Potato Research (2008) 51:101–111
DOI 10.1007/s11540-008-9093-2

Effects of Mulch and Potato Hilling on Development of Foliar Blight (*Phytophthora infestans*) and the Control of Tuber Blight Infection

R. O. Nyankanga · H. C. Wien · O. M. Olanya

Received: 2 July 2007 / Accepted: 8 May 2008 /
Published online: 12 August 2008

Abstract Foliar and tuber blight caused by *Phytophthora infestans* accounts for significant losses in potatoes in field and storage. Nevertheless, limited research has been published on the effects of cultural practices on late blight control. Field experiments were conducted in two years on Howard gravely loam soil in New York State to evaluate the effectiveness of mulching using oat straw and hilling in preventing tuber blight infection for cvs Allegany and Katahdin. Potato hilling and mulching had little effect on foliar blight development. The cultivar affected the disease development in the foliage, with cv. Allegany showing lower foliar late blight than cv. Katahdin. Tuber blight incidence averaged 25% for cv. Allegany and 3% for cv. Katahdin in hilled plots, while in the mulched plots the incidence of tuber blight averaged 33% for cv. Allegany and 10% for cv. Katahdin. The straw hay mulch was ineffective in tuber blight control. Tubers set at a soil depth of more than 7 cm had lower tuber blight incidence than shallow tubers set at a depth of less than 7 cm. In both years, hilling provided partial protection of tubers but its effectiveness was limited in the presence of favourable conditions for late blight development. Even though large hills had proportionally a lower tuber blight incidence than medium-sized hills, the difference between the different hill sizes was not significant. These studies

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

R. O. Nyankanga · H. C. Wien
Cornell University, 134A Plant Science Building, Ithaca, NY 14853, USA

O. M. Olanya (✉)
USDA-ARS, New England Plant, Soil and Water Laboratory, Orono, ME 04469, USA
e-mail: modesto.olanya@ars.usda.gov

Present address:
R. O. Nyankanga
Department of Plant Science and Crop Protection, University of Nairobi,
P.O. Box 30197, Nairobi, Kenya

suggest that the use of cultivars with foliage resistance to late blight in combination with cultural practices may partially reduce the incidence of tuber blight.

Keywords Cultivars · Cultural practices · Mulch · Potato hilling · *Phytophthora infestans* · Tuber blight

Introduction

Potato late blight, caused by *Phytophthora infestans* (Mont.) de Bary is one of the most devastating diseases of potatoes worldwide (Erwin and Ribeiro 1996). The pathogen infects foliage and tubers, resulting in tuber yield loss due to premature death and tuber rot in the field and storage. Tubers become infected when sporangia produced on leaf and stem lesions are washed into the soil (Lacey 1967a, b; Lapwood 1977). Blighted tubers can transmit blight onto potato seed and may predispose tubers to secondary soft rots. Survival in potato tubers is an over-wintering mechanism for *P. infestans* (Andrivon 1995), and infected tubers can be important sources of initial inoculum (Hirst and Stedman 1962). The blighted tubers are also known to predispose non-diseased seed tubers to blight through transmission of spores, especially if potato seed pieces are cut (Lambert et al. 1998). The transportation of infected seed potato tubers can introduce new genotypes of *P. infestans* into other potato producing areas (Lambert et al. 1998).

The management of tuber blight has often been accomplished by control of foliage blight involving the use of host plant resistance or fungicide applications (Cooke and Little 2002). Fungicide applications to control foliar late blight and vine kill using desiccants prior to harvest are the most common methods for reducing tuber infection (Stevenson 1993). The relationships between levels of foliar blight and incidences of tuber blight have been investigated with variable results. Some authors have reported low incidences of tuber blight at harvest in the apparent absence of foliar blight (Lacey 1967b). In other cases, low incidences of tuber blight have been reported after high levels of foliar blight epidemics (Hirst et al. 1965; Olanya et al. 2002). Similarly, research reports have indicated high levels of tuber infection even in fields where numerous applications of protectant and curative fungicides were applied (Flier et al. 1998). In other field experiments, researchers have also suggested greater foliar and tuber blight attributed to more aggressive strains of *P. infestans* on potato tubers (Fry and Goodwin 1997; Lambert and Currier 1997; Flier et al. 1998; Kirk et al. 2001). Therefore, tuber blight has been a major concern for seed and processing potato production because of the unpredictability of storage losses and the management of foliar late blight has been suggested as an option for reducing tuber blight and rots.

