Elevated pH and Associated Reduced Trace-Nutrient Availability as Factors Contributing to Take-All of Wheat upon Soil Liming

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ABSTRACT

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Studies of take-all of wheat caused by *Gaeumannomyces graminis* var. *tritici* tested whether increased severity of the disease in areas where soil had been amended with limestone was the result of increased pH of the rooting medium or of calcium or magnesium supplied by the amendments. Hoagland's solution was used as a source of plant nutrients and was applied to a silica sand rooting medium with calcium or magnesium at normal (1H), twice (2H), or three times (3H) the amount in Hoagland's solution, each at pH 4.5, 5.5, 6.5, 7.5, and 8.5. Take-all severity increased with increasing pH but not with increasing amount of calcium or magnesium. Increasing calcium from 1H to 3H had no effect on take-all, but increasing magnesium from 2H to 3H resulted in less severe take-all. Uptake of copper, magnesium, and iron (as determined by leaf-tissue analysis of plants supplied with normal [1H] Hoagland's solution) was significantly less at pH 7.5 and 8.5 than at the three lower pH levels; for zinc, uptake was significantly less at pH 5.5 and above than at pH 4.5. The pH values associated with reduced uptake of trace nutrients corresponded generally to the pH values at which the incidence and severity of take-all was increased. At least part of the favorable effect of liming on take-all may result from host-plant predisposition resulting from inadequate supplies of certain essential plant nutrients at the elevated pH.

Additional key words: soilborne pathogens, *Triticum aestivum*.

Take-all of wheat and the patch disease of turf, caused by *Gaeumannomyces graminis* (Sacc.) Müller and Von Arx var. *tritici* Walker and var. *avenae* (Turner) Walker, respectively, are more severe if the soil is limed and less severe as the soil becomes more acid (2,3,8,9,14,15). The two kinds of limestones commonly used are calcitic ($CaCO_3$) and dolomotic $(Ca,Mg)CO_3$. Besides raising soil pH, liming compounds increase the amount of calcium and/or magnesium in the soil. Ponchet (12) concluded that increased pH and not increased calcium increased the incidence of take-all. Huber (5) has suggested more recently, however, that the increased take-all with lime may be an effect independent of any pH effect.

We observed in earlier work (13) that increasing or decreasing the amount of calcium to twice (2H) or half (1/2H) the concentration in Hoagland's solution had no effect on take-all of wheat, whereas similar adjustments in the concentration of magnesium resulted in less and more take-all, respectively, relative to the amount of disease with normal (1H) Hoagland's solution. These data are evidence against the possibility that increased take-all following lime application results from increased levels of calcium and/or magnesium. We also observed that deficiencies in trace nutrients (copper, zinc, and possibly manganese and iron) favored take-all. These trace nutrients become less available in soil with increasing soil pH (1,4,7,10,11) and with increasing rhizosphere pH (15), suggesting that increased take-all upon liming may result from nutrient deficiency in the host.

In southern Brazil, as well as in western Washington and Oregon, soils originally strongly acid (with pH values as low as 4.5) have been limed repeatedly over past years to eliminate aluminum and manganese toxicity. This practice, in addition to the naturally high rainfall in these areas, has favored take-all (2). If liming favors take-all by reducing the availability of essential plant nutrients,

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then the possibility exists that disease severity can be decreased in limed soils through application of the deficient nutrients. This study was undertaken to investigate whether the increase in take-all with liming is a pH effect or a result of the increase in calcium or magnesium. We attempted further to determine whether increased disease could be correlated with reduced availability of trace nutrients to the plant.

