# Effects of Pest and Soil Management Systems on Potato Diseases

O. M. Olanya[1]*, D. H. Lambert[2], and G. A. Porter[2]

[1]USDA-ARS, New England Plant, Soil and Water Laboratory, Orono, ME 04469, USA
[2]Department of Plant, Soil and Environmental Sciences, Deering Hall, University of Maine, Orono, ME 04469, USA
*Corresponding author: Tel: 207-581-3632; Fax: 207-866-0404; Email: modesto.olanya@ars.usda.gov

## ABSTRACT

**Long-term cropping systems research is important in order to reduce production costs, to control crop pests, and to optimize the sustainability of agro-ecosystems. Soil amendment use, improved disease management practices, and careful cultivar choice are some of the potential components for improving potato production systems. This research was conducted in long-term cropping systems plots in order to evaluate the impact of soil amendments, pest management practices, and cultivar on foliar and soil-borne potato diseases and to assess the relationships of soil and pest management practices to disease levels and soil microbial activity. Fungicide applications for management of foliar diseases varied betweem the pest management systems (e.g., biological, reduced input, and conventional). Incidence of potato foliar diseases was quantified five times during the cropping season. The impact of soil amendment and pest management practices on soil microbial activity and tuber-borne diseases was also investigated. Low incidences of foliar and selected soil-borne diseases were recorded. Disease levels varied between years, cultivars, pest management, and soil amendments. Significant differences between cultivars were detected for early blight, white mold, and black dot. The cultivar Superior had higher incidence of white mold and black dot, while cv Atlantic had higher early blight incidence. Pest management system significantly affected foliar early blight incidence in 1998, but not in 1997. Pest management system did not affect late blight, white mold, or black dot incidence, or tuber disease incidence in either year. The addition of soil amendments significantly impacted tuber black dot incidences. Microbial activity responded to increasing temperature as the season progressed and was significantly enhanced by the addition of manure and compost soil amendments; however, lower disease incidence was not associated with increased microbial activity. While pest management practices were not major determinants of disease levels in these experiments, the results show that soil amendments can increase incidence of selected tuber diseases and microbial activity in soils.**

## RESUMEN

**La investigación sobre sistemas de cultivo a largo plazo es importante para reducir costos de producción, controlar enfermedades y optimizar la sostenibilidad de los sistemas agro ecológicos. Las enmiendas de suelo, prácticas mejoradas de manejo de enfermedades y cuidadosa elección del cultivar, son algunos de los componentes potenciales para mejorar los sistemas de producción de papa. Esta investigación fue realizada en parcelas de cultivo a largo plazo, con el objeto de evaluar el impacto de enmiendas de suelo, manejo de enfermedades y cultivar empleado, sobre las enfermedades foliares y las transmitidas por el suelo y de evaluar las relaciones del suelo y prácticas de manejo de plagas con los niveles de enfermedad y actividad microbiana del suelo. Las aplicaciones de funguicidas para el control de enfermedades foliares, varió con los sistemas de manejo sanitario (biológico, gasto reducido y convencional). La**

Accepted for publication 8 May 2006.
ADDITIONAL KEY WORDS: Potato diseases, cropping systems, soil amendments, microbial activity, compost, manure, *Solanum tuberosum*

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture and the University of Maine.

**incidencia de enfermedades foliares se evaluó cinco veces durante el desarrollo del cultivo. También se investigó el efecto de enmiendas, prácticas de control sobre la actividad microbiana del suelo y las enfermedades transmitidas por tubérculos. Se registró baja incidencia de enfermedades foliares y transmitidas por el suelo. Los niveles de enfermedad variaron entre años, cultivares, manejo sanitario y enmiendas de suelo. Se detectaron diferencias significativas entre cultivares para tizón temprano, moho blanco y mancha negra. La variedad Superior tuvo la más alta incidencia de moho blanco y mancha negra, mientras que el cultivar Atlantic tuvo mayor incidencia de tizón temprano. El sistema de manejo sanitario afectó significativamente la incidencia de tizón temprano, moho blanco o mancha negra en 1998, pero no en 1997. El sistema de manejo sanitario no afectó la incidencia de tizón tardío, moho blanco, mancha negra o enfermedades al tubérculo en ambos años. La aplicación de enmiendas al suelo influenció significativamente la incidencia de mancha negra en el tubérculo. La actividad microbiana respondió al aumento de temperatura a medida del avance de la estación y fue significativamente incrementada cuando se agregó al suelo enmiendas de estiércol y compost; sin embargo, la baja incidencia de enfermedad no estuvo asociada con el incremento de la actividad microbiana. Aunque las prácticas de manejo sanitario no fueron un determinante del nivel de enfermedades en estos experimentos, los resultados demuestran que las enmiendas pueden incrementar la incidencia de determinadas enfermedades al tubérculo y la actividad microbiana del suelo.**

## INTRODUCTION

Plant diseases are a significant constraint to potato production in Maine. Among the important diseases often encountered in Maine potato fields are late blight (*Phytophthora infestans* (Mont.) de Bary), early blight (*Altenaria solani* (Ellis & G. Martin) L.R. Jones & Grout.), white mold (*Sclerotinia sclerotiorum* (Lib.) de Bary), black dot (*Colletotrichum coccodes* (Wallr.) S.J. Hughes), Rhizoctonia stem canker and tuber black scurf caused by *Rhizoctonia solani* Kuhn., and silver scurf caused by *Helminthosporium solani* Durieu & Mont. (Lambert and Salas 1996; Johnson et al. 1998; Groves 2002; Olanya et al. 2002; Larkin and Honeycutt 2002, 2006). Bacterial soft rot caused by *Erwinia* spp. (*Plectobacterium* spp.) (Reeves et al. 1999a), common scab (*Streptomyces scabiei* (Thaxter) Lambert & Loria (Reeves et al. 1999b), and virus diseases (Lambert et al. 2003) are often recorded in potato fields in Maine and contribute to reduction in tuber quality. Although these diseases are commonly observed in Maine, incidence and severity are variable (Lambert and Salas 1996). This variability can be attributed to inoculum levels and seasonal climatic differences. In Maine, foliar diseases such as late blight have historically resulted in the most significant economic loss (Folsom et al. 1955; Lambert and Salas 1996). Early blight, white mold, and Rhizoctonia stem and stolon cankers can also result in significant economic damage (Lambert and Salas 1996; Johnson et al. 1998; Larkin and Honeycutt 2002). Frequent fungicide applications in response to weather patterns are widely used for control of late and early blight (Shtienberg and Fry 1990; Raposo et al. 1993; Baker et al. 2004). In contrast, soil-borne pathogens have most often been managed through the use of crop rotations and other cultural practices (Honeycutt et al. 1996; Larkin and Honeycutt 2002).