Although considerable research on cultivar differences, fungicide effects and host-resistance factors with regard to foliar and tuber blight has been conducted (Flier et al. 1998; Platt and Tai 1998; Olanya et al. 2006; Nyankanga et al. 2007), comparatively few experiments have explored the use of cultural practices for control of potato tuber blight (Bain and Moller 1999). The use of ridging or hilling has been cited as cultural practices for reduction of tuber blight by preventing or minimizing direct contact of inoculum with tubers and filtering out spores before they are transported to the tubers (Lacey 1966; Rowe and Secor 1993). However, experimental evidence on the effectiveness of hilling and other cultural barriers for the management of tuber blight has not been adequately obtained. The objective of this study was to determine the effectiveness of potato hilling and mulching for controlling tuber infection by *P. infestans* under field conditions.

Materials and Methods

Field Establishment and Plot Design

Trials were carried out at the Homer C. Thompson Vegetable Research Farm of Cornell University in Freeville, NY, USA on Howard gravely loam soil (loamy, skeletal, mixed mesic, Glossoboric Hapludalf). In 1998, two cultivars, Allegany and Katahdin, were used, while in 1999 only cv. Allegany was used. Certified potato seed pieces weighing 50–70 g were machine-planted into plots 4 m long at a spacing of 25 cm within the rows and 1 m between the rows. The plot size was 16 m^2 and there were 16 hills per row. At the time of planting, a blend of nitrogen, phosphorus and potassium ($13N:13P_2O_5:13K_2O$) was banded into rows at a rate of 1,150 kg ha^{-1}. Plots consisted of four rows and were separated by 1 m of bare ground. Weeds were controlled by application of pre-emergence herbicide and hand weeding. All standard agronomic practices were conducted.

Potato Hilling and Mulching Experiment

The plots were planted on 3 June 1998. The trial was established as a factorial experiment consisting of two soil cover treatments (mulch and hilling) plus a control and two cultivars, Allegany and Katahdin. The experiment was laid out in a split-plot design with the soil covers as main plots, the two cultivars as subplots and four blocks. Hilling and mulching treatments were applied on 16 July, 6 weeks after planting. Plots were hilled to 12 cm by running a tractor-mounted disc once through the plots, while mulching was established by use of straw hay. An average of 20 kg of oats straw was applied in each plot (16 m^2). The control plots were only covered with soil using a planter at the time of planting. Care was taken to make the mulch and hills as comparable as possible. To control the likelihood of early onset of late blight, the plots were sprayed with chlorothalonil (Bravo, Weather Stik, Zeneca) at a rate of 0.7 l ha^{-1} once per week until the plots were inoculated.

Potato Hilling Size Experiment

The effects of potato hilling size on tuber blight were examined in 1999. The experiment was planted on 24 June. Three levels of hilling were examined. Plots were established as described in the previous section using cut seed pieces of cv. Allegany. Hilling was done 5 weeks after planting before the rows had closed. Other cultural practices were as outlined for the 1998 trial. Different hill sizes were established by either running a tractor-mounted disc once for the medium-sized hills (12 cm) or twice for the large hills (25 cm). The seed pieces in the control plots were covered using a planter only at the time of planting, with no further hilling. The uniformity of the hills was achieved by adding soil by hand. Treatments were assigned in a completely randomized block design with four blocks. Soil depth was measured on four hills per plot 2 months after planting.

Foliage Inoculation

Plots were inoculated using *P. infestans* (US-8) multiplied on leaflets on 28 August 1998. The *P. infestans* isolate US940480 (US-8 lineage) was originally isolated from potato leaves in New York State in 1994 and characterized as US-8, A2 mating type (Fry and Goodwin 1997). Sporangia were harvested by gently washing them with distilled water and then adjusting the concentration (2×10^6 sporangia per ml) using a haemocytometer. To stimulate zoospore release, the sporangia were incubated at 4 °C for 2 h (Lacey 1967a). Potato foliage was inoculated with inoculum by spraying it in the early evening using a knapsack sprayer on 13 September 1998 and on 26 August 1999. In both years, after inoculation and when required during plant growth, plots were irrigated in the early evening at a rate of 0.2 cm of water for 2–3 h to promote conditions conducive for late blight development.