MATERIALS AND METHODS

Preparation of inoculum, silica sand rooting medium, and Hoagland's nutrient solution; method of disease assessment; and environmental conditions were as previously described (13). Briefly, quartz sand (30-mesh) contained in 9 × 11-cm paper (disposable) pots and infested with 1% (w/w) ground oat inoculum containing the pathogen was used as the rooting medium. A layer of inoculum-free sand 1.5 cm thick was used to separate the seed from the inoculum, which permitted the wheat roots to grow for a short distance before coming into contact with the fungus. Another 1.5-cm-thick layer of sand was used to cover the seeds. Pots were watered using full-strength (1H) Hoagland's solution as the basic treatment. The Hoagland's solution contained the following components in milligrams per liter: 175 of K_2HPO_4, 500 of KNO_3. 820 of $Ca(NO_3)_2$, 240 of $MgSO_4$, 2.8 of H_3BO_3, 1.8 of $MnCl_2{\cdot}4H_2O$, 0.2 of $ZnSO_4{\cdot}7H_2O$, 0.08 of $CuSO_4{\cdot}5H_2O$, 0.09 of $H_2MoO_4{\cdot}H_4O$ and 36 mg of chelate ethylene diamine tetraacetic acid ($C_{10}H_{12}FeN_2NaO_8$).

Eight surface-sterilized seeds were planted per pot. The stand was thinned to five plants per pot after emergence. Plants were grown for 40–50 days in a growth chamber at 15 C with a photoperiod (18,000 lx) of 12 hr. Disease severity was assessed by counting the number of infected roots per plant and scoring each plant on a 0–4 disease index (13), in which 0 meant no disease and 4, the most severe disease.

To determine whether the effect of liming results from increased calcium or increased pH, a factorial experiment was used to provide all combinations of five pH levels (4.5, 5.5, 6.5, 7.5, or 8.5) and three concentrations of calcium (200, 400, or 600 mg/L, as $CaSO_4$). The pH values were adjusted using either sodium hydroxide or sulfuric acid. The amounts of sulfate added during pH adjustment were only 1/20–1/60 of the amounts already present in the Hoagland's solution, and the amounts of sodium added were always 1/5 or less of the amounts of potassium or calcium present. Another experiment was conducted using the same five pH levels and three magnesium levels (48, 96, or 144 mg/L as $MgSO_4$). Plant tissue analysis (Oregon State University Department of Horticulture, Plant Analysis Laboratory, Corvallis 97330) by arc emission was used to evaluate micronutrient uptake at each pH level by plants that received calcium at the 1H (200 mg/L) concentration. Plant tops were removed and composited for each of the four pots (replicates) representing each pH level. Each composite leaf sample was then divided into three subsamples, which were analyzed separately.

RESULTS AND DISCUSSION

The mean number of roots produced by uninoculated (check) plants was significantly less at higher pH levels regardless of amount of calcium or magnesium added. The mean numbers of roots per plant in the absence of the pathogen were 11.1, 11.7, and 11.9 for 200, 400, and 600 mg of calcium per liter of Hoagland's solution, respectively; these were not significantly different at $P=0.05$. In contrast, the mean number of roots at different pH levels in the same experiment were 12.3, 12.2, 12.3, 10.8, and 10.3 for pH 4.5, 5.5, 6.5, 7.5, and 8.5, respectively, with the numbers at pH 7.5 and 8.5 being significantly lower ($P=0.05$) than at other pH values. For magnesium, the mean numbers of roots on uninoculated plants were 9.9, 10.6, and 10.8 for 48, 96, and 144 mg of magnesium, respectively, with the number for 48 mg being significantly less than the numbers that developed with 96 and 144 mg of magnesium. The number of roots on uninoculated plants was uniformly 10.6–10.8 at pH values between 4.5 and 7.5 when magnesium was the variable, and roots were significantly ($P=0.05$) fewer (9.3) only when the pH had been adjusted to 8.5.

When the pathogen was present, both the number and percentage of diseased roots and also the disease rating increased with increasing pH of the rooting medium (Tables 1 and 2). Again calcium per se had no significant or consistent effect on the total number of roots produced, nor did this element appear to affect disease severity (Table 1). In contrast, increasing the amount of magnesium was again stimulatory to number of roots produced but, in addition and as reported previously (13), this element resulted in significantly fewer diseased roots per plant and less disease severity (Table 2).