The problems and costs associated with pests in conventional production systems have increased the need for research on pest management using alternative cropping systems. The influences of soil amendments and crop rotations have been studied in various pathosystems and documented as key factors for reduction of populations of *Verticillium* sp. in soil (Green and Papavizas 1967). In other studies, researchers have shown that crop rotations may be more effective for reduction of *R. solani* in certain soils than in others (Weinhold et al. 1978). The use of non-host crops in cropping sequence studies has been shown to reduce the soil-borne populations of *Verticillium dahliae* and *R. solani* (Davis and McDole 1979; Larkin et al. 2003). The uses of various types of composts for soil-borne disease management have been reported by Hoitink and Fahy (1986). In continuous cropping sequence studies in southeastern Idaho, it was observed that total potato yields were significantly reduced in continuous potato compared to potato-grain rotations (McDole and Dallimore 1978). In Maine, selected potato diseases and weed populations were adversely affected by soil amendment use and pest management practices (Lambert and Salas 1996; Gallandt et al. 1998). Different three-year cropping systems and crop rotations have been reported to have significant effects on soil microbial communities as well as Rhizoctonia stem canker and black scurf of potato in central and northern Maine

(Larkin 2003; Larkin and Honeycutt 2002, 2006). In a study on the effects of crop rotation, nitrogen fertilization and their interaction on potato growth and yield, continuous cropping of potato resulted in significantly more Rhizoctonia stem lesions than other rotations (Honeycutt et al. 1996). The extent to which long-term potato-based cropping systems can influence disease dynamics, soil microbial activity, and tuber yield under Maine conditions is not fully characterized. The research reported in this paper was conducted in an established potato-cropping system study in order (1) to evaluate the impact of pest and soil management practices on the incidences of foliar and soil-borne potato diseases and (2) to assess the relationship of soil, crop, and pest management to disease levels and soil microbial activity in potato field plots. Although no fungicides were targeted for management of white mold, common scab, and silver scurf diseases, the build-up of pathogen propagules or diseases is often affected by soil management, cultivar differences, or the interactions of soil management and pest management with cultivars. Therefore, the interactive effects of soil and pest management on these diseases on two potato cultivars were also investigated. The two cultivars were used because of the differences in their maturity dates (early vs medium) and possible variation in their susceptibility to various potato diseases.

# MATERIALS AND METHODS

## *Establishment of Field Plots and Treatments*

This study used experimental plots that were established at the University of Maine's Aroostook Research Farm in Presque Isle, Maine, during 1991. Details of the first 6 years of the project are provided in Gallandt et al. 1998. The experiment consists of 96 plots, 44.08 × 14.59 m (length × width) in a split-plot randomized complete block design with four blocks. The main plots were pest management systems (biological [BIO], conventional [CONV], and reduced input [RI]). These pest management systems describe the general philosophies used for insect, foliar disease, and weed management. Subplots were a factorial combination of soil management system (amended [AMD] and non-amended [CHK]) and potato varieties (Superior and Atlantic). This paper reports on data collected during the 1997 and 1998 growing seasons. Certified potato seedpieces were planted at a 23-cm in-row spacing using a two-row planter. The planting dates were 2-5 June 1997 and 28 May to 1 June 1998. The rows were spaced at 0.91 m, and the planting depth was 5 to 10 cm. There were 16 rows per plot. Pre-planting tillage was done using a disk at a depth of 12.7 to 17.8 cm and two tillage passes.

Soil management system treatments have been in place since the experiment was initiated in 1991. In the CHK soil management system, at-planting chemical fertilizers were applied to the potato crop at the rate of 1344 kg ha$^{-1}$ 10-10-10. Post-planting fertility consisted of the application of 57 kg of N ha$^{-1}$ as urea ammonium nitrate (UAN) solution. A 2-year potato-barley rotation was followed in the CHK system. The barley plots were under-seeded with a mixture of red clover and timothy. In the AMD soil management system, solid-bedded cow manure (45 Mg ha$^{-1}$) and compost (22 Mg ha$^{-1}$) made from waste potatoes, sawdust, and ash were applied in the spring just prior to tillage. A reduced at-planting rate of 672 kg ha$^{-1}$ 10-10-10 fertilizer was applied at planting and no post-planting N was applied. A two-year potato green manure rotation was followed in the AMD system. The green manure crop consisted of a mixture of oats, peas, and hairy vetch. All potato plots included in the current report followed either barley (CHK system) or green manure (AMD system) rotation crops.

The CONV and RI pest management systems used commercially available pesticides for insect and disease control. Both systems used IPM approaches; however, higher pest thresholds and lower labeled rates or less frequent applications were used in the RI system. The foliar fungicide programs were targeted primarily toward effectiveness on late and early blight. In the CONV system weekly fungicide applications were used to provide a protectant program based on Dithane (a.i. mancozeb, Dupont Agricultural Products, Wilmington, DE) and Bravo 500 (a.i. chlorothalonil, Syngenta Crop Protection, Greensboro, NC). This protectant program was supplemented with one to two applications of Ridomil (a.i. metalaxyl Allegiance, Gustafson Inc., Plano, TX), a systemic fungicide. Scheduling of the RI fungicide program followed recommendations of the University of Maine Cooperative Extension late blight forecasting system (Krause et al. 1975). It was a protectant program based primarily on mancozeb. The goal was to reduce applications and rates of fungicide if pest forecasting indicated a low risk of late blight infection. The BIO pest management system used Kocide (a.i. copper hydroxide, Chemical Corp., Houston, TX). Materials, rates, and number of applications for foliar fungicides are summarized in Table 1. Fungicide applications were initiated in July and completed in late August to early September depending on the year. The pesticides were applied using a 10-row sprayer. Insect pest management in the BIO system relied on biological and bio-rational approaches using IPM for scheduling. Insect pest management in the CONV system utilized commercially available insecticides and recommended IPM thresholds. The RI program used the same conventional insecticides, but less conservative IPM thresholds. Weed control in BIO plots was accomplished by two cultivations with a spring-tine cultivator and conventional between-row cultivation and hilling. The CONV plots received herbicides (typically metribuzin, Dupont Agricultural Products, Wilmington, DE) at labeled rates followed by between-row cultivation and hilling. The herbicide rate in the RI system was one-half that of the CONV system.