Disease Assessments

Foliage blight was assessed by visually rating individual subplots for percentage leaf and for stem area affected by late blight at an interval of 2–4 days after observation of the first symptoms. For each observed area and assessment date, the area under the disease progress curve was calculated as given by Shaner and Finney (1977). Tubers were assessed for symptoms of late blight at harvest. The haulm was removed and tubers were hand-harvested from 16 hills from each of the middle two rows for evaluation of tuber infection. The tubers were harvested on 12 October 1998 and on 26 August 1999. During harvesting, tubers were separated into two depth classifications based on tuber location from the upper surface; those from the top 7 cm and those set deeper than 7 cm. They were evaluated for symptoms after 2 weeks of storage at 4 °C and 90% relative humidity. Tubers from each plot and each depth category were evaluated for the presence or absence of lesions symptomatic of late blight. As part of the assessment, tubers with symptomatic lesions were sliced to confirm the presence of brown discoloration typical of late blight infection. The incidence of tuber blight was calculated on the basis of the percentage of tubers showing late blight symptoms.

Data Analyses

Foliage blight was analysed by computing the area under the disease progress curves (AUDPC). The percentage incidence of tuber blight was square-root-transformed and analysed using analysis of variance (ANOVA). The effectiveness of hilling and mulching was analysed using ANOVA and planned orthogonal contrasts among the different treatments. The pairwise comparisons of means were done using Tukey's least significant difference statistics. All the analyses were done using SAS (SAS Institute, Cary, NC, USA).

Results

Late Blight Development on Foliage

In both years, there was rapid disease development on the potato foliage. In 1999, foliage was virtually destroyed within 3 weeks (Fig. 1a). The size of tuber hilling had little effect on disease development on foliage (Fig. 1b). The cultivar, however, significantly ($P<0.05$) affected foliage disease development as cv. Allegany resulted in lower disease development than cv. Katahdin (Fig. 1a).

Effect of Mulch and Hilling on Depth of Tuber Set and Incidence of Tuber Blight

Most tubers were set at intermediate depth in the soil. Hilling increased the proportion of tubers that were set at a soil depth in excess of 7 cm as compared with the mulch and control treatments. The average depth of set also increased slightly by hilling (Table 1). The proportion of tubers formed at the two soil depths was similar

