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Influence of Herbicides on Aphanomyces Root Rot of Peas

Root rot diseases are major limiting factors in pea production throughout the world. Losses vary according to soil type, soil moisture, and climate but are estimated at 10% in the United States. In areas of intensive production, such as around processing plants, continued cropping to peas is often not economical because root rots are so severe; loss estimates should include the transportation costs that are increased by continual moving to new production fields.

Of the several fungi causing root rot diseases of peas—including *Fusarium solani* (Mart.) Appel & Wr. f. sp. *pisi* (F. R. Jones), *Rhizoctonia solani* Kuehn, and *Pythium* spp.—*Aphanomyces euteiches* Drechs. is considered the most important. More than 80% of root rot losses are attributed to *A. euteiches* alone (8).

Control Before Herbicides

A field indexing procedure for assessing root rot potential before planting was developed by Sherwood and Hagedorn (11) in 1958 and Reiling et al (9) in 1960. The procedure was ideal for assessing Aphanomyces root rot potential. Control at that time was based on avoiding fields with a high disease risk, and the method was rapidly adopted by pea producers in the Midwest.

Avoiding diseased fields continued to be the basis of root rot control until 1971, when J. E. Mitchell and D. J. Hagedorn reported the use of fenaminosulf (Lesan, formerly Dexon). This fungicide was effective and labeled for use but was not considered economical to use.

Herbicides' Wide-Ranging Effects on Root Diseases

During the past decade, many researchers have examined the influence of herbicides on root diseases. The data have shown a wide range of effects, varying from suppression to enhancement of disease (1). In a 1977 review, Altman and Campbell (1) summarized three major effects of herbicides on the incidence and severity of plant disease: 1) a herbicide may directly decrease disease incidence or severity by increasing host structural or biochemical defenses or by decreasing growth of potential pathogens; 2) a herbicide may directly increase disease incidence or severity by reducing host structural defenses, by stimulating exudations from host plants, by stimulating pathogen growth, or by inhibiting microflora antagonistic to potential pathogens; and 3) herbicides may indirectly affect disease incidence or severity by causing microclimate changes due to weed and secondary host eliminations, by altering the population or activities of microbial antagonists, or by altering the rhizosphere through changes in organic substances exuded by roots. More subtle indirect effects may be as important as direct effects.

In 1971, Carlson and Hopen (3) noted that pea root rot was less severe where trifluralin (Treflan®, Elanco) was applied to the soil for weed control; this was observed under severe disease pressure. In 1973, we began a closer examination of the phenomenon. In glasshouse studies, both trifluralin and dinoseb (Premerge III®, Dow) applied at field rates suppressed disease where *A. euteiches* had been inoculated into sterile soil. Field studies in 1974 showed that dinoseb suppressed root rot better than trifluralin did. In 1974, 1975, and 1976, extensive field trials were conducted with pea processors in central and northern Illinois to further evaluate several dinitroaniline herbicides alone or in combination and dinoseb alone or in

Table 1. Yield and disease severity indices in a large field plot in 1976 with preplant incorporated herbicides

Treatment	Rate (kg/ha)	Adjusted yield[x,y] (kg/ha)	DSI[x] at bloom
Dinoseb	6.72	6,610 a	58.1 a
Dinoseb + trifluralin[z]	6.72 + 0.56	5,620 ab	70.7 bc
Dinitramine	0.37	5,550 ab	65.4 ab
Propachlor	4.48	5,480 ab	71.1 bc
Trifluralin	0.56	4,720 bc	69.8 bc
Untreated	···	2,980 c	79.1 c

[x] Disease severity index: 0 = no disease, 100 = completely rotted roots. Means in each column not sharing common letters are significantly different by Wishart's multiple comparison test for covariance at the 0.05 level.
[y] Yields of shelled peas adjusted by covariance to mean tenderometer value of 139.
[z] Tank mix.

