J. C. Tu
Harrow Research Station, Agriculture Canada, Harrow, Ont.

Integrated Control of the Pea Root Rot Disease Complex in Ontario

Southern Ontario is a prime agricultural district in Canada, and processing green peas are grown there to supply the domestic market. In 1983, Ontario growers farmed 8,600 ha of peas (3). A survey of 550 ha showed that 26.5% of the plants had root rot disease (Fig. 1), and many fields showed total losses. When root rots were kept under control, a yield of 5 t/ha could be achieved. In Ontario in 1983, average yields were 2.2 t/ha. The value of this yield loss of 2.8 t/ha, or approximately 24,000 t, was estimated at $6 million U.S. (3).

Pea root rot is a worldwide problem, and more than 20 different fungi can cause the disease (20). In Canada, Basu et al (5) reported that the most frequently isolated root rot fungi of peas were *Fusarium solani* (Mart.) Appel & Wr. f. sp. *pisi* (F. R. Jones) Snyd. & Hans., *F. oxysporum* Schlecht. f. sp. *pisi* Snyd. & Hans., and *Pythium* spp.; *Ascochyta pinodella* L. K. Jones and *Rhizoctonia solani* Kühn were isolated occasionally. The report was based on limited disease surveys and pathogen isolation and was insufficient to develop an integrated disease control (IDC) strategy for the Ontario pea root rot complex. A detailed survey was therefore undertaken to obtain information about epidemiology, cultural practices, and environmental factors so that necessary research could be conducted and an IDC program developed.

Epidemiology

Etiology. Approximately 50% of the commercial fields in Essex and Kent counties of southwestern Ontario were surveyed during late May and mid-June in 1983, and 782 cultures were isolated and identified. Frequencies of isolation of *F. solani, F. oxysporum, Aphanomyces euteiches* Drechs., and *Pythium* spp. were 7:4:1:1 (17). Other fungi, e.g., *R. solani, A. pinodella*, and *Thielaviopsis basicola* (Berk. & Br.) Ferraris, were isolated only occasionally. Overall disease severity and yield loss are the sum contributed by each component fungus.

The incidence of pea root rots in southern Ontario averaged 26.5%. Disease severity of each root rot was determined on a scale of 0 to 9, where 0 = <10% of root with symptoms, 1 = 10–20% of root with symptoms, etc., 9 = plant dead. The severity of disease caused by *F. solani* (root rot), *F. oxysporum* (wilt), *Pythium*, and *Aphanomyces* averaged 3.2, 8.7, 2.6, and 4.0, respectively. Isolates of *F. oxysporum* were identified as races 1 and 2 by means of a comparative differential scheme (12) and known races provided by J. M. Kraft of Prosser, Washington. The ratio of race 1 to race 2 was 7:4.

On the basis of this information, and assuming that hosts, environmental conditions, and cultural practices are random relative to isolation, a simple disease damage index (DDI) can be developed to rank the root rot fungi according to etiologic importance. The DDI of a root rot equals the total amount of root rot × the frequency of occurrence of each root rot fungus × the severity of disease caused by each fungus. The DDIs (Table 1) show that Fusarium wilt is the most serious problem, followed by Fusarium root rot. Plants with Fusarium wilt usually die, whereas plants with Fusarium root rot show various degrees of stunting and yellowing and often droop during warm, sunny afternoons but rarely die. Pythium and Aphanomyces root rots are considered to be minor problems in Ontario.

Symptoms. *F. solani* f. sp. *pisi* routinely infects the cotyledon, epicotyl, and hypocotyl (Fig. 2), and the disease progresses to the soil line and down the root system. Early symptoms are stunting and epinasty. Reddish brown streaks on the roots coalesce as the disease progresses, and the infected areas later appear dark to chocolate brown. Severely affected plants are stunted and chlorotic, and lower leaves die.

F. oxysporum f. sp. *pisi*, races 1 and 2, infects peas during the early stages of plant growth. Early symptoms are yellow to light orange discoloration in the vascular tissue of the taproot in an otherwise normal looking root system. Later, the discoloration extends upward to the basal stem (Fig. 3). Yellowing of the leaves starts from the basal part of the plant and progresses to the tip. The disease progresses quickly on a warm sunny day, and the plants die rapidly.

Pythium spp. are the same fungi that cause damping-off in young seedlings. When the plants grow older and become more lignified, however, the infection tends to be directed toward young feeder roots. The roots break off at areas where soft rot develops, which usually appear tan to light brown (Fig. 4). Diseased plants appear to lack vigor and often show some stunting and yellowing, with reduced yields.