In CONV and RI, potato vine dessication was accomplished using labeled rates of diquat (Zeneca Agricultural Products, Wilmington, DE). Vines were removed using a flail mower in the BIO system. The vine dessication/flail mowing dates were 9 September 1997 and 17 September 1998. Harvest took place on 26 September to 1 October 1997 and 5-6 October 1998 and was accomplished with a two-row potato digger. All tubers in the center four rows of each plot were picked up by hand and weighed in the field. Two 22-g tuber samples were randomly collected per plot based on a W-shaped sampling pattern for determination of size and grade. Two additional 22-kg samples were collected for evaluation of tuber-borne diseases and were similarly obtained. These tubers were placed in 12 C storage at 90% R.H. and then washed and visually evaluated as described below.

## *Disease Occurrence and the Effect of Pest Management and Cultivar on Incidences of Foliar and Stem Diseases*

Incidence of early blight, late blight, white mold, and black dot were visually assessed at five times at 10- to 14-day intervals during each cropping season (James 1971). Disease assessments were made on 30 randomly selected potato plants per plot using a W-shaped sampling pattern. This pattern was repeated three times in each plot for a total of 90 plants per assessment. Disease incidence was expressed as percentage (number of diseased plants / total number of plants × 100). In both years, environmental variables such as temperature and relative humidity for calculation of severity values for late blight and infection threshold for early blight were obtained from the University of Maine Cooperative Extension weather station located at the site (Krause et al. 1975).

Four randomly chosen plants per plot were removed, washed, and assessed for Rhizoctonia stem canker incidence on 14 July 1997 and 30 July 1998. The incidence of stem and stolon cankers and black dot on stems was visually assessed.

TABLE 1—*Foliar disease control program in the potato cropping systems research project during 1997 and 1998 at Presque Isle, Maine.*

| | | Frequency and amount of active ingredient (a.i.) used | | | |
|---|---|---|---|---|---|
| | | 1997 | | 1998 | |
| Pest Management System[y] | Product[x] | Number of applications | Total a.i kg ha$^{-1}$ | Number of applications | Total a.i. kg ha$^{-1}$ |
| Biological[y] | copper products | 8 | 7.90 | 10 | 10.42 |
| Reduced Input[y] | copper products | 1 | 0.67 | 1 | 0.84 |
| | mancozeb | 7 | 10.73 | 9 | 16.02 |
| | Total | 8 | 11.40 | 10 | 16.86 |
| Conventional[y] | copper products | 1 | 0.67 | 1 | 0.84 |
| | mancozeb | 3 | 4.85 | 6 | 10.75 |
| | chlorothalonil | 4 | 5.20 | 4 | 2.33 |
| | metalaxyl | 2 | 0.46 | 1 | 0.22 |
| | Total | 10 | 11.18 | 12 | 14.14 |

[x]Fungicides were applied for control of foliar diseases and specifically for late and early blight.
[y]Pest management systems describe the general philosophies used for insect, foliar disease, and weed management. The biological foliar disease management program was based on foliar copper products with the a.i. totals calculated as copper hydroxide equivalents. The reduced input program was based primarily on foliar protection using mancozeb with rates and frequencies reduced relative to the conventional program if blight forecasting (blitecast model) by the University of Maine Cooperative Extension indicated that disease risk was low. In the conventional program, protectant fungicides, primarily mancozeb or chlorothalonil, were applied on a weekly basis and a systemic fungicide, metalaxyl, was applied one to two times per year based on recommendations in 1997 and 1998.

The sampling pattern was the same as described above. Stem and stolon lesions caused by *R. solani* were determined by quantifying the percentage of stems and stolons area occupied by fungal lesions.

### *Effects of Soil Management and Cultivar on Tuber-borne Diseases*

Incidence of tuber-borne diseases were assessed after storage of samples for 2 months at 12 C. Tuber samples were washed and then subjected to visual assessment for black scurf, black dot, common scab, and silver scurf. The black dot and silver scurf were differentiated based on morphological observation of sclerotia under dissecting scope immediately after washing of tuber samples. The presence of silver scurf was verified by microscopic observation of spores of *H. solani* obtained on a two-sided tape. The percentages of tuber surface area occupied by scab, silver scurf lesions, black scurf and black dot sclerotia were assessed. The sample size was 50 tubers per plot.

### *Effects of Management System, Sample Date, and Cultivar Effects on Soil Microbial Activity*

Soil microbial activity was quantified in the experimental plots using the fluorescein diacetate hydrolysis method (Schnurer and Rosswall 1982). Soil samples were obtained from all 96 experimental plots using a W-shaped sampling pattern. Soil cores were obtained to a depth of 20 cm. A total of 10 soil cores were sampled per plot, thoroughly mixed to form a composite sample, and taken to the laboratory for analysis. After incubation, absorbance readings of the soil samples in which fluorescein diacetate was added was subtracted from the control treatment to determine soil microbial activity. Soil microbial activity was quantified four times each year (30 June, 15 July, 8 August, and 4 September).

### *Data Analysis on the Effect of Pest and Soil Management and Cultivars on Disease Incidences*

Prior to analysis, percentage data for disease incidences were subjected to tests for normality of variances using the Shapiro-Wilk test on the Analysis of Variance (AOV) residuals (Proc GLM, SAS 2003). In all cases, normal distributions and equal variances were detected, except for black dot incidence on potato stems, where the assumptions of normality and equality variances were not met. Therefore, the data were subjected to square root transformation to correct these problems prior to analysis. Analysis of variance was used to evaluate the effects of pest, soil management systems, cultivar, and their interactions (Proc GLM; SAS 2003). The significance of soil management system, cultivar, and their interactions was tested by using the residual error terms. Comparisons between treatment means were computed by using Fisher's LSD test at $P < 0.05$. Comparisons of Rhizoctonia stem and stolon lesion infections (incidence / severity) with stem and stolon lesion numbers as well as incidence and severity of black scurf on potato tubers were made by analysis of variance. Treatment effects on the incidences of tuber-borne black scurf (*Rhizoctonia* sp.), black dot (*Colletotrichum* sp.), silver scurf, and common scab were also determined by analysis of variance (Proc GLM, SAS 2003).

## RESULTS

### *Disease Occurrence and Effect of Pest Management and Cultivar on Foliar and Stem Diseases*

Few potato diseases were detected during the first, second, and third evaluation dates of each growing season; however, foliar disease symptoms were observed at the subsequent dates (Figures 1 and 2). Higher levels of early blight were found on Atlantic during both years (Figures 1 and 2). Early blight incidence was significantly affected by pest management system in 1998 ($P < 0.05$; Table 2). Late blight was not observed in 1997, but was present at very low levels in 1998 (data not presented). There were no significant effects of pest management, soil management, or cultivar on foliar late blight incidence.