Table 2. Yield and disease severity indices of peas planted in soil treated with dinoseb and trifluralin in 1977

Treatment	Rate (kg/ha)	Adjusted yield[y] (kg/ha)	DSI[z] at bloom
Dinoseb	6.72	5,632	39.4 a
Trifluralin	0.56	5,107	38.8 a
Untreated	···	1,747	69.2 b

[y] Yields of shelled peas adjusted by covariance to mean tenderometer value of 139.
[z] Disease severity index: 0 = no disease, 100 = completely rotted roots. Means followed by different letters are significantly different from untreated at the 0.01 level by *t* test.

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Fig. 1. Four classes used to rate pea root rot severity: 0 = no disease, 1 = infection of secondary roots or isolated lesions on taproot and epicotyl, 2 = extensive destruction of secondary root system, and 3 = decay of entire root system.

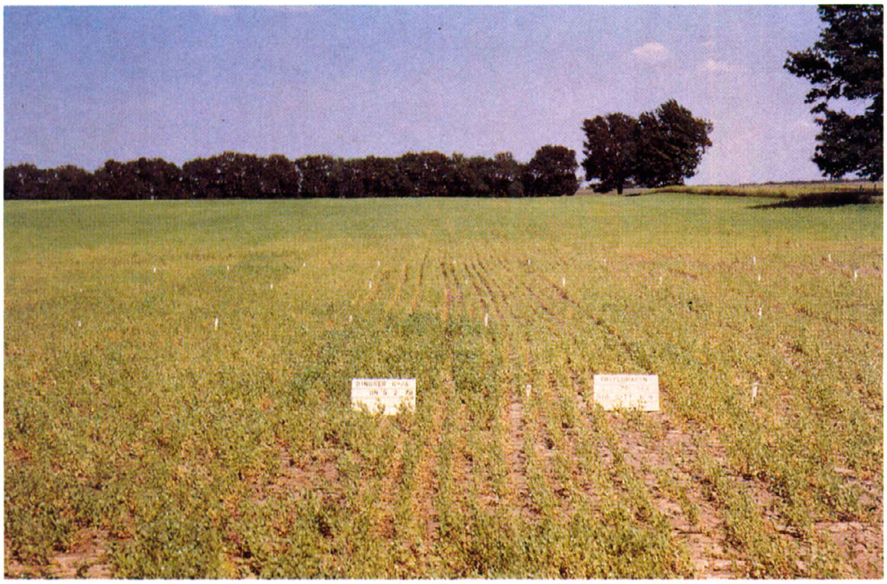

Fig. 2. Comparison of dinoseb and trifluralin in controlling Aphanomyces root rot in a commercial processing pea field where disease was so severe that the field was not harvested.

combination with the dinitroaniline materials for root rot suppression, weed control, and effects on yield. Close contact was maintained with Harvey et al at the University of Wisconsin, who were also working on the problem (6,12). Although their work initially included only dinitroaniline materials, they confirmed the hypothesis of protection by trifluralin and other dinitroaniline herbicides. Their research and work done at the University of Minnesota by Grau and Reiling (4,5) also indicated that the dinitroaniline herbicides suppressed pea root rot in the field. Grau's studies showed that dinitramine was more effective in root rot control than trifluralin but was more phytotoxic to peas. Laboratory studies were also done to help understand the effects observed in the field.

Field Studies

We adapted the field indexing procedure for use in our studies. We used the four root rot classifications shown in Figure 1 to calculate a disease severity index (DSI): the number of plants in each class multiplied by that class number, divided by the total number of plants multiplied by the number of classes. The quotient is multiplied by 100 to give a scale of 0 (no root rot) to 100 (completely rotted roots).

In 1974, a field with a root rot index of 82 was selected for field scale studies. Disease development was so severe that the field was not harvested, and only the plots treated with dinoseb were green at normal harvest time (Fig. 2). Dinoseb had been applied preemergence but was incorporated by a 2.5-cm rain immediately after application. Subsequently, we began to evaluate dinoseb as a preplant incorporated material.