A. euteiches infects the epicotyl of peas at the early seedling stage and the roots at

Table 1. Disease damage index (DDI) of each fungus in the Ontario root rot complex (average incidence = 26.5%)

Fungus	F.O.[a]	D.S.[b]	DDI
Fusarium solani	7/13	3.2	45
F. oxysporum	4/13	8.7	71
Pythium spp.	1/13	2.6	5
Aphanomyces euteiches	1/13	4.0	8

[a] Frequency of occurrence.
[b] Disease severity, based on a 0–9 scale, where 0 = <10% of root with symptoms, 1 = 10–20% of root with symptoms, etc., 9 = plant dead.

any growth stage. Infected areas of the epicotyl first become water-soaked, then turn brown. The cortical tissue softens and is easily sloughed. The epicotyl of severely diseased seedlings may rot completely, and the seedlings collapse and die. If the roots become infected, light brown lesions develop and enlarge and spread into the cortex. The cortex tissues turn dark chocolate brown, become soft, and are easily sloughed (Fig. 5). Surviving plants usually show yellowing of the lower leaves, poor growth, and severe stunting. Yield is severely curtailed.

Disease cycle. The four main root rot fungi in Ontario have similar disease cycles. *F. oxysporum* and *F. solani* produce conidia and septate mycelia during the infectious stage and chlamydospores during the resting stage. *Pythium* spp. and *A. euteiches* produce zoospores and aseptate mycelia during the infectious stage and oospores during the resting stage. *P. ultimum*, however, does not produce zoospores. Both chlamydospores and oospores can survive in soil for many years. Fungal populations increase rapidly in soils on which peas and other susceptible legumes have been grown but decrease gradually over time in the absence of susceptible hosts. *Fusarium* spp. may also survive on the roots of nonhost crops. *Pythium* and *Aphanomyces* spp. have a wide host range and may survive pathogenically or saprophytically by colonizing other crops and weeds (10). Any of the main root rot fungi can be disseminated by movement of contaminated soil, diseased plant debris, and contaminated or infected seed.

Fig. 1. Patches of root rot in a field of green peas.

Cultural Practices

In Ontario, peas are grown on medium to heavy clay loam soil. Fields are chisel-plowed, smoothed, and cultipacked before seeding. Seeds are treated with a chemical formulation consisting of captan, diazinon, and lindane to control maggots, wireworms, and decay. Successive sowings are made during April and early May on the basis of accumulated heat units. The seeds are sown in 20-cm rows at a rate of 250–400 kg/ha, depending on seed size and percentage of germination. For weed control, a postemergence herbicide, usually MCPB or MCPA/MCPB (1:15), is applied at the three-trifoliate stage. Green peas are harvested in late June and most of July, and fields are then left bare until the next spring (4).

Most cultivars in use are highly susceptible to the root rot complex. A 3-year rotation with two of four crops, i.e., wheat, soybean, corn, or snap bean, is generally practiced.

Herbicide predisposition of pea to root rot. The effect of MCPB or MCPA/MCPB on pea root rot was investigated in a heavily infested field, using a split-plot design. When the plants reached the three-trifoliate stage, one-half of each plot was sprayed with MCPA/MCPB at a recommended rate (1.7 kg/ha). One week after spraying, plants in the sprayed area were more chlorotic and wilted than those in the control area. Spraying with MCPB or MCPA/MCPB appeared to be a stress factor that increased root rot severity and quickened the expression of root rot symptoms.

Many herbicides are stressful and predispose plants to disease, including root rots (1). Dinitroaniline herbicides, however, have been found to lessen the severity of some root rots (1,16). Several dinitroaniline and triazine herbicides, including pendimethalin, cyanazine, trifluralin, and oryzalin, are reported to have fewer adverse effects on peas with root rot than the phenoxy herbicides, e.g., MCPA, MCPB, and MCPA/MCPB (19). For example, when compared with trifluralin, MCPA/MCPB promoted disease development that resulted in increased severity and quickened symptom expression; this adverse effect increased with temperatures from 20 to 28 C (19). Healthy plants, on the other hand, did not appear to be adversely affected by either trifluralin or MCPA/MCPB treatment. In fact, MCPA/MCPB slightly stimulated plant growth. Apparently, pea plants with Fusarium wilt and Fusarium root rot were more susceptible than healthy plants to phenoxy herbicides, whereas no such difference was observed in trifluralin-treated peas (19).