Incidence of white mold was very low in 1997 (Figure 1) and was not affected by cultivar, pest, or soil management treatments. Disease incidence was much higher in 1998 and significantly greater white mold incidence was detected on Superior than Atlantic ($P < 0.01$; Figure 2). Pest and soil management systems had no effect on white mold incidence.

Black dot incidence was relatively high during both growing seasons (Figures 1 and 2). Mean incidence of black dot was significantly greater on Superior than on Atlantic during both growing seasons ($P < 0.01$; Figures 1 and 2). No significant differences in black dot incidence were detected between pest or soil management treatments. There were no significant

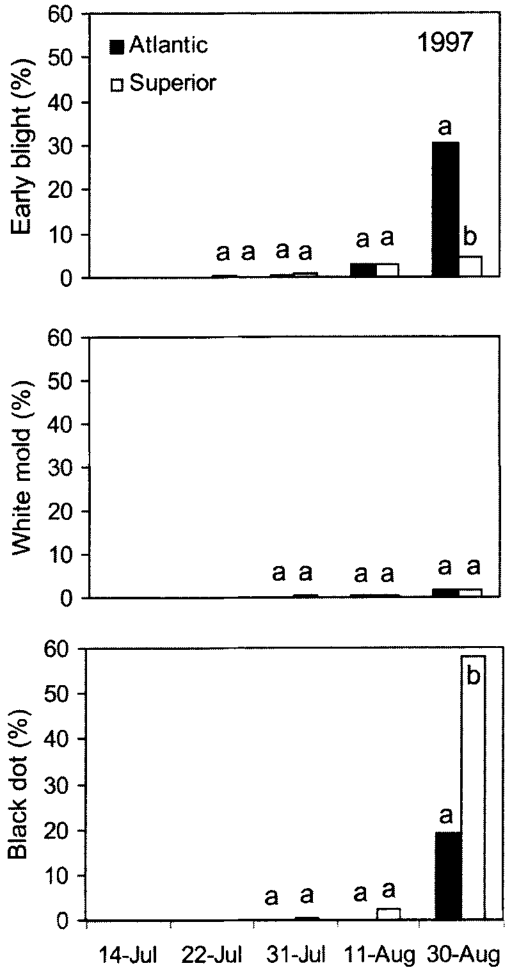


**FIGURE 1.**
**Mean incidence (%) of potato foliar diseases quantified on two cultivars in a cropping systems experiment during 1997. Disease incidence was assessed on a sample size of 90 potato plants per plot at five evaluation times during the cropping season.**

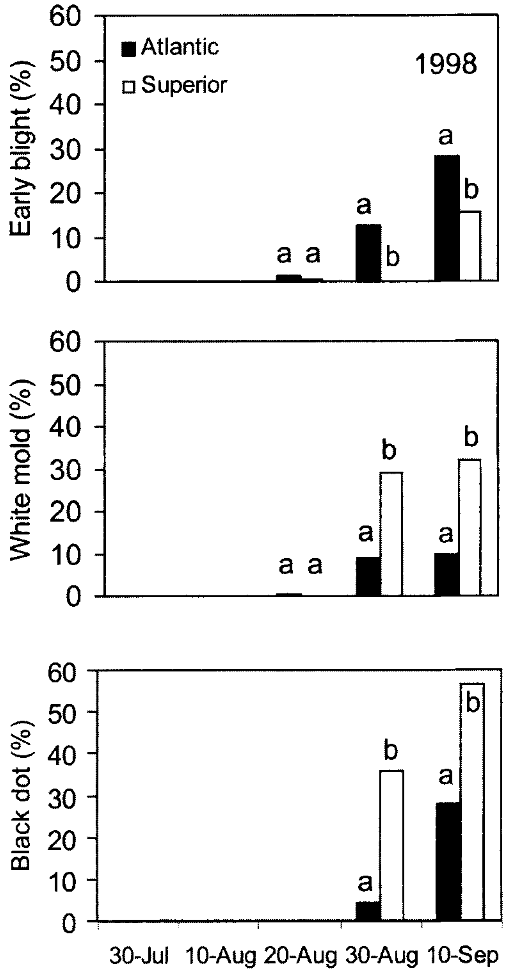


**FIGURE 2.**
**Mean incidence (%) of potato foliar diseases quantified on two cultivars in a cropping systems experiment during 1998. Disease incidence was assessed on a sample size of 90 potato plants per plot at five evaluation times during the cropping season.**

effects of pest and soil management on stolon canker incidences (data not presented). The average incidence of stem cankers was similar for the 2 years, 29.1 vs 27.5 in 1997 and 1998, respectively.

## *Effects of Soil Management and Cultivar on Tuber-borne Diseases*

Pest management system did not significantly affect the incidences of tuber-borne diseases in either year (Table 3). The AMD soil management system significantly increased black dot incidence in both years (Table 3), but there were no significant effects on common scab and silver scurf (Figure 3). Atlantic had significantly lower incidence of silver scurf than Superior in 1998 (2.2% and 12.4%, respectively).

There was a significant soil management x cultivar interaction for black dot incidence in 1997 ($P < 0.01$) and common scab incidence in 1998 ($P < 0.05$, Table 3). The average incidence of black dot across the two cultivars was 27.9 and 14.6 for AMD vs CHK in 1997, and then 4.2 and 2.0 for the AMD vs CHK, respectively, in 1998. Cultivar effects were also significant in 1997 ($P < 0.01$; Atlantic 22.6% vs Superior 33.1%) in the amended treatments (Figure 4). The percentage of Atlantic

TABLE 2—*Analysis of variance on the effect of pest management and cultivar on incidences of potato foliar and stem diseases in 1997 and 1998 at Presque Isle, Maine*[x].