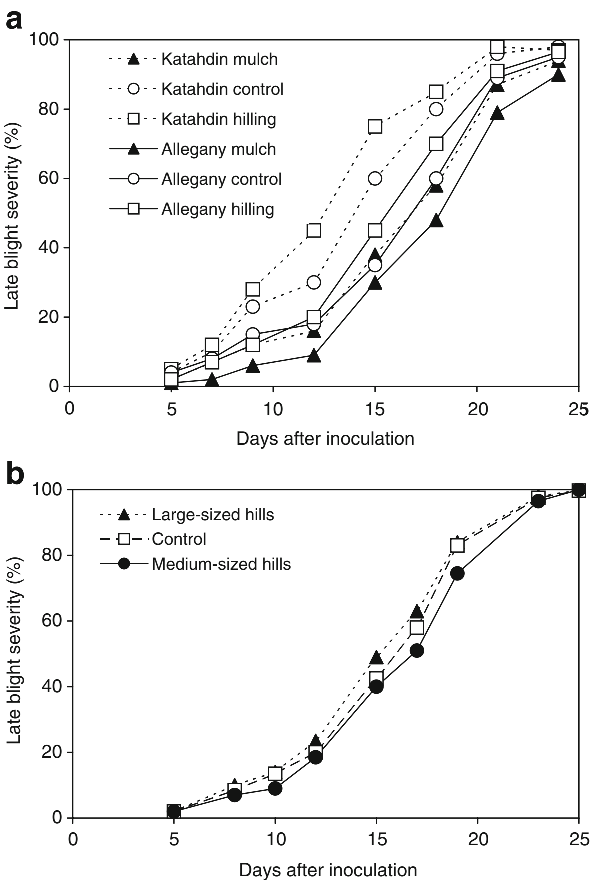

Fig. 1 Late blight epidemics on potato plots during the field experiments at Freeville, NY, USA. **a** Effects of mulch and hilling on foliage blight for cvs Allegany and Katahdin in 1998 and **b** effects of different hill sizes on foliage blight on cv. Allegany in 1999. Data refer to the percentage of foliage blight based on visual assessment on a scale of 0–100%

Table 1 Effect of hilling and mulching treatments on distribution of potato tubers in ridges (percentage of tubers) and depth of set of tubers in cvs Allegany and Katahdin in field experiments conducted on Howard gravely loam soil at Freeville, NY, USA in 1998 and 1999

Year and cultivar	Cover type	Proportion of tubers (%)		Average depth (cm)[a]
		<7 cm deep[a]	>7 cm deep[a]	
1998				
Allegany	Hill	43.5 b	56.5 a	10.8 a
	Mulch	65.1 a	34.9 b	9.3 b
	Control	76.5 a	23.5 b	8.6 b
	$LSD_{0.05}$	18.1	20.5	1.01
Katahdin	Hill	43.7 b	56.3 a	9.6 a
	Mulch	61.2 a	38.8 b	8.7 b
	Control	56.4 a	34.6 b	8.9 b
	$LSD_{0.05}$	15.3	16.2	0.7
1999				
Allegany	Large hills (25 cm)	34.9 c	65.1 a	13.2 a
	Medium-sized hills (12 cm)	41.8 b	58.2 b	9.7 b
	Control	73.4 a	26.6 c	7.1 b
	$LSD_{0.05}$	19.6	20.1	3.45

LSD least significant difference

[a] Means with the same *letters* are not significantly different ($P<0.05$)

between cv. Allegany and cv. Katahdin in 1998. In 1999, a larger hill resulted in a higher proportion of tubers set in excess of 7 cm depth (Table 1).

The incidence of tuber blight (number of tubers diseased expressed as a percentage of the total number of tubers assessed) varied between 1998 and 1999. A high incidence of tuber blight was observed in 1999 when the average percentage of tubers with blight was 27±7% as compared with 18±4% in 1998. In 1998, hilling significantly ($P<0.05$) reduced tuber infection as compared with the control and mulching treatments, except for cv. Katahdin tubers set at a soil depth in excess of 7 cm, for which the difference was not significant (Fig. 2, Table 2). The deeper-set tubers showed lower infection than shallower-set tubers (Fig. 2). The hilling of the potato crop in 1998 partially reduced tuber infection when compared with the control and mulch treatments (Table 2). A comparison of the incidence of tuber blight (number of tubers diseased expressed as a percentage of the total number of tubers assessed) in 1998 revealed that the average incidence of blighted tubers in the control plots was 15±9%, in the mulched plots was 20±7% and in the hilled plots was 14±5%. When data were averaged across cultivars and analysed for the percentage of tuber blight incidences, pairwise comparisons of treatments versus control and hill versus control showed significant ($P<0.05$) effects for tubers at depths in excess of 7 cm (Table 2). Orthogonal treatment contrasts for tuber blight incidences for cv. Allegany were significant for tubers set at a soil depth of less than 7 cm (hill vs control and hill vs mulch). The pairwise comparisons of treatment effects versus control as well as hill versus control were significant for cv. Katahdin when tuber blight incidences at the two depths were bulked (Table 2).