Dinitroaniline herbicides disrupt the flagella of zoospores (16) and thus reduce the severity of root rots caused by phycomycetous fungi such as *Pythium*, *Aphanomyces*, and *Plasmodiophora* (1). Because most fields in Ontario have a high density of *Fusarium* spp. and a low density of *Pythium* spp. (5,17), the

Fig. 2. Fusarium root rot (*F. solani* f. sp. *pisi*) of pea.

Fig. 3. Fusarium wilt (*F. oxysporum* f. sp. *pisi*) of pea: (A) Wilted plants on right, healthy plant on left; (B) root symptoms.

reduction in severity of pea root rot may be attributable to something other than disruption of the flagella of zoospores. The phenoxy compounds MCPA, MCPB, and MCPA/MCPB are somewhat similar in structure and function to 2,4-D and are growth promoters (2), whereas the dinitroaniline herbicides inhibit protein synthesis and tend to reduce root elongation (2). Possibly, the decrease in severity of root rot in plants treated with dinitroaniline herbicides is associated with reduced root and cellular elongation, in contrast to the increased root elongation and plant growth induced by phenoxy herbicides. Rapid growth usually results in thinner, more tender cell walls and also places a physiological demand on the roots. Further research is needed to elucidate the mechanism causing this difference.

Seed treatment. Treatment of seeds with captan alone does not control the fungi that cause pea root rot in Ontario. Results are better with new formulations that include fungicides specific to *Aphanomyces* spp. and/or *Pythium* spp., such as metalaxyl (Ridomil), furalaxyl (Fongarid), benalaxyl (Galben), and Dowco 444.

Field tests with treated seed (60 g a.i./100 kg) of the pea cultivar GG 313 (wrinkle-seeded) showed that captan + Galben + Ridomil (formulation a) and captan + Dowco 444 + Ridomil (formulation b) were more effective than other combinations. These two formulations not only protected seeds from rots and damping-off but also had residual effects against the root rot complex. For seeds treated with formulation a, formulation b, or captan or not treated, germination was 84, 82, 78, and 64%, respectively; the root rot index (0–9 scale) 1 month after germination was 7.1, 7.5, 8.6, and 8.8, respectively. The high root rot indices were expected, because of the residual effects of seed treatment chemicals and because GG 313 is highly susceptible to root rots.

Soil compaction. Pea plants grown in areas of soil compacted by tractors and tillage equipment have often been reported as being stunted and having increased incidence and severity of root rot (9,21). We have found that plants grow taller and have significantly lower root rot incidence and disease severity in raised (0.2 m) seedbeds than in conventionally prepared flat seedbeds. Better plant growth and reduced root rots are correlated with lower soil penetrometer readings (Table 2). Improved soil drainage and aeration in raised beds may also contribute to reduction of root rot.

Lack of surface drainage. Pea fields in southwestern Ontario have medium to heavy clay loam soil and most are tiled. Because the fields are normally smoothed and cultipacked before seeding to prepare a flat ground surface for harvesting, no surface drainage is provided. Tile drains often cannot drain water quickly after a heavy rain, so temporary puddles form in the lower areas of a field. Plants grown in the flooded areas are usually stunted and have a higher incidence of root rot. For peas in high and low areas, plant heights average 56.2 and 14.5 cm and rot rot indices are 7.8 and 8.7, respectively.

Green manure crops. Soils in southwestern Ontario are generally low in organic matter owing to continuous cash-crop farming. Low soil organic matter affects soil texture in terms of porosity and crumb formation and consequently hinders root development and plant growth. Root rots are known to be greater in number and more severe in soil with low organic matter. Incorporation of organic matter reportedly reduced root rot in several crops (7,8,14). In an attempt to increase soil organic matter and prevent wind and soil erosion during the winter, various green manure crops were sown immediately after peas were harvested. By mid- or late October, the crops were at full-blossom stage and were chopped and disked into the soil. Peas were planted the next spring, and the severity of root rot was assessed in late June. Oats, sorghum, sudangrass, and corn significantly reduced the severity of root rot, when compared with fields left bare; oats was the most effective, followed by sorghum, then sudangrass (18).

Tillage practices. Several tillage practices were evaluated for effectiveness in alleviating soil compaction. Fall chisel plow + spring flat seedbed preparation and fall plow + spring raised seedbed preparation significantly reduced root rot severity, compared with conventional fall plow + spring flat seedbed preparation. Root rot was most severe with fall plow + compaction, followed by fall plow + fall seedbed preparation (18).