Field research was done in 1975 and 1976 with pea processors in central and northern Illinois. Fields with a high root rot index were selected. Because both weed and root rot control were research objectives, propachlor, a herbicide used for grass control in peas and with no known effects on *A. euteiches*, was included with the dinitroaniline herbicides dinitramine (Cobex, U.S. Borax) and trifluralin (Treflan) and the dinitrophenol herbicide dinoseb (Premerge III); dinitramine, trifluralin, and dinoseb showed the most promise for root rot control in our glasshouse work and studies in Wisconsin and Minnesota. Combinations of trifluralin and dinoseb were evaluated to see if trifluralin would provide annual grass weed control, which dinoseb does not.

Data from a large field plot in northern Illinois in 1976 showed that the dinoseb and the dinitramine plots had significantly lower root rot indices than the propachlor, trifluralin, dinoseb + trifluralin, or untreated plots (Table 1). Yield data reflected the root rot indices

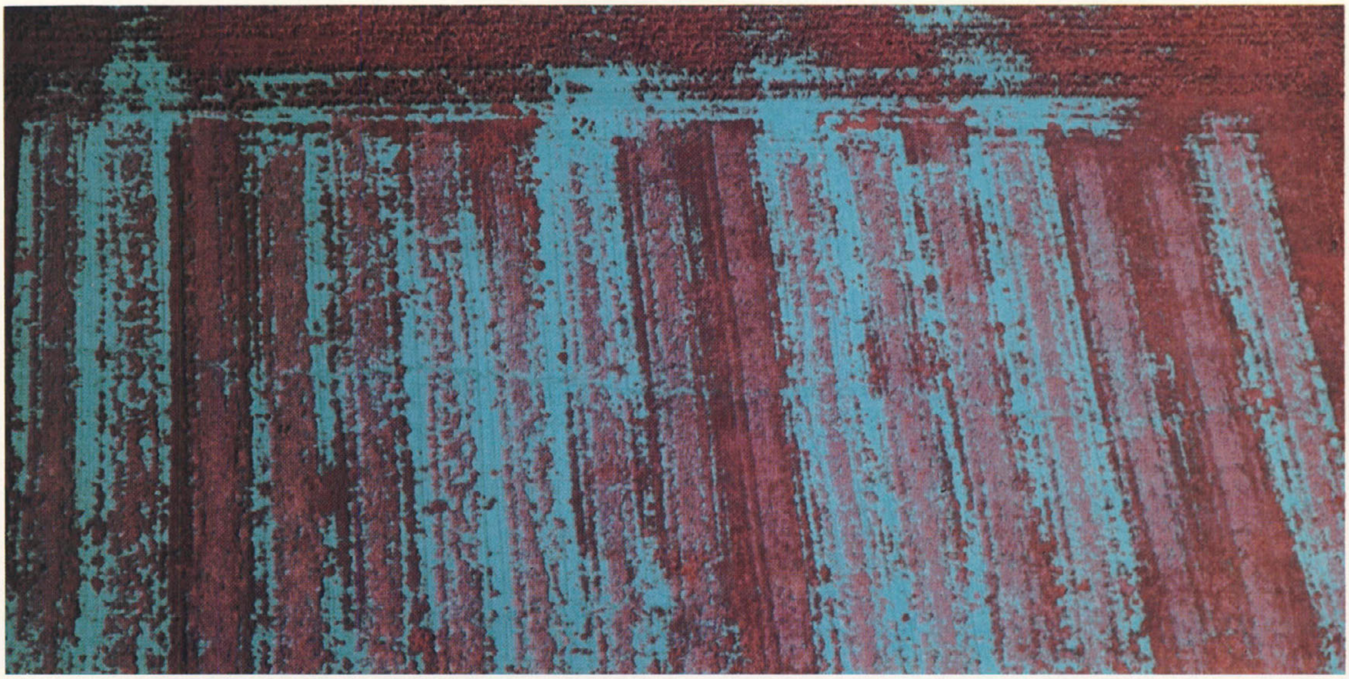

Fig. 3. Infrared aerial photograph of 1976 field plots. Peas were planted in 3-m wide plots, and treatments were 4.5 m wide. Crop and weed populations are reduced where blue-gray soil shows; dark red areas are weeds. Crop across top of photograph is corn; note effect of dinitroaniline herbicides sprayed beyond border of plots. P = propachlor, 4.48 kg/ha, applied preemergent; T = trifluralin, 0.56 kg/ha, applied preplant incorporated (PPI); D = dinoseb, 6.72 kg/ha, PPI; TD = trifluralin, 0.56 kg/ha, + dinoseb, 6.72 kg/ha tank mix, PPI; DM = dinitramine, 0.37 kg/ha, PPI; C = untreated control.

with the exception of propachlor, for which yield reflected reduced weed competition where root rot significantly thinned the stand. Figure 3 shows the reduced pea stands in untreated plots and plots treated with dinitroaniline herbicides, as well as reduced weed competition in these plots and those treated with propachlor.