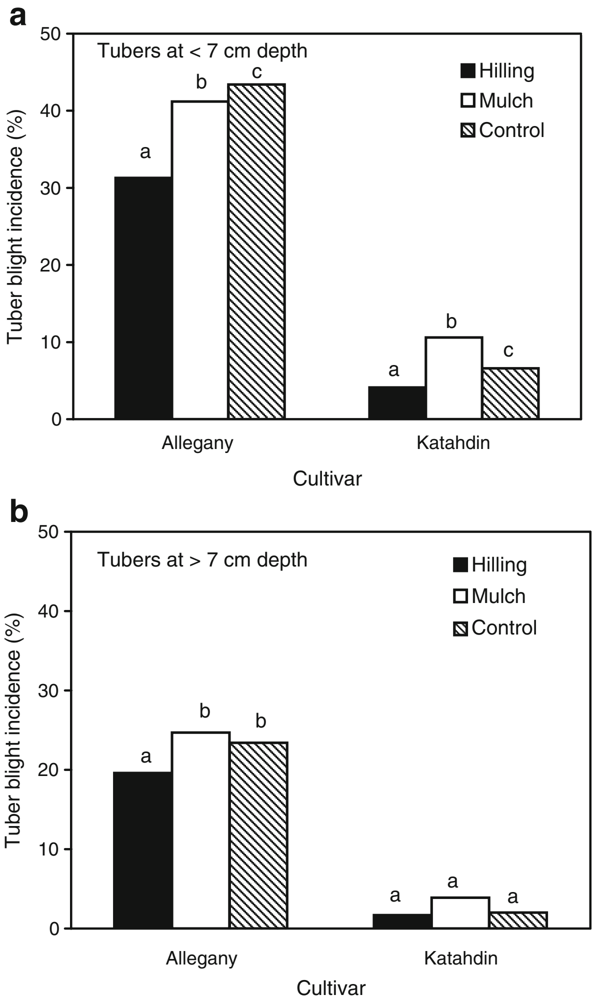

Fig. 2 Incidence of tuber blight on potato cvs Allegany and Katahdin as affected by hilling and oat straw mulch in a field experiment conducted at Freeville, NY, USA in 1998. **a** Incidence on tubers from shallow soil depths (less than 7 cm) and **b** incidence on tubers from greater soil depths (more than 7 cm). Same *letters* indicate that means are not significantly ($P<0.05$) different on the basis of Fisher's protected least significant difference. Data refer to the number of tubers with blight expressed as a percentage of the total number of tubers

Effect of Hill Size on Incidence of Tuber Blight

Tuber blight incidence (number of tubers diseased expressed as a percentage of the total number of tubers assessed) averaged 31±7% in the control plots, 29±4% in the medium-sized hills and 20±7% in plots with the large hills. There was a significant reduction in tuber blight incidence in large hills, but the percentage of blight-infected tubers below medium-sized hills did not differ significantly from that of the control and large hill treatment (Fig. 3).

Discussion

In this study, we tested the hypothesis that hilling and mulching will act as barriers to reduce and filter out inoculum before sporangia and zoospores are carried to the

Table 2 Orthogonal contrasts for incidence of tuber blight in the field experiment with potato cvs Allegany and Katahdin with foliage inoculated with *Phytophthora infestans* (US-8) in Freeville, NY, USA in 1998

Orthogonal contrast for	Depth[a]	MS	*F*	*P*
Combined cultivars				
Treatments vs control	<7 cm	483.4	2.2	0.1559
	>7 cm	260.3	5.53	0.0310*
	Total	726.5	5.18	0.0282*
Hill vs control	<7 cm	187.5	0.86	0.3681
	>7 cm	307.7	6.54	0.0204*
	Total	487.4	3.48	0.0695
Hill vs mulch	<7 cm	114.3	0.52	0.4801
	>7 cm	50.9	1.08	0.3123
	Total	6.3	0.04	0.0833
Allegany				
Treatments vs control	<7 cm	39.7	0.14	0.7145
	>7 cm	181.4	2.95	0.1201
	Total	97.2	0.64	0.4548
Hill vs control	<7 cm	257.9	4.20	0.0509*
	>7 cm	89.9	0.53	0.5549
	Total	170.1	1.12	0.3312
Hill vs mulch	<7 cm	295.3	5.60	0.0329*
	>7 cm	77.4	1.26	0.2912
	Total	40.7	1.03	0.4614
Katahdin				
Treatments vs control	<7 cm	614.8	4.09	0.0737
	>7 cm	87.3	3.60	0.0902
	Total	425.4	8.71	0.0162*
Hill vs control	<7 cm	506.5	3.37	0.0995
	>7 cm	76.7	3.15	0.1095
	Total	338.7	6.93	0.0272*
Hill vs mulch	<7 cm	4.2	0.03	0.8902
	>7 cm	1.7	0.07	0.7972
	Total	1.2	0.02	0.8800