| | | Early blight | | Late blight | | White mold | | Black dot | |
|---|---|---|---|---|---|---|---|---|---|
| Source of variation[y] | df | 1997 | 1998 | 1997[z] | 1998 | 1997 | 1998 | 1997 | 1998 |
| Pestmgt | 2 | .4908 | .0160* | | .3930 | .1925 | .6424 | .9153 | .0708 |
| Soilmgt | 1 | .3738 | .7997 | | .8498 | .3648 | .2277 | .3078 | .6540 |
| Cultivar | 1 | .0001** | .0001** | | .2540 | .4674 | .0002** | .001** | .0019** |
| Pestmgt*soilmgt | 2 | .7823 | .8090 | | .4860 | .4464 | .3031 | .9948 | .6455 |
| Pestmgt*cultivar | 2 | .2589 | .3631 | | .6195 | .1140 | .7266 | .8654 | .1325 |
| Soilmgt*cultivar | 1 | .6348 | .8990 | | .2153 | .0573 | .7273 | .2933 | .8247 |
| Pestmgt*soilmgt*cultivar | 2 | .5334 | .7389 | | .1065 | .6216 | .9790 | .6437 | .7798 |

*Significant at $P < 0.05$, **significant at $P < 0.01$.
[x]Pestmgt = biological, reduced inpu,t and conventional; soilmgt = amended and unamended; cultivars = Atlantic and Superior.
[y]The pestmgt effects were tested by blocks*pestmgt error term. All other treatment effects were tested by pooled error term (blocks*cultivar*pestmgt*soilmgt).
[z]No disease was recorded.

TABLE 3—*Analysis of variance on soil management and cultivar effects on incidences of potato tuber-borne diseases in 1997 and 1998 at Presque Isle, Maine*[x].

| | | Black dot | | Common scab | | Silver scurf | |
|---|---|---|---|---|---|---|---|
| Source of variation[y] | df | 1997 | 1998 | 1997 | 1998 | 1997[z] | 1998 |
| Pestmgt | 2 | .3267 | .3910 | .3765 | .0941 | | .2338 |
| Soilmgt | 1 | .0001** | .0350* | .2039 | .1055 | | .1692 |
| Cultivar | 1 | .0811 | .1533 | .1366 | .0865 | | .0230* |
| Pestmgt*soilmgt | 2 | .2319 | .6981 | .5895 | .0216* | | .9337 |
| Pestmgt*cultivar | 2 | .1348 | .7523 | .5309 | .0656 | | .7211 |
| Soilmgt*cultivar | 1 | .0082** | .1407 | .1722 | .0213* | | .2024 |
| Pestmgt*soilmgt*cultivar | 2 | .1312 | .0458* | .5207 | .0210 | | .2427 |

*Significant at $P < 0.05$, **significant at $P < 0.01$.
[x]Pestmgt = biological, reduced input, and conventional; soilmgt = amended and unamended; cultivars = Atlantic and Superior.
[y]The pestmgt effects were tested by blocks*pestmgt error term. All other treatment effects were tested by pooled error term (blocks*cultivar*pestmgt*soilmgt).
[z]No disease was recorded.

and Superior tubers affected by soil-borne diseases in AMD was 53.2% and 72.7%, respectively, in 1997 compared to 41.9% and 37.2% for the same varieties in CHK treatments.

### *Effect of Management System, Sample Date, and Cultivar on Soil Microbial Activity*

Total soil microbial activity varied between pest management systems during 1997 ($P < 0.05$). In July sampling, microbial activity in BIO and RI were not significantly different, but were significantly higher than the CONV pest management treatment. In the August sampling, microbial activity in BIO was significantly higher than the CONV and RI systems (Figure 5).

Significant differences in microbial activity were recorded among sampling months (Table 4, $P < 0.01$). Microbial activity increased during July and August, but decreased in September (Figure 5). Except in September, microbial activity differed significantly ($P < 0.01$) between soil amendments in both years ($P < 0.01$) with significantly higher July and August microbial activity recorded in AMD soils (Figure 5).

## DISCUSSION

No late blight was detected during the 1997 cropping season, and very low incidence of late blight was recorded in 1998. This indicates that under low disease pressure all pest management systems were equally effective for control of late blight. The occurrence of early blight in the later part of the season suggests that environmental conditions such as temperature, relative humidity, and rainfall were partially conducive for disease development. Differences in seasonal

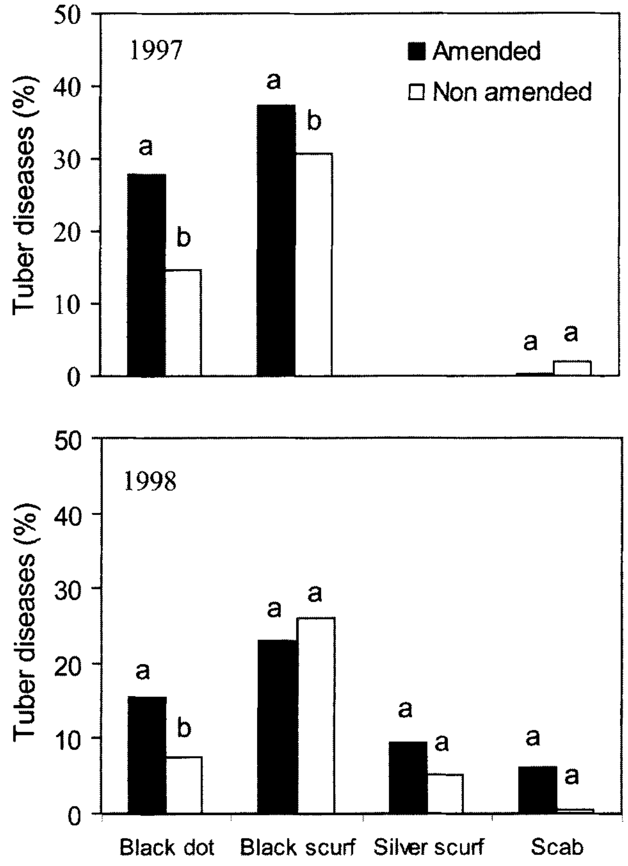


**FIGURE 3.**
**Effects of soil management system on tuber-borne diseases. Disease incidence was quantified by visual assessment of tubers after harvest and storage. The number of tubers with visual disease symptoms was expressed as a percentage of total tubers assessed, and a sample size of 50 tubers per treatment and replication were used.**