To determine the relative effect of root rot and weeds (primarily *Setaria* spp.), we analyzed the data by multiple regression analysis, using the following equation: Ya = 12579.5 − 115.5181 (DSI at bloom) − 0.6464 (broadleaf weeds kg/ha) + 5.1153 (pea plants/m^2) + 0.0110 (grass weeds kg/ha) explains 91.85% ($R^2 = 0.89185$) of the variation in yield observed in this field plot. DSI at bloom was the most important factor in determining yield, followed by the influence of broadleaf weeds, then pea stands; the last two factors are indicators of herbicide toxicity and plant death due to disease. The next most important factor was grass weeds.

Results of field tests with the same commercial grower in 1977 were essentially the same (Table 2). These studies have been reported in detail by Sacher et al (10).

Table 3. Disease indices and stand counts of 'Little Marvel' peas in roots inoculated with *Aphanomyces euteiches* and treated with herbicides in glasshouse experiments

Treatment[v]	Rate (kg/ha)	DSI at[w] first flower
Dinitramine	0.56[x]	69.6 ghi[y]
Ethalfluralin	0.89[x]	56.8 def
Oryzalin	1.34[x]	48.9 cd
Oryzalin + trifluralin	0.56 + 0.56	35.7 ab
Trifluralin + dinoseb	0.67 + 3.32	61.9 efg
Dinoseb	3.32 PrE[z]	68.4 ghi
Dinoseb	3.32	51.3 cde
Dinoseb	6.72	26.0 a
Dinoseb	2.00 PoE[z]	81.4 j
Trifluralin	0.67	51.6 cde
Profluralin	0.67[x]	68.4 ghi
Penoxylin	1.34	81.8 j
Butralin	1.78[x]	40.7 bc
Fluchloralin	1.11	79.8 ij
Untreated	...	86.1 j

[v] All herbicides preplant incorporated unless noted.
[w] Disease severity index: 0 = no disease, 100 = completely rotted roots.
[x] Treatments showing phytotoxicity.
[y] Means not followed by a common letter are significantly different at the 0.01 level by Fisher's LSD test.
[z] PrE = applied preemergent, PoE = applied postemergent.

Glasshouse, Laboratory Studies

While field studies were in progress, several dinitroaniline herbicides alone or in combination with dinoseb were compared for Aphanomyces root rot control and for phytotoxicity in the

Table 4. Effect of dinoseb and trifluralin on *Aphanomyces euteiches* in cornmeal broth cultures

	Mycelial mat weight of 7-day-old cultures in grams			
	μg/ml herbicide			
Treatment	**0**	**1**	**5**	**25**
Untreated	0.216[z]	...	...	...
Trifluralin	...	0.0070 b	0.0068 b	0.0072 b
Dinoseb	...	0.0095 b	0.0062 b	0.0068 b

[z] Means not followed by the same letter are significantly different at the $P=0.01$ level using Duncan's new multiple range test.