Cultivar selection. Most cultivars used in Ontario are highly susceptible to both Fusarium wilt and root rot. To determine if any cultivars are resistant to the Ontario root rot complex, several obtained from various research organizations and seed companies were evaluated for specific resistance to Fusarium wilt and nonspecific resistance to Fusarium, Pythium, and Aphanomyces root rots. Some pathotypes of *F. solani*, *P. ultimum*, and *A. euteiches* have been

Fig. 4. Pythium root rot (*Pythium* spp., most often *P. ultimum*) of pea; healthy plant on left.

Fig. 5. Aphanomyces root rot (*A. euteiches*) of pea.

Table 2. Incidence and severity (average of 2 years of data) of root rot in pea cultivar GG 451 grown in raised (0.2 cm) and flat seedbeds in root-rot infested field

	Seedbed	
Parameter	**Raised**	**Flat**
Plant height (cm)	65.1 a[x]	54.6 b
Disease incidence (%)	100.0 a	100.0 a
Disease severity[y]	7.7 a	8.8 b
Soil penetrometer[z] reading at 20 cm (kg/cm^2)	11.0	18.0

[x] Means within rows followed by same letter are not significantly different (P = 0.05) according to Duncan's multiple range test.

[y] Based on a 0–9 scale, where 0 = < 10% of root with symptoms, 1 = 10–20% of root with symptoms, etc., 9 = plant dead.

[z] Bush Recording Soil Penetrometer model Mark I with 12.83-mm cone (Findlay, Irvine, Ltd., Midlothian, Scotland).

reported (6,11,13), but these are not believed to be highly specialized yet.

Each year from 1983 to 1986, between 100 and 158 lines were tested in four replications of single-row plots in a completely randomized plot. Root rot severity was rated on a 0–9 scale during the last week of June; 20 plants were examined in each plot. All cultivars with a rating higher than 4.0 were eliminated from further testing, and new cultivars were added to the test in subsequent years. Table 3 lists the cultivars and lines that showed resistance throughout the test years. Although most of the cultivars were susceptible (root rot index >4.0), many were moderately to highly resistant (root rot index ≤4.0). Bolero and Sprite, two cultivars with moderate resistance, were introduced as part of an integrated disease control program in southwestern Ontario and have contributed significantly to improved yields. Many cultivars have a better root rot index (i.e., 1.1–3.0) than Bolero and Sprite (Table 3) and offer further potential for controlling root rot.

Table 3. Cultivars and lines showing resistance to pea root rot throughout a 3-year (1983–1985) trial in which more than 220 were tested

Root rot index[a]	Cultivars and lines
1.1–2.0	189171, RS-7
2.1–3.0	Frontier, Green Giant 531 (Harrow selection), Melody, Minn 108, Puget, SN5, WSU R22
3.1–4.0	Alpha I, Bolero, Early Frosty, Early Perfection, Frosty, Haral, Home Guard, Little Sweetie, M-129, Maro, Massette, Mercurio, New Era, Olympia, Parlay, Perfection W. R., Sprite

[a] Based on a 0–9 scale, where 0 = <10% of root with symptoms, 1 = 10–20% of root with symptoms, etc., 9 = plant dead. Any cultivar or line with a rating higher than 4.0 was eliminated from further testing.

Soil Indexing

Root rot fungi are soil inhabitants, and the incidence and severity of root rots are related to the density of inocula in the soil. Because fields in which root rots have been severe are likely to have the same problem the next time a susceptible cultivar is planted, the density of inocula in a field should be determined before peas are planted. Sherwood and Hagedorn (15) developed a soil-indexing method for common root rot (*A. euteiches*). We adapted the method to the Ontario pea root rot complex (predominantly *F. solani* and *F. oxysporum*) and determined the relationship between the root rot index and yield (Fig. 6). The method is laborious and costly, however, and we are recommending an on-site program in which growers test selected cultivars in a small area 1 year before the pea crop is grown.

Conclusions

The results of our survey and research led to the following conclusions:

1. Many commercial cultivars have good tolerance or resistance to Ontario's root rot complex.

2. Phenoxy herbicides such as MCPA, MCPB, and MCPA/MCPB predispose peas to root rot, whereas dinitroaniline and triazine herbicides such as cyanazine, oryzalin, pendimethalin, and trifluralin do not.

3. Peas grown in raised seedbeds have significantly lower root rot incidence and severity than those grown in flat seedbeds.

