of disease constraints to cereal yields: crop/food loss appraisal reports. *FAO Plant Protection Bulletin 30:* 3-8.

Gough, F.J., Merkle, O.G. 1977. The effect of speckled leaf blotch on root and shoot development of wheat. *Plant Disease Reporter 61:* 597-599.

James, W.C., Shih, C.S., Callbeck, L.C., Hodgson, W.A. 1973. Interplot interference in field experiments with late blight of potato (*Phytophthora infestans*). *Phytopathology 63:* 1269-1275.

Jones, D.G., Rowling, R.D.W. 1976. The reaction of two spring wheat varieties exposed to epidemics of *Septoria nodorum* and *S. tritici* of varying intensity and duration. *Journal of Agricultural Science, Cambridge, 87:* 401-406.

Kirby, E.J.M. 1974. Ear development in spring wheat. *Journal of Agricultural Science, Cambridge, 82:* 437-447.

Kirby, E.J.M. 1977. The growth of the shoot apex and the apical dome of barley during ear initiation. *Annals of Botany 41:* 1297-1308.

Lim, L.G. 1982. Effects of powdery mildew and leaf rust on the apical development and yield of barley (*Hordeum vulgare* L.). Ph.D. thesis, Lincoln College, University of Canterbury, New Zealand. 325 pp.

Lim, L.G., Gaunt, R.E. 1981. Leaf area as a factor in disease assessment. *Journal of Agricultural Science, Cambridge 97:* 481-483.

Marsh, B.a'B. 1971. Measurement of length in random arrangements of lines. *Journal of Applied Ecology 8:* 265-267.

Martin, N.E., Hendrix, J.W. 1974. Anatomical and physiological responses of Baart wheat roots affected by stripe rust. Washington Agricultural Experiment Station, Technical Bulletin No. 77. 17 p.

Unger, P.W., Eck, H.V., Musick, J.T. 1981. Alleviating plant water stress. *In:* "Modifying the Root Environment to Reduce Crop Stress". Eds. G.F. Arkin and H.M. Taylor. American Society of Agricultural Engineers. St. Joseph, Michigan. pp 61-93.

Walters, D.R., Ayres, P.G. 1981. Growth and branching pattern of roots of barley infected with powdery mildew. *Annals of Botany 47:* 159-162.

Williams, J.R., Jones, D.G. 1972. Epidemiology of *Septoria tritici* and *S. nodorum.* VI. Effect of time of initial infection on disease development and grain yield in spring wheats. *Transactions of the British Mycological Society 59:* 273-283.

Zadoks, J.C., Chang, T.T., Konzak, C.F. 1974. A decimal code for the growth stages of cereals. *Weed Research 14:* 415-421.