These results confirm the findings of Ponchet (11) that the effect of liming on take-all is a pH effect independent of calcium levels. The results also confirm our earlier findings (13) that increasing calcium in the range provided by one half to three times the concentration in Hoagland's solution has no measurable effect on take-all, whereas increasing magnesium over a comparable range is suppressive to take-all. Finally, the results confirm our earlier observation that treatments that result in fewer roots per plant are generally the same treatments that result in greater susceptibility of the plant to take-all. In general, the incidence and severity of take-all at a given pH value was lower when magnesium sulfate was applied than when calcium sulfate was applied, possibly because the increased plant vigor with increasing amounts of magnesium partially offset the effect of higher pH in such treatments.

The concentration of copper in the leaf tissue was uniformly high (18–20 ppm) at pH 4.5, 5.5, and 6.5 but only 3–4 ppm at pH 7.5 and 8.5 (Table 3). Uptake of zinc dropped by about 50% as the pH was elevated from pH 4.5 to 5.5 and by an additional 25% as the pH was elevated from 6.5 to 8.5. Manganese uptake based on leaf analysis was uniform (80–100 ppm) at pH 4.5, 5.5, and 6.5 but significantly less (63–65 ppm) at pH 7.5 and 8.5. Paradoxically, the iron content of the leaves was enhanced somewhat ($P = 0.05$) as the pH was elevated from 4.5 to 5.5 or 6.5 but then dropped to substantially

TABLE 1. Effect[a] of pH[b] and calcium[c] on the number of roots and severity of take-all on wheat grown in a silica sand rooting medium infested with *Gaeumannomyces graminis* var. *tritici*

	Total No. of roots at Ca level (mg/L)				No. of diseased roots at Ca level (mg/L)				Percent of roots diseased at Ca level (mg/L)				Disease rating[d] at Ca level (mg/L)			
pH	200	400	600	Mean	200	400	600	Mean	200	400	600	Mean	200	400	600	Mean
4.5	11.9 b	11.8 a	12.0 b	11.9 b	5.8 c	7.9 b	6.2 b	6.6 d	49 e	67 c	51 c	55 c	1.7 e	2.7 c	2.0 d	2.1 e
5.5	10.5 c	11.5 a	11.8 b	11.3 c	5.7 c	8.1 b	7.7 a	7.2 c	54 d	71 b	65 b	63 b	2.0 d	3.0 b	2.5 c	2.5 d
6.5	13.0 a	12.0 a	12.7 a	12.6 a	8.6 b	7.2 c	8.3 a	8.0 b	66 c	60 d	65 b	64 b	3.0 c	2.8 c	2.7 c	2.8 c
7.5	11.5 b	10.4 b	9.7 c	10.5 d	8.5 b	9.1 a	8.1 a	8.6 a	74 b	87 a	84 a	82 a	3.6 b	4.0 a	3.8 a	3.8 a
8.5	10.1 c	10.1 b	9.5 c	9.9 e	9.8 a	5.8 d	8.2 a	7.9 b	96 a	57 d	86 a	80 a	3.9 a	2.5 d	3.5 b	3.3 b
Mean	11.4 f	11.2 f	11.1 f		7.7 e	7.6 e	7.7 e		68 d	68 d	70 d		2.8 f	2.9 f	2.9 f	

[a] Each value is the mean of four replicates with five seedlings per pot. Data taken 27 days after sowing. Within any given column, means with a common letter are not significantly different at $P=0.05$, according to Duncan's multiple range test.

[b] pH adjusted by adding H_2SO_4 or NaOH.

[c] Ca added as $CaSO_4$ in Hoagland's solution.

[d] 0 = no disease, 4 = most severe disease.