*Significant at $P<0.05$

[a] Category of tubers set at a depth of less than 7 cm or a depth exceeding 7 cm. The total presents the combined incidence of tuber blight in the two categories

tubers. Therefore, it was envisaged that larger potato hills will be more effective than small hills in filtering out the *P. infestans* inoculum. Our results indicated that hilling had only a partial effect, while mulching was ineffective in reducing tuber infection. These results differ with those of Glass et al. (2001), who observed that hill sizes had no effect on the level of tuber infection in field plots inoculated with new strains of *P. infestans*. Our results are consistent with the observations of Lacey (1966), who recommended good ridging after observing higher levels of tuber infection on shallower tubers in a ridge.

The recommendation for hilling is based on the ability to directly suppress inoculum or filter it out before it reaches tubers. It is expected that shallow tubers, which are more prone to infection than deeper tubers, will benefit most from barrier treatments. The results from this study did not fully support this hypothesis. This is

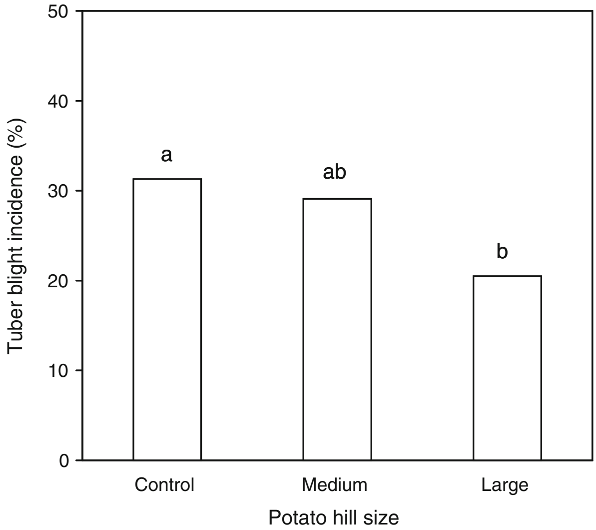

Fig. 3 Effect of hill size on incidence of potato tuber blight on cv. Allegany in a field experiment conducted in Freeville, NY, USA in 1999. Same *letters* indicate that means are not significantly ($P > 0.05$) different on the basis of Fisher's protected least significant difference. Data refer to the number of tubers with blight expressed as a percentage of the total number of tubers

partially due to movement of pathogen propagules and the effectiveness of the treatments to control this movement under the conditions of these field trials.

Ambient and soil microclimatic factors may affect the occurrence of tuber blight even when cultural practices are applied for tuber blight management. In our study, relatively conducive ambient temperatures were recorded in 1998 and 1999, and in 1999, wet weather was observed during the epidemic in September (data not shown). Other studies have shown that movement of fungal propagules is influenced by soil moisture, soil type and soil temperature. Dubey and Stevenson (1996) demonstrated that 0.6 cm of water could move sporangia in sandy soils to depths of 40 cm. Pfender et al. (1977) observed that zoospores of *P. megasperma* moved 65 mm in sandy loam soil and rarely moved 24 mm through silt loam soil during a single season. Infection by citrus rot (*Phytophythora* spp.) has been observed to be high at high soil moisture owing to favourable conditions for the production of zoospores. Zan (1962) noted that zoospores of *P. infestans* penetrated further into the soil than did sporangia when washed by rain. Thus, the effectiveness of any barrier will be dependent on the soil conditions, prevailing environmental conditions, level of foliage infection or height of diseased foliage, and soil type. Hilling in 1998 partially prevented tuber infection (Fig. 2, Table 2) but in 1999 only use of large hills reduced infection as compared with no hilling, whereas the difference between medium-sized and large hills was not significant. This could have been due to the differences of late blight in the two years. In 1998, the level of foliage blight was not as high as in 1999. Also in 1999, there was a lot of rain in September, during which the foliage blight occurred. Another possible explanation for the small differences in tuber blight observed in our experiments could be the longevity of sporangia survival in soil. It has been documented that sporangia of *P. infestans* can survive in soil for up to 2 months (Evenhuis et al. 2006). It is possible that during lifting of the tubers at harvest, sporangia that had not yet reach tubers came into contact with the tubers and caused tuber infection at this stage.