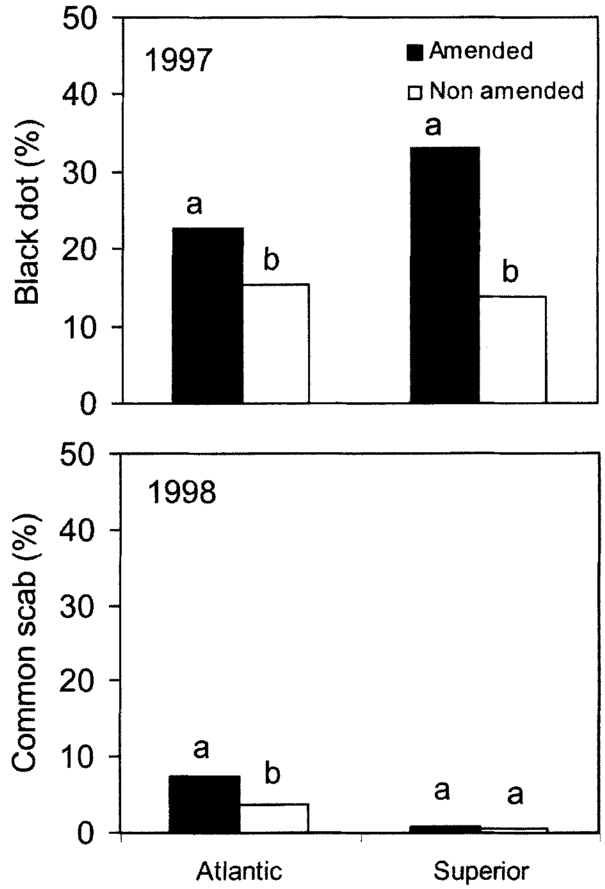


**FIGURE 4.**
**Interactive effects of soil management x cultivar for black dot and common scab (%) tuber diseases. Data represents average disease values grouped by cultivars for amended and non-amended treatments.**

development of potato diseases in relation to environmental factors have been previously reported by other researchers. Adams and Stevenson (1990), in a field study on the management of early blight and late blight noted that environmental conditions such as splashing rain and air currents affect spore dispersal while alternating wet and dry periods with optimum temperatures of 18 to 26.7 C are conducive for foliar disease development.

With the exception of early blight in 1998, pest management system was equally effective on foliar late blight, but did not significantly affect white mold or black dot incidences. Our foliar fungicide treatments were targeted to control early and late blight. None of the fungicides used would be expected to be particularly effective on white mold or black dot. Our results provide evidence that growers have a wide range of flexibility for early and late blight control programs provided that disease pressure is relatively light as it was under our experimental conditions. In the RI, the rates and timing intervals of fungicide applications were considerably lower than in CONV for foliar late blight control. Therefore, the RI, which

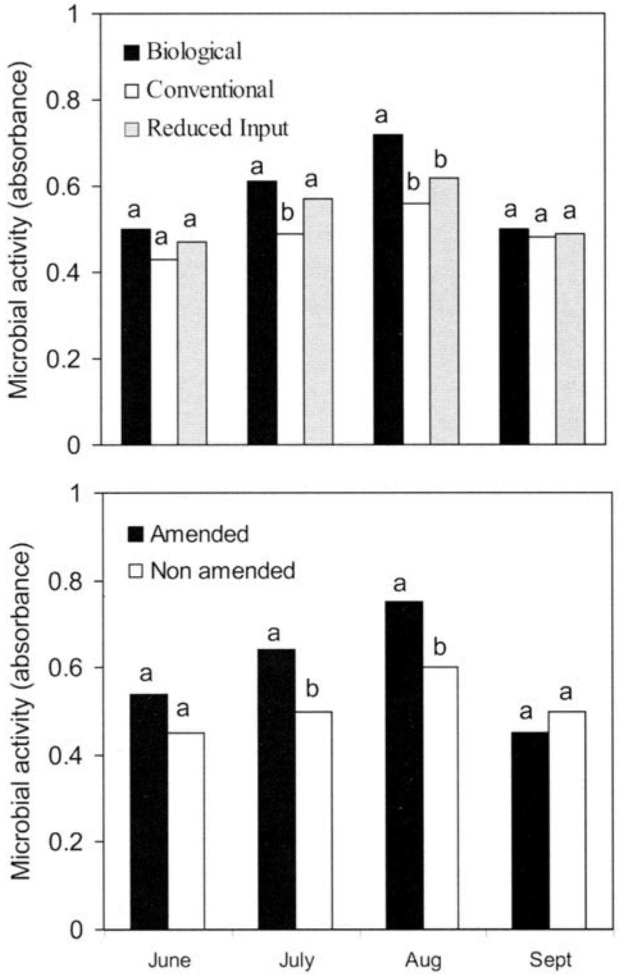


**FIGURE 5.**
**Effects of pest management and soil amendment on microbial activity in a cropping systems experiment at Presque Isle in 1997 and 1998. Soil samples were obtained from plots with varying pest management (conventional, biological and reduced input) and soil management systems (amended or unamended). Microbial activity was determined using fluorescein diacetate hydrolysis method. The data represent averages for each treatment and sampling period over the 2 years.**

uses pest threshold levels, may be better suited as a pest management strategy for control of diseases, insects, and weeds.

Previous research has indicated that an integrated approach is needed for the management of Rhizoctonia stem or stolon cankers, and other tuber-borne diseases of potato (Larkin and Honeycutt 2002; Peters et al. 2004). Crop rotations and the use of biofumigant *Brassica* crops were effective methods for control of stem canker and black scurf (Larkin and Honeycutt 2002; Larkin et al. 2003, 2006). Diversity of

TABLE 4—*Analysis of variance on management system, sample date, and cultivar effects on soil microbial activity (absorbance)*[x].

| Source of variation[y] | df | P > F 1997 | P > F 1998 |
|---|---|---|---|
| Pestmgt | 2 | .0332* | .5974 |
| Soilmgt | 1 | .0001** | .0001** |
| Cultivar | 1 | .002** | .3200 |
| Pestmgt*soilmgt | 2 | .2600 | .7941 |
| Pestmgt*cultivar | 2 | .0153* | .9779 |
| Soilmgt*cultivar | 1 | .1854 | .4699 |
| Pestmgt*cultivar*soilmgt | 2 | .4614 | .2346 |
| Month of assessment (moa)[z] | 3 | .0010** | .0001** |
| Pestmgt*moa | 6 | .0700 | .4502 |
| Soilmgt*moa | 3 | .0812 | .3706 |
| Cultivar*moa | 3 | .1555 | .6316 |
| Soilmgt*pestmgt*moa | 18 | .0616 | .1568 |

*Significant at $P < 0.05$, **significant at $P < 0.01$.
[x]Pestmgt = biological, reduced input, and conventional; soilmgt = amended and unamended; cultivars = Atlantic and Superior.
[y]The pestmgt effects were tested by blocks*pestmgt error term. All other treatment effects were tested by pooled error term (blocks*cultivar*pestmgt*soilmgt).
[z]Microbial activity (moa) were assessed in June, July, August, and September in both years.