TABLE 2. Effect[a] of pH[b] and magnesium[c] on the number of roots and severity of take-all of wheat grown in a silica sand rooting medium infested with *Gaeumannomyces graminis* var. *tritici*

pH	Total No. of roots at Mg level (mg/L)				No. of diseased roots at Mg level (mg/L)				Percent of roots diseased at Mg level (mg/L)				Disease rating[d] at Mg level (mg/L)			
	48	96	144	Mean	48	96	144	Mean	48	96	144	Mean	48	96	144	Mean
4.5	10.2 b	9.4 b	10.7 ab	10.1 b	5.7 b	4.9 c	4.9 b	5.2 c	56 cd	52 b	47 c	52 c	1.3 c	1.5 c	1.4 bc	1.4 d
5.5	18.8 a	10.1 a	10.5 b	10.4 a	5.6 b	6.8 a	5.5 b	6.0 b	53 d	68 a	53 bc	58 b	1.6 bc	2.0 b	1.6 ab	1.7 c
6.5	9.9 bc	9.4 b	11.0 a	10.1 b	5.9 b	6.5 ab	5.0 b	5.8 b	60 bc	70 a	46 c	59 b	2.0 b	2.9 a	1.0 c	2.0 b
7.5	9.6 c	9.5 b	10.2 b	9.7 c	6.9 a	6.3 b	6.2 a	6.4 a	72 a	55 b	61 a	66 a	2.7 a	3.2 a	1.4 bc	2.4 a
8.5	9.0 d	8.3 c	9.3 c	8.9 d	5.8 b	4.6 c	5.2 b	5.2 c	66 ab	56 b	56 ab	59 b	2.7 a	2.1 b	1.9 a	2.2 a
Mean	9.9 e	9.3 f	10.3 d		6.0 d	5.8 d	5.4 e		62 d	60 d	53 e		2.1 f	2.3 e	1.5 g	

[a] Each value is the mean of four replicates with five seedlings per pot. Data taken 26 days after sowing. Within any given column, means with a common letter are not significantly different at $P = 0.05$, according to Duncan's multiple range test.
[b] pH adjusted by adding H_2SO_4 or NaOH.
[c] Mg added as $MgSO_4 \cdot 7H_2O$ in Hoagland's solution.
[d] 0 = no disease, 4 = most severe disease.

TABLE 3. Effect of pH on concentration of copper, iron, manganese, and zinc in leaves of wheat seedlings grown in a silica sand rooting medium containing normal Hoagland's solution

pH[a]	Concentration[b] (ppm) in leaves			
	Cu	Zn	Fe	Mn
4.5	18.5 a	44.8 a	148.0 b	86.3 a
5.5	20.0 a	23.8 b	206.0 a	98.8 a
6.5	18.0 a	23.5 b	249.0 a	90.1 a
7.5	4.3 b	15.5 b	70.0 c	65.0 a
8.5	3.3 b	12.8 b	69.5 c	63.4 b

[a] pH of Hoagland's solution was adjusted by adding NaOH or H_2SO_4.
[b] Each value is the mean of four replicates. For each trace nutrient, values with a common letter are not significantly different at $P = 0.05$, according to Duncan's multiple range test. Plant analysis was performed at the Plant Analysis Laboratory, Oregon State University.

lower levels at pH 7.5 and 8.5. The drop in tissue concentration of each of the four trace nutrients was greatest as the pH was raised from 6.5 to 7.5; this was approximately the same pH change that tended to produce the greatest increase in incidence and severity of take-all (Table 1). Levels of copper and zinc at pH 7.5 and 8.5 were below the sufficiency levels reported by Jones (6) for several crop species, although levels of iron and magnesium appeared sufficient even at these pH levels. Probably a deficiency of only one of the several critical nutrients (13) would be sufficient to predispose wheat to take-all.

These results suggest that deficiency of trace nutrients in over-limed soils (eg, those in which pH is elevated above 6.5) should be considered a factor favorable to take-all development. A deficiency of potassium (13,17) may also be related to the severity of take-all in some areas of Brazil. Nitrogen, phosphorus, potassium, magnesium, and trace nutrients all should be maintained at levels sufficient to avoid crop deficiencies. This is especially important for wheat crops grown while the inoculum potential is still low (13,16,17); proper nutrition may significantly reduce take-all severity under such conditions.