The reduction of water movement in the ridge and alteration of soil environmental conditions by soil covers have been suggested to reduce tuber infection. Lacey

(1966) suggested that movement of inoculum is channelled through cracks made by the stem or water moving along the stem. However, in a recent study, it was shown that in sandy soils with irrigation, movement of inoculum could take place anywhere on the hill surface (Glass et al. 2001). Black polyethylene has been found to be effective in preventing tuber infection as compared with other barriers since the polyethylene plastic material blocks penetration of water and thus inoculum from reaching the tubers and also alters the soil environment by increasing soil temperature (Glass et al. 2001). In the present study, the hilling and mulching treatments were designed to act as a barrier or filter of inoculum but neither apparently could sufficiently block water from the tubers. Mulch treatments did not prevent tuber infection and in some cases even slightly increased tuber infection as compared with the controls. This could have been caused by straw mulch lowering soil temperature and maintaining humid soil conditions for longer periods than in the controls. The cooler and humid conditions in mulched plots will have rendered mulch ineffective in controlling infection.

The study was conducted on Howard gravely loam, which has good permeability to water. Even though the movement of *Phytophthora* propagules in the soil was not measured, it is possible that with prevailing precipitation combined with irrigation sporangia could easily have been moved beyond the 25-cm depth of the large hill used in this study.

Soil temperatures measured in an adjacent experiment indicated that conditions were conducive for zoospore formation. Zoospores have been shown to penetrate deeper than sporangia (Zan 1962). This, in combination with highly porous soils with cool soil temperatures and high precipitation, may have made hill sizes in 1999 ineffective in suppressing tuber infection.

The study has shown that direct prevention of tuber blight using cultural practices is limited and is dependent on the prevailing environmental conditions. Hilling showed some reduction especially on cv. Katahdin but was less effective on cv. Allegany. In all depth categories, cv. Katahdin showed less infection than cv. Allegany. Thus, it seems that cultural practices combined with tuber resistance may limit tuber infection. In conditions conducive for tuber blight, use of mulches and hilling will likely not be effective. Cultural practices that will curtail movement of water and alter the soil conditions to be non-conducive may be more successful in limiting epidemics when combined with resistant cultivars and foliage blight control. Additional research is required to test whether tuber resistance will complement cultural practices. The best option as indicated by this study still lies in the complete control of foliage blight and the use of tuber resistance.

Acknowledgements The authors are grateful to the Rockefeller Foundation for partially funding this research as part of the first author's Ph.D. dissertation at Cornell University. We thank Professor William Fry's laboratory for culture of US-8 isolate and the USDA-ARS, New England Plant, Soil and Water Laboratory for technical and logistical support.

References

Andrivon D (1995) Biology, ecology, and epidemiology of the potato late blight pathogen *Phytophthora infestans* in soil. Phytopathology 85:1053–1056

Bain RA, Moller K (1999) Factors influencing tuber infection by *Phytophthora infestans.* In: Schepers H, Bouma E (eds) Proceedings of the workshop on the European network for development of an integrated control strategy of potato late blight, Uppsala, Sweden, 9–13 September 1998. PAV – special report no. 5. Applied research for arable farming and field production of vegetables, Lelystad, pp 210–227

Cooke LR, Little G (2002) The effect of foliar application of phosphanate formulations on the susceptibility of potato tubers to late blight. Pest Manag Sci 58:17–25

Dubey T, Stevenson WR (1996) Factors affecting the movement and viability of sporangia of *Phytophthora infestans* in soil (abstr.). Phytopathology 89:S61–S62

Erwin DC, Ribeiro OK (1996) Phytophthora diseases worldwide. American Phytopathological Society Press, St Paul