crops in a crop rotation was noted to be effective for disease control (Marshall 1991; Thurston 1992). Similarly, planting of disease-free seed potato has been observed to be most effective for disease management when soil inoculum levels are low (Powelson et al. 1993; Honeycutt et al. 1996). Therefore, control of black scurf and other soil- and tuber-borne diseases, such as silver scurf, scab, and black dot, may be best managed by use of resistant varieties, planting pathogen-free seed, and maintaining soil properties that are favorable to crop growth. Crop rotation and the use of organic soil amendments are components of soil management that can promote conditions for crop development. Several authors (Huber and Watson 1970; Cook et al. 1978; Coffey 1984; Borst 1986) have demonstrated that incorporation of green manure rotations crops and organic amendments can stimulate soil microbial activity and reduce the impact of soil-borne pathogens on crops. In our two-year study, the addition of compost and manure as soil amendments did not affect incidences of foliar diseases or tuber black scurf, but the amendments significantly increased the incidences of black dot and silver scurf on potato tubers. Our results indicate that soil amendments affect soil properties in a manner that enhanced development of these superficial tuber diseases, particularly black dot. Based on the past studies, the addition of organic substrates would be expected to increase the numbers and diversity of microbes, which might have been expected to reduce pathogen numbers through competition or antagonism. It would appear that such competition and antagonism were ineffective for black scurf or not present in this system; however, we did not directly quantify microbial interactions.

Our research shows that the amended system did have higher total microbial activity during the cropping cycle. This was expected since soil amendments, such as compost and manure, provide substrates that can provide an energy and nutrient source for soil microbial activity. Larkin et al. (2006) also showed that manure-amended soils resulted in higher microbial activity and numerous other changes in soil microbial characteristics, and Larkin (2003) documented the diversity of soil microbial communities under different potato-cropping systems. Organic matter from compost may increase soil moisture, reduce stress and contribute to large canopy, thereby permitting the presence of inoculum. For example, *Streptomyces* and *Rhizoctonia* spp. are facultative saprophytes which live on debris (Peters et al. 2004), while *Helminthosporium* and *Colletotrichum* persist on debris (Olivier and Loria 1998) allowing for pathogen presence. Our results differ from previous research which indicated the addition of organic amendments reduced incidence of soil-borne pathogens in numerous pathosystems (Huber and Watson 1970; Cook et al. 1978). The addition of amendments such as mulches and chicken manure reduced the incidence of root damage of avocado plants incited by *Phytophthora cinnamomi* (Coffey 1984; Borst 1986). This has been explained in terms of enhanced competition among soil micro-organisms for nitrogen, carbon or both, thus resulting into a reduction of pathogen numbers in soil. Similarly, the addition of compost (Hoitink and Fahy 1986) and diversification of crop ecosystems (Demster and Coaker 1974) were demonstrated to be effective for disease and insect control. Although soil microbial activity was significantly increased by soil amendments, foliar disease levels were not significantly affected, and incidence of two different superficial diseases on potato tubers increased. Soil amendments alter soil conditions such as soil acidity, organic matter content, nutrient concentrations, aggregation, moisture retention, and aeration (Gallandt et al.1998). Consequently, these changes in soil conditions would be expected to affect soil-borne pathogen biology and perhaps tuber susceptibility. In other situations, nutritional interactions were noted to affect diseases (Lambert et al. 2005). Therefore, differential effects of soil amendments on potato diseases might have been expected due to the marked different nutrient management programs in the AMD compared to CHK soil management systems.

In addition to the effects of soil amendments, variation in soil microbial activity was detected between sampling times and years. The variation in soil microbial activity in subsequent sampling times suggest that microbial activity increases as soil temperatures and crop growth increases during July and August. An increase in microbial activity in soils in response to increases in soil temperatures has been previously reported (Schnurer and Rosswall 1982).

Differences in the incidences of early blight, white mold and stem canker were detected between the two potato cultivars, which was expected based on the characteristics of the varieties. We found greater incidence of early blight on Atlantic compared to Superior. Superior is early maturing and this may have resulted in the early defoliation of Superior so that symptoms were less prevalent relative to Atlantic, which is medium maturing. Higher incidence of early blight has been previously reported on foliage of medium-late to late-maturing varieties (Teng and Bissonnette 1985; Lambert and Salas 1996). The high incidence of stem canker on Superior suggests that it is more susceptible to stem canker than Atlantic. The differences in cultivar susceptibility to potato foliar diseases have been previously recorded (Adams and Stevenson 1990). Variation in cultivar susceptibility to tuber-borne diseases, caused by black scurf, black dot, silver scurf and common scab has also been reported (Powelson et al. 1993).

We conclude that the potato varieties and environmental conditions during the growing season were major determinants of disease incidence and severity in this production system. Because of the low foliar disease levels in both years, biological, conventional, and reduced input fungicide programs were equally effective. Potato tuber disease incidences and severity were selectively affected by the addition of soil amendments. Incidence of black dot and black scurf tended to increase in the amended system, possibly due to changes in the soil physical environment. Microbial activity responded to increasing temperature as the season progressed and was significantly enhanced by the addition of manure and compost in the amended soil management system; however, lower disease incidences and severity were not associated with increased microbial activity during this two-year study.

## ACKNOWLEDGMENTS

We are grateful to Dr. W.W. Kirk of Michigan State University for review of the manuscript. We thank the staff of Aroostook Research Farm and the New England Plant, Soil and Water Laboratory (USDA-ARS) for technical and logistical support. Funding for this research was provided by USDA-CSRS Special Grants Program awards 91-3414-5904 and 94-34141-0040, the University of Maine, and the Maine Potato Board.


## LITERATURE CITED


Adams SS and WR Stevenson. 1990. Water management, disease development, and potato production. Am Potato J 67:3-11.

Baker KM, WW Kirk, J Andersen and JM Stein. 2004. A problem case study: Influence of climatic trends on late blight epidemiology in potatoes. Acta Hort 638:37-42.

Borst G. 1986. Observations on a biological root rot control trial in the Fallbrook Area. Calif Avocado Soc 70:107-110.

Coffey MD. 1984. An integrated approach to the control of avocado root rot. Calif Avocado Soc 68:61-68.

Cook RJ, MG Boosalis and B Doupnik. 1978. Influence of crop residues on plant diseases. *In*: Crop Residue Mangement Systems. ASA Spec Publ 31. Madison, WI. pp 147-163.