LITERATURE CITED

1. Bohn, H. L., McNeal, B. L., and O'Conner, G. A. 1979. Soil Chemistry. John Wiley & Sons, New York. 329 pp.
2. Cook, R. J. 1981. The effect of soil reaction and physical conditions. Pages 343–353 in: Biology and Control of Take-All. M. J. C. Asher and P. J. Shipton, eds. Academic Press, London. 538 pp.
3. Glynne, M. D. 1935. Incidence of take-all on wheat and barley on experimental plots at Woburn. Ann. Appl. Biol. 22:225-235.
4. Hausenbuiller, R. L. 1972. Soil Science, Principles and Practice. W. M. C. Brown Co., Dubuque, IA. 504 pp.
5. Huber, D. M. 1981. The role of nutrients and chemicals. Pages 317–341 in: Biology and Control of Take-All. M. J. C. Asher and P. J. Shipton, eds. Academic Press, London. 538 pp.
6. Jones, J. B. Jr. 1972. Plant tissue analysis for micronutrients. Pages 319–346 in: Micronutrients in Agriculture. J. J. Mortredt, P. M. Giordano, and W. L. Lindsay, eds. Soil Sci. Soc. Am. Inc., Madison, WI. 666 pp.
7. Kamprath, E. J., and Foy, C. D. 1971. Lime-fertilizer-plant interactions in acid soils. Pages 105–151 in: Fertilizer Technology and Use. R. A. Olson, T. J. Army, J. J. Hanway, and V. J. Kilmer, eds. Soil Sci. Soc. Am. Inc., Madison, WI. 611 pp.
8. Kirby, R. S. 1922. The take-all disease of cereals and grasses. Phytopathology 12:66-88.
9. Kirby, R. S. 1925. The take-all disease of cereals and grasses caused by *Ophiobolus cariceti* (Berkeley and Broome) Saccardo. Mem. Cornell Agric. Exp. Stn. No. 88. 45 pp.
10. Lindsay, W. L. 1972. Inorganic phase equilibria of micronutrients in soils. Pages 41–57 in: Micronutrients in Agriculture. J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay, eds. Soil Sci. Soc. Am. Inc., Madison, WI. 666 pp.
11. Lucas, R. E., and Knezek, B. 1972. Climatic and soil conditions promoting micronutrient deficiencies in plants. Pages 265–288 in: Micronutrients in Agriculture. J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay, eds. Soil Sci. Soc. Am. Inc., Madison, WI. 611 pp.
12. Ponchet, J. 1962. Étude des facteurs qui conditionnent le développement du piétin-echaudage: *Linocarpon cariceti* B. et Br. Ann. Epiphyt. 13:151-165.
13. Reis, E. M., Cook, R. J., and McNeal, B. L. 1982. Effect of mineral nutrition on take-all of wheat. Phytopathology 72:224-229.
14. Rosen, H. R., and Elliot, J. A. 1923. Pathogenicity of *Ophiobolus cariceti* in its relationship to weakened plants. J. Agric. Res. 25:351-358.
15. Sarkar, A. N., and Wyn Jones, R. G. 1982. Effect of rhizosphere pH on the availability and uptake of Fe, Mn, and Zn. Plant Soil 66:361-372.
16. Slope, D. B., Salt, G. A., Broom, E. W., and Gutteridge, R. J. 1978. Occurrence of *Phialophora radicola* var. *graminicola* and *Gaeumannomyces graminis* var. *tritici* on roots of wheat in field crops. Ann. Appl. Biol. 88:239-246.
17. Trolldenier, G. 1982. Influence of potassium nutrition and take-all on wheat yield in dependence on inoculum density. Phytopathol. Z. 103:340-382.