Table 7. Effect of dinoseb and trifluralin on root rot disease severity index of peas one year after treatment

Treatment	Rate (kg/ha)	DSI[y] at bloom
Untreated	...	66.3 a[z]
Dinoseb	6.72	66.1 a
Trifluralin	0.56	84.3 b

[y] Disease severity index: 0 = no disease, 100 = completely rotted roots.
[z] Means followed by different letters are significantly different from untreated at $P = 0.10$ by the t test.

Table 5. Effect of trifluralin and dinoseb on production of primary spores and zoospores by *Aphanomyces euteiches*

		Zoospore rating[w]		
Treatment	**μg/ml**	**16 hr**	**36 hr**	**Number of primary[x] spores/1 mm³**
Untreated	...	3	3	9.25 a
Trifluralin 0–16 hr[y]	1.0	0	0	0
	0.1	0	0	2.25 f
	0.01	0	2	1.25 fg
	0.001	0	2	5.25 de
	0.0001	3	...	8.50 abc
Trifluralin 16–36 hr[z]	1.0	3	0	...
	0.1	3	0	...
	0.01	3	0	...
	0.001	3	0	...
	0.0001	3	0	...
Dinoseb 0–16 hr[y]	3.0	0	...	...
	1.0	0	3	0
	0.1	2	3	0
	0.01	3	3	7.00 cd
	0.001	3	3	9.00 a
Dinoseb 16–36 hr[z]	3.0	3	1	...
	1.0	3	2	...
	0.1	3	2	...
	0.01	3	2	...
	0.001	3	2	...

[w] Mean zoospore rating: 0 = 0 zoospores per microscopic field, 1 = 1–15 zoospores, 2 = 16–30 zoospores, 3 = about 30 zoospores.
[x] Means not followed by the same letter are significantly different at $P = 0.01$ level.
[y] Mycelial mats washed four times with salt solution. (After Mitchell and Yang. Phytopathology 56:917-922.)
[z] Mycelial mats washed four times with salt solution amended with herbicide.

Table 6. Effect of dinoseb and trifluralin on oospore production by *Aphanomyces euteiches*

Treatment	μg/ml	Mature oospores/ 6 mm disk[y]
Untreated	...	68.25 a[z]
Dinoseb	3.0	47.50 a
	1.0	57.00 a
	0.1	77.25 a
	0.01	62.25 a
Trifluralin	1.0	222.25 b
	0.1	200.00 b
	0.01	195.00 b

[y] Average of five replicates after 10 days' growth on cornmeal agar.
[z] Means not followed by the same letter are significantly different at the $P=0.1$ level using Duncan's new multiple range test.

glasshouse. Data from a representative experiment (Table 3) are in good agreement with field data.

In laboratory studies of the effect of dinoseb and trifluralin on growth and reproduction of *A. euteiches*, the rates used were approximately those of the field studies; 2×10^6 lb of soil in an acre plow layer was assumed. Both dinoseb and trifluralin decreased mycelial growth in cornmeal broth cultures (Table 4). Trifluralin reduced the number of primary spores (those encysted at the end of the endosporangium) at concentrations greater than 0.001 μg/ml in the sporulation solutions and eliminated the production of motile zoospores at concentrations greater than 0.0001 μg/ml (Table 5). In addition, trifluralin's effect on zoospore motility was partially reversible when sporulating mycelial mats were washed free of the herbicide. An interesting finding was that aflagellate zoospores were produced by primary spores and that these zoospores produced normal cultures when placed on cornmeal agar. These data are in good agreement with those of Grau (4) and Teasdale et al (12). These observations were the basis for hypothesizing that trifluralin controls Aphanomyces root rot by eliminating or reducing the number of motile zoospores, the infective propagules of *A. euteiches* (Fig. 4).