Davis JR and RE McDole. 1979. Influence of cropping sequences of soil-borne populations of *Verticillium dahliae* and *Rhizoctonia solani*. *In*: B Schippers and W. Gams, (eds), Soil-borne Plant Pathogens. Academic Press, New York. pp 399-405.

Dempster JP and TH Coaker. 1974. Diversification of crop ecosystems as a means of controlling pests. *In*: DP Jones and ME Solomon (eds), Biology in Pest and Disease Control. Blackwell Scientific Publications, Oxford. pp 106-114.

Folsom D, GW Simpson and R Bonde. 1955. Maine potato diseases, insects and injuries. Maine Agric Exp Sta Bulletin No 469.

Gallandt ER, EB Mallory, AR Alford, FA Drummond, E Groden, M Liebman, MC Marra, JC McBurnie and GA Porter. 1998. Comparison of alternative pest and soil management strategies for Maine potato production systems. Amer J Altern Agric 13:146-161.

Green RJ and GC Papavizas. 1967. The effect of carbon source, carbon to nitrogen ratios and organic amendments on survival of propagules of *Verticillium albo-atrum* in soil. Phytopathology 58:567-570.

Groves CL. 2002. Characterization of *Phytophthora infestans* from Maine during 1999 to 2000. Amer J Potato Res 79:325-333.

Honeycutt CW, WM Clapham and SS Leach. 1996. Crop rotation and N fertilization effects on growth, yield, and disease incidence in potato. Am Potato J 73:45-61.

Hoitink HAJ and PC Fahy. 1986. Basis for the control of soil borne plant pathogens with compost. Ann Rev Phytopath 24:93-114.

Huber DM and RD Watson. 1970. Effect of organic amendment on soil-borne plant pathogens. Phytopathology 70:22-26.

James C. 1971. A manual of assessment keys for plant diseases. Canada Department of Agriculture Publication No 1458.

Johnson SB, M Kleinhenz, JD Dwyer, T Griffin, OM Olanya, DH Lambert and GA Porter. 1998. First report of white mold on soybean in Maine. Plant Dis 82:832.

Krause RA, LB Massie and RA Hyre. 1975. BLIGHTCAST, a computerized forecast of potato late blight. Plant Dis Rep 59:95-98.

Larkin RP. 2003. Characterization of soil microbial communities under different potato cropping systems by microbial population dynamics, substrate utilization and fatty acid profiles. Soil Biol Biochem 35:1451-1466.

Larkin RP, M Albert and TS Griffin. 2003. Control of soilborne pathogens of potato with *Brassica* crop rotations. Phytopathology 93:S48. (abst)

Larkin RP and CW Honeycutt. 2002. Crop rotation effects on Rhizoctonia canker and black scurf of potato in central Maine, 1999-2000. Biological and Cultural Tests for Control of Plant Diseases (online) Report 17:PT05, The American Phytopathological Society, St. Paul, MN.

Larkin RP and CW Honeycutt. 2006. Effects of different 3-year cropping systems on soil microbial communities and soil-borne diseases of potato. Phytopathology 96:68-79.

Larkin RP, CW Honeycutt and TS Griffin. 2006. Effect of swine and dairy manure amendments on microbial communities in three soils as influenced by environmental conditions. Biol Fert Soils, in press.

Lambert DH, L Levy, VA Mavrodieva, SB Johnson, MJ Babcock and ME Vayda. 2003. First report of *Potato mop-top virus* on potato from the United States. Plant Dis 87:668.

Lambert DH, ML Powelson and WR Stevenson. 2005. Nutritional interactions influencing diseases of potato. Amer J Potato Res 82:309-319.

Lambert DH and B Salas. 1996. Plant Diseases. *In*: The ecology, economics and management of potato cropping systems: A report of the first four years of the Maine Potato Ecosystem Project. Maine Agric Forest Exp Sta Bulletin No 843. pp 119-128.

Marshall D. 1991. Crop diversity for plant pathogen control. *In*: D Pimentel (ed), CRC Handbook of Pest Management in Agriculture, Vol. 1. CRC Press, Boca Raton, FL. pp 569-577.

McDole RE and CE Dallimore. 1978. Continuation of cropping sequence studies on coarse textured soils in southeastern Idaho. Am Potato J 55:221-225.

Olanya OM, DH Lambert, SB Johnson and JD Dwyer. 2002. Assessment of the impact of midseason late blight development on yield of Russet Norkotah. Int J Pest Manag 48:139-146.

Olivier C and R Loria. 1998. Detection of *Helminthosporium solani* from soil and plant tissue with species-specific PCR primers. FEMS Microbiol Letters 168:235-241.

Peters RD, AV Sturz, MR Carter and JB Sanderson. 2004. Influence of crop rotation and conservation tillage practices on the severity of soil-borne potato diseases in temperate humid agriculture. Can J Soil Sci 84:397-402.

Powelson ML, KB Johnson and RC Rowe. 1993. Management of diseases caused by soilborne pathogens. *In*: RC Rowe (ed), Potato Health Management. American Phytopathological Society, St. Paul, MN. pp 149-158.

Raposo R, DS Wilks and WE Fry. 1993. Evaluation of potato late blight forecasts modified to include weather forecasts: a simulation analysis. Phytopathology 83:103-108.

Reeves AF, OM Olanya, JH Hunter and JM Wells. 1999a. Evaluation of potato varieties and selections for resistance to bacterial soft rot. Amer J Potato Res 76:183-189.

Reeves AF, OM Olanya, GH Sewell and DH Lambert. 1999b. Maine, common scab and net necrosis. *In*: Performance evaluations of potato clones and varieties in the northeastern states—1997. Maine Agric Forest Exp Sta Misc Pub No 741. pp 32-33.

Teng PS and HL Bissonnette. 1985. Estimating potato yield responses from chemical control of early blight in Minnesota. Am Potato J 62:595-606.

Thurston HD. 1992. Sustainable Practices for Plant Disease Management in Traditional Farming Systems. Westview Press, San Francisco.

SAS Institute Inc. 2003. SAS / STAT Guide for Personal Computers, Vers 6. SAS Institute Inc., Cary, NC.

Schnurer J and T Rosswall. 1982. Fluorescein diacetate hydrolysis as a measure of total microbial activity in soil and litter. Appl Environ Microbiol 43:1256-1261.

Shtienberg D and WE Fry. 1990. Quantitative analysis of host resistance, fungicide, and weather effects on potato early and late blight using computer simulation models. Am Potato J 67:277-286.

Weinhold AR, T Bowman and DH Hall. 1978. Rhizoctonia disease in California. Am Potato J 55:56-57.