Evenhuis A, Kessel GJT, van Bekkum PJ (2006) Epidemiology of *P. infestans* in relation to tuber blight-survival of *P. infestans* sporangia in field soils. In: Westerdijk CE, Schepers HTAM (eds) Proceedings of the ninth workshop of an European network for development of an integrated control strategy of potato late blight, Tallinn, Estonia, 19th–23rd October 2005. PPO – special report no. 11. Applied Plant Research, Lelystad, pp 223–228

Flier WG, Turkensteen LJ, Mulder A (1998) Variation in tuber pathogenicity of *Phytophthora infestans* in the Netherlands. Potato Res 41:345–354

Fry WE, Goodwin SB (1997) Resurgence of the Irish potato famine fungus. Bioscience 47:363–371

Glass JR, Johnson KB, Powelson ML (2001) Assessment of barriers to prevent the development of potato tuber blight caused by *Phytophthora infestans*. Plant Dis 85:521–528

Hirst JM, Stedman OJ (1962) The infection of potato late foliage and tubers by *Phytophthora infestans*. In: Rothamst Exp St Rep 1961. Rothamsted Experiment Station, Harpenden, pp 113–114

Hirst JM, Stedman OJ, Lacey J, Hide GA (1965) The epidemiology of *Phytophthora infestans.* IV. Spraying trials, 1959 to 1963, and the infection of tubers. Ann Appl Biol 55:373–395

Kirk WW, Felcher KJ, Douches DS, Niemira BA, Hammerschmidt R (2001) Susceptibility of potato (*Solanum tuberosum* L.) foliage and tubers to the US-8 genotype of *Phytophthora infestans*. Am J Potato Res 78:319–322

Lacey J (1966) The distribution of healthy and blighted tubers in potato ridges. Eur Potato J 9:86–96

Lacey J (1967a) The role of water in the spread of *Phytophthora infestans* in the potato crop. Ann Appl Biol 59:245–255

Lacey J (1967b) Susceptibility of potato tubers to infection by *Phytophthora infestans*. Ann Appl Biol 59:257–264

Lambert DH, Currier AI (1997) Differences in tuber rot development for North American clones of *Phytophthora infestans*. Am Potato J 74:39–41

Lambert DH, Currier AI, Olanya MO (1998) Transmission of *Phytophthora infestans* in cut potato seed. Am J Potato Res 74:39–43

Lapwood DH (1977) Factors affecting the field infection of potato tubers of different cultivars by blight (*Phytophthora infestans*). Ann Appl Biol 85:23–42

Nyankanga RO, Wien HC, Olanya OM, Ojiambo PS (2007) Relationship between late blight (*Phytophthora infestans*) of potato on tuber and foliage, as affected by the disease severity on foliage, cultivar resistance, and atmospheric and soil variables. Can J Plant Pathol 29:372–387

Olanya OM, Lambert DH, Johnson SB, Dwyer JD (2002) Assessment of the impact of mid-season late blight infection on disease development and yield of potato variety Russet Norkotah in Maine. Int J Pest Manag 48:139–146

Olanya OM, Ojiambo PS, Nyankanga RO (2006) Dynamics of development of late blight (*Phytophthora infestans*) in potato, and comparative resistance of cultivars in the highland tropics. Can J Plant Pathol 28:84–94

Pfender WF, Hine RB, Stangehellini ME (1977) Production of sporangia and release of zoopores by *Phytophthora megasperma* in soil. Phytopathology 67:657–663

Platt HW, Tai G (1998) Relationship between resistance to late blight in potato foliage and tubers of cultivars and breeding selections with different resistance levels. Am J Potato Res 75:173–175

Rowe RC, Secor GA (1993) Managing potato health from emergence to harvest. In: Rowe RC (ed) Potato health management. American Phytopathological Society, St Paul, pp 35–57

Shaner G, Finney RE (1977) Effect of nitrogen fertilization on the expression of slow-mildewing resistance in knox wheat. Phytopathology 68:657–663

Stevenson WR (1993) Management of early blight and late blight. In: Rowe RC (ed) Potato health management. American Phytopathological Society, St Paul, pp 141–147

Zan K (1962) Activity of *Phytophthora infestans* in soil in relation to tuber infection. Trans Br Mycol Soc 45:205–221