Also of interest is that the number of oospores produced by the fungus increased in the presence of trifluralin (Table 6), thereby multiplying the number of propagules in the soil and potentially raising the DSI. In 1977, disease severity indices taken in plots treated in 1976 were higher at $P = 0.10$ in plots treated with trifluralin (Table 7). This experiment was not repeated in other years.

By comparison, dinoseb did not influence oospore production but reduced primary spore production, thereby decreasing zoospore production at concentrations greater than 0.1 μg/ml (Table 5). Dinoseb's effects on zoospore production were also reversible when sporulating mycelial mats were washed free of the herbicide. Although the proposed mechanism of control is the same, dinoseb and trifluralin reduce the potential number of infective propagules in different ways. Trifluralin causes the zoospores to be aflagellate, which prevents them from moving through the soil water to infect pea roots. Dinoseb prevents or reduces the production of primary spores, thereby reducing the number of zoospores. The concentrations used in our laboratory studies are well below the estimated soil concentrations, based on water solubility of these herbicides.

The mechanism whereby these herbicides interfere with motile zoospore production is unclear. Hess and Bayer (7) reported that trifluralin may cause production of aflagellate zoospores by inhibiting the formation of microtubules necessary for generation of flagella. Dinoseb's effect on primary spore formation may be explained by a more general inhibition of cellular processes through uncoupling oxidative phosphorylation (2).

Choosing the Herbicide

Both dinoseb and trifluralin are highly effective against Aphanomyces root rot of peas at economical field rates, with dinoseb providing consistently superior control. Trifluralin offers better control of annual grass weeds. The interaction of weed control, phytotoxicity, and disease control should be considered in selecting herbicides. Although no combination of herbicides used in our studies was ideal, other combinations might prove more effective.

If pea producers obtain excellent stands, weed pressures are minimal, and root rot is a limiting factor, dinoseb would be an excellent choice. Where weed pressure as a limiting factor is as great as or greater than disease control, trifluralin + dinoseb or trifluralin alone is the best choice. The effect of these herbicides on *A. euteiches* suggests they may be beneficial in controlling fungal pathogens with similar life cycles.