4. A green manure crop such as oats, sorghum, or sudangrass reduces root rot severity in subsequent pea crops.

5. Soil compaction increases root rot incidence and severity.

6. Fall chisel plow or fall plow + spring raised seedbed reduces root rot severity more than other tillage practices.

7. Seed treatment with captan + Galben + Ridomil is more effective than captan alone in reducing the incidence of rots and damping-off.

8. An on-site soil indexing exercise reliably determines the level of field infestation as well as cultivar susceptibility.

These conclusions form the foundation of our IDC program: planting resistant cultivars, using seed treatment formulations, avoiding MCPA/MCPB, reducing soil compaction, practicing fall chisel

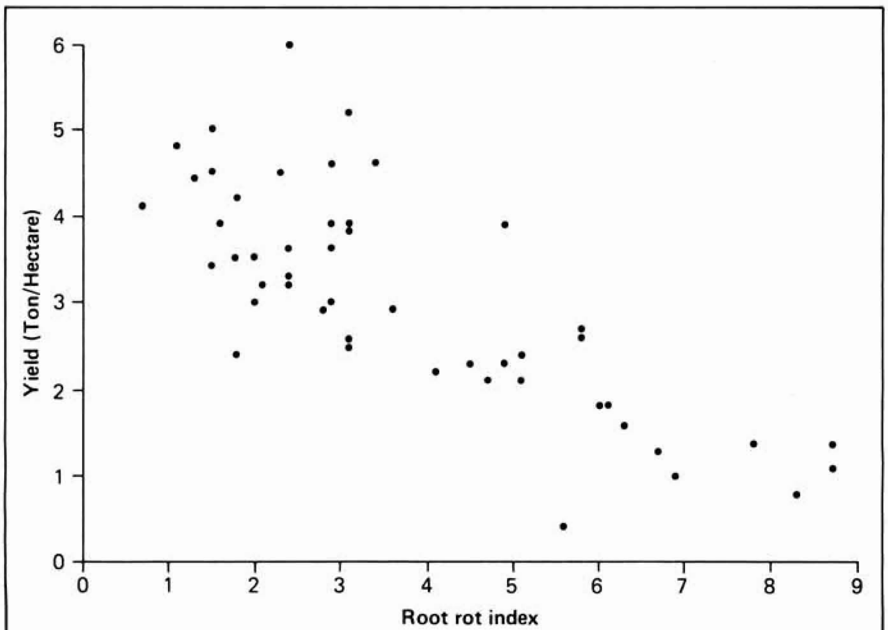

Fig. 6. Relationship between root rot index and yield of green peas.

J. C. Tu

Dr. Tu is a research plant pathologist with Agriculture Canada at the Harrow Research Station in Ontario. He obtained his B.Sc. and M.S. degrees from National Taiwan University and his Ph.D. degree in 1966 from Washington State University at Pullman. He investigates diseases of white beans, soybeans, and peas. His current interests center on epidemiology, etiology, and integrated pest management of these crops.

Table 4. Average pea yields in Essex County, Ontario, for 1983, 1984, and 1985

Cultivar	Hectarage	Average yield (kg/ha)
	1983	
GG 512	315.2	1,663.6
Mini 381	178 2	1,389.7
GG 451	11.0	2,215.0
E. J. 235	84.1	2,109.1
Sparkle	97.7	1,228.1
GG 313	148.6	1,029.1
All	834.8	1,421.5
	1984	
GG 512	306.8	3,334.5
Mini 381	121.8	2,837.7
GG 451	400.5	3,063.9
E. J. 235	90.9	1,841.1
Sparkle	66.4	2,570.7
All	986.4	2,974.3
	1985	
GG 512	62.3	2,842.0
Mini 381	49.1	4,066.4
GG 451	65.0	4,500.8
Bolero	215.0	4,381.6
Spring	187.3	3,254.1
Sprite	201.8	5,047.6
All	780.5	4,150.4

plow or fall plow + spring raised seedbed, using soil indexing, and planting green manure crops in the intervals between pea crops. The average yield per hectare increased from 1,421 kg in 1983 to 2,974 kg in 1984 to 4,150 kg in 1985 (Table 4). In Essex County alone, this yield increase was valued at about $500,000 U.S. in 1984 and $1 million in 1985. The increase is attributable to selecting fields with low root rot infestation, discontinuing use of MCPB and MCPA/MCPB, and replacing susceptible cultivars such as GG 313 and E.J. 235 with resistant cultivars such as Bolero and Sprite; the increase in 1985 is also partially attributable to favorable weather conditions. Practicing the recommended cultural practices should stabilize yields in the 3,000–4,500 kg/ha range. Yields of 5,000–6,000 kg/ha could be achieved by adopting other IDC measures, which largely depends on efforts by extension workers.