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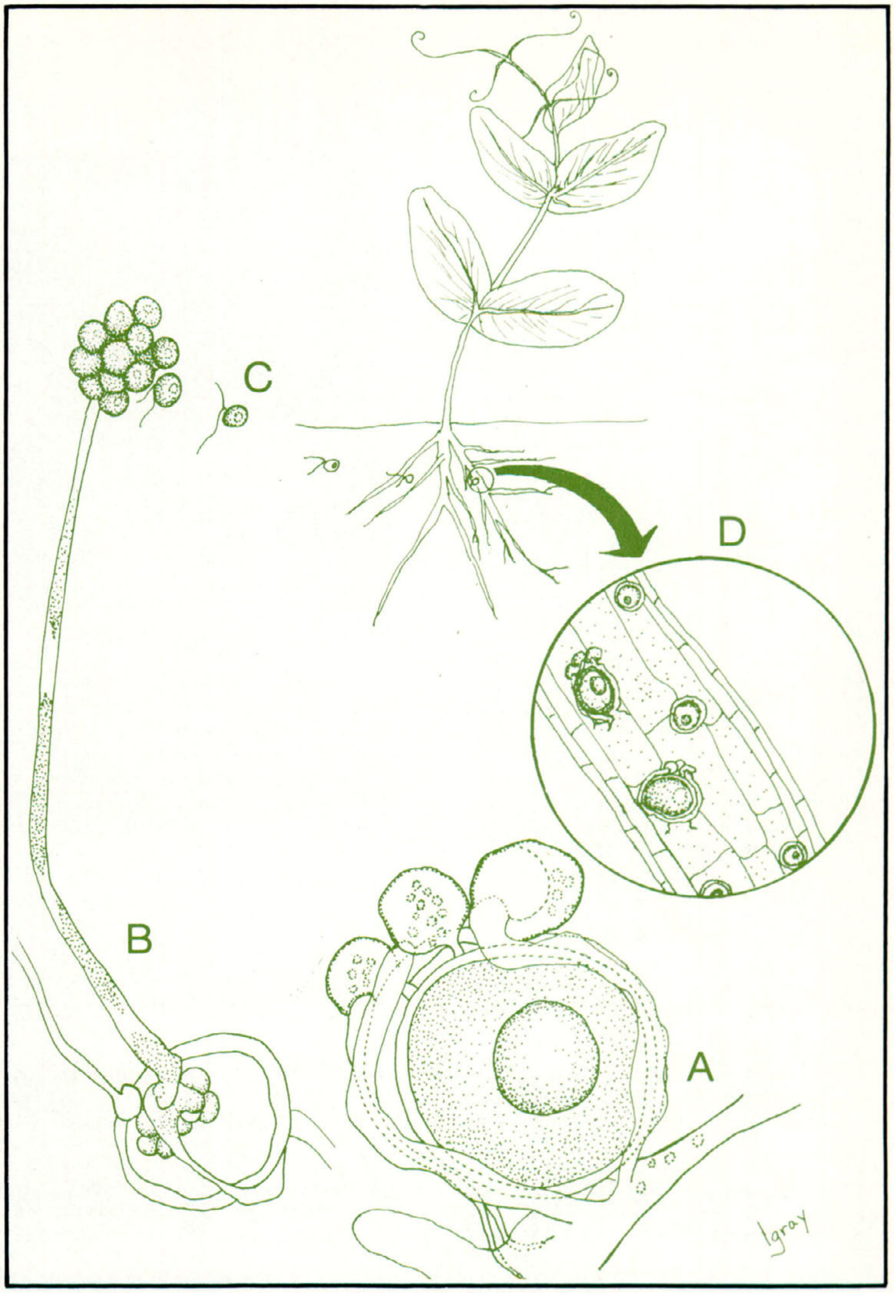

Fig. 4. Life cycle of *Aphanomyces euteiches*: (A) Resting oospore with several antheridia. (B) Germinated oospore with endosporangium and encysted primary spores at tip. (C) Biflagellate zoospores developing from primary spores. (D) Oospores in pea root tissue.

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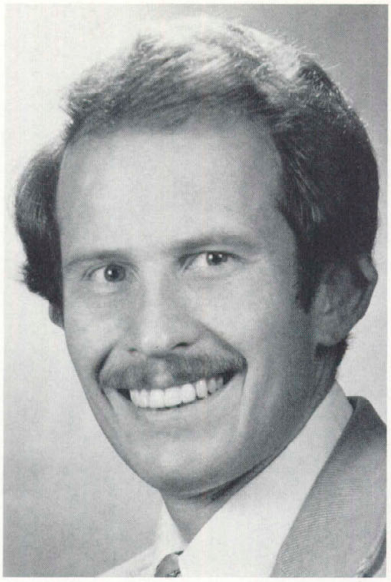

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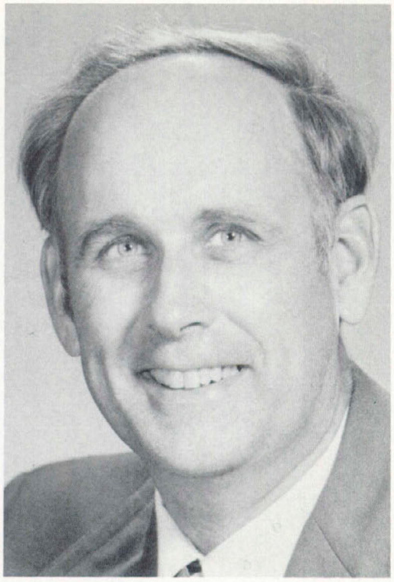

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