Literature Cited

1. Altman, J. 1985. Impact of herbicides on plant diseases. Pages 227-231 in: Ecology and Management of Soilborne Plant Pathogens. C. A. Parker, A. D. Rovira, K. J. Moore, and P. T. W. Wong, eds. American Phytopathological Society, St. Paul, MN. 358 pp.
2. Anonymous. 1974. Herbicide Handbook of the Weed Science Society of America. 3rd ed. Weed Science Society of America, Champaign, IL. 430 pp.
3. Anonymous. 1983. Agriculture statistics for Ontario. Ont. Agric. Food Minist. Publ. 20. Toronto, Ont. 80 pp.
4. Anonymous. 1983. Vegetable production recommendations. Ont. Agric. Food Minist. Publ. 363. 62 pp.
5. Basu, P. K., Crete, R., Donaldson, A. G., Gourley, C. O., Haas, J. H., Harper, F. R., Lawrence, C. H., Seaman, W. L., Toms, H. N. W., Wong, I., and Zimmer, R. C. 1973. Prevalence and severity of diseases of processing peas in Canada, 1970–71. Can. Plant Dis. Surv. 53:49-57.
6. Bolton, A. T., Donaldson, A. G., and Nuttall, V. W. 1970. Variation in isolates of *Fusarium solani* f. *pisi* collected from processing peas in Ontario. Can. Plant Dis. Surv. 50:108-109.
7. Borst, G. 1983. Organic matter helps control root rot spread (*Phytophthora cinnamomi avocade*). Avocado Grower 7(12):38-39.
8. Bouhot, D. 1981. Induction of a biological resistance to *Pythium* in soils by the contribution of an organic matter. Soil Biol. Biochem. 13:269-274.
9. Burke, D. W., Hagedorn, D. J., and Mitchell, J. E. 1970. Soil conditions and distributions of pathogens in relation to pea root rot in Wisconsin soils. Phytopathology 60:403-406.
10. Hagedorn, D. J., ed. 1984. Compendium of Pea Diseases. American Phytopathological Society, St. Paul, MN. 57 pp.
11. Kraft, J. M., and Burke, D. W. 1970. *Pythium ultimum* as a root pathogen of beans and peas in Washington. Plant Dis. Rep. 55:1056-1060.
12. Kraft, J. M., and Haglund, W. A. 1978. A reappraisal of the race classification of *Fusarium oxysporum* f. sp. *pisi*. Phytopathology 68:273-275.
13. Pfender, W. F., and Hagedorn, D. J. 1983. Disease progress and yield loss in Aphanomyces root rot of peas. Phytopathology 73:1109-1113.
14. Pittman, U. J., and Horricks, J. S. 1972. Influence of crop residue and fertilizers on stand, yield and root rot of barley in southern Alberta. Can. J. Plant Sci. 52:463-469.
15. Sherwood, R. T., and Hagedorn, D. J. 1958. Determining common root rot potential of pea fields. Wis. Agric. Exp. Stn. Bull. 531. 12 pp.
16. Teasdale, J. R., Harvey, R. G., and Hagedorn, D. J. 1979. Mechanism for the suppression of pea (*Pisum sativum*) root rot by dinitroaniline herbicide. Weed Sci. 27:195-201.
17. Tu, J. C. 1986. Incidence and etiology of pea root rots in southwestern Ontario. Can. Plant Dis. Surv. In press.
18. Tu, J. C., and Findlay, W. I. 1986. The effects of different green manure crops and tillage practices on pea root rots. Proc. Br. Crop Prot. Conf. Pests Dis. In press.
19. Tu, J. C., and Hamill, A. S. 1986. Differential effect of two groups of herbicides, dinitroaniline and phenoxy, on pea root rot. Proc. Br. Crop Prot. Conf. Pests Dis. In press.
20. U.S. Department of Agriculture. 1960. Index of Plant Diseases in the United States. Agric. Handb. 165. U.S. Government Printing Office, Washington, DC. 531 pp.
21. Vigier, B., and Raghavan, G. S. V. 1980. Soil compaction effect in clay soils on common root rot in canning peas. Can. Plant Dis. Surv. 60